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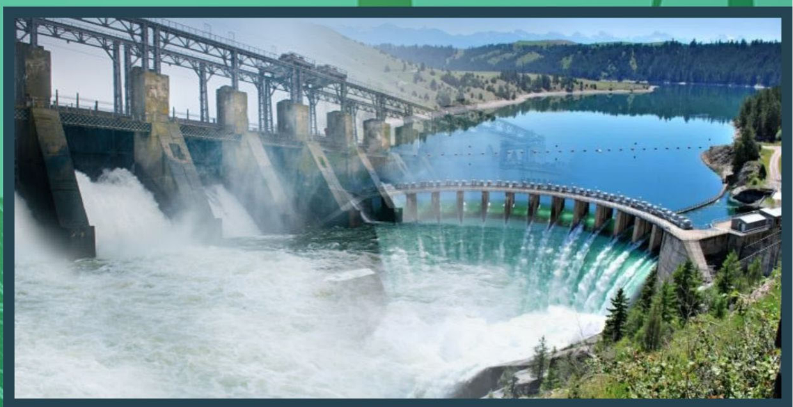

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About the Journal

The Journal of Digital Food, Energy & Water Systems (JD-FEWS) is a peer-reviewed bi-annual publication that publishes recent and innovative deployment of emerging digital technologies in Food, Energy, and Water Systems. Food, energy, and water resources are interconnected scarce resources that require systems and technologies to foster sustainable management and effective utilization. The journal is also interested in articles that explore the nexus between at least two of these resources. The journal considers the following topics as long as they are deployed in the Food, Energy & Water space:

- Advanced Metering Infrastructure (AMI)
- Algorithm development
- Artificial Intelligence
- Blockchain and distributed ledger technology
- Case studies
- Cybersecurity
- Data mining & Big data
- Human-Computer Interaction
- Intelligent Forecasting
- Internet of Things
- Machine Learning
- Mathematical Optimization
- Robotics
- System architectures
- Wireless Sensor Networks

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The Awareness and Adoption of Artificial Intelligence for Effective Facilities Management in the Energy Sector

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Abstract—Most sectors of the Nigerian economy, including the energy sector, have been infiltrated by digital technologies, including artificial intelligence (AI), where they have been extensively investigated. The research aims primarily to assess the perception of AI in facility management and identify the prospects and challenges of the adoption of AI in the energy sector. The study adopted the quantitative methodology approach, using a structured questionnaire to a sample size of 384 respondents. The questionnaire was administered to professionals such as mechanical, civil, electrical, computer, and mechatronics engineers and project managers within the North-central geopolitical zone of Nigeria. Data gathered was analyzed using descriptive analysis (mean value, weighted total, and relative importance index). The study based on findings concludes that there is a high awareness level about AI in the energy sector. Also, awareness about some selected AI technologies, machine & deep learning, robotics, and speech recognition had a high awareness level. The study also concludes that improved energy management, efficiency and transparency, remote reading of energy meters, and improved planning, operation & control of power systems were prevalent prospects of AI adoption. The major challenging factors to adopting AI in the Nigerian energy sector are outdated power system infrastructure, cellular technologies, a scarcity of qualified experts and data scientists, and a growing threat from cyber-attacks. The study recommends improved awareness and technical know-how of energy sector personnel and adequate power system infrastructure to provide a stable power supply.

Keywords—Artificial intelligence**,** Awareness, Energy Sector, Facilities management

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1 Introduction

Artificial intelligence (AI) is a type of "deep learning" that enables machines to analyze information on a very sophisticated level on their own, allowing them to perform complicated functions such as facial recognition and speech recognition [1]. According to [2], AI systems can quickly extract insights from massive, heterogeneous data sets and discover correlations that might otherwise go missed by humans. As a result, AI is a powerful tool for improving people's daily lives [3]. From self-driving cars and industry automation to smart home apps like Siri and Alexa, AI has significantly impacted society [4]. AI has become one of the most advanced technologies used in numerous industries in the twenty-first century. The primary motivation for implementing AI is to combine multiple areas like medicine, renewable power, and education [5].

Artificial intelligence is commonly employed for solar power plant irradiance prediction and estimated power output, as well as wind speed prediction and projected power output from wind farms [4]. Recently, end-to-end technology such as artificial intelligence robotics and wireless communications have been developed and widely used for energy digitization [6]. The utility business is undergoing a shift from a steady environment to a volatile, technology-driven environment [7]. Hence, AI in collaboration with other technologies can be effective instruments for resolving issues and supporting key stakeholders in making complex decisions during power networks' planning, execution, and maintenance phases. Furthermore, the advanced application of AI in the power sector is crucial in smart-grid set-ups, notably timely fault discovery and enhanced forecast for renewable energy [8]. According to [9], artificial intelligence can help the energy business capitalize on the expanding opportunities created by digital technologies and the incorporation of renewables. Energy generation, distribution, and finances required are critical to the global economy [4]. These cannot be achieved with the present electrical grid infrastructure, which is outdated with insufficient fault protection. AI advancements are revolutionizing the energy business the emerging technologies. AI has been utilized to accomplish a wide range of tasks, leading to improved performance of the sector [10]. [6] made a detailed description of some tasks of AI in the Energy Industry (see Figure 1).

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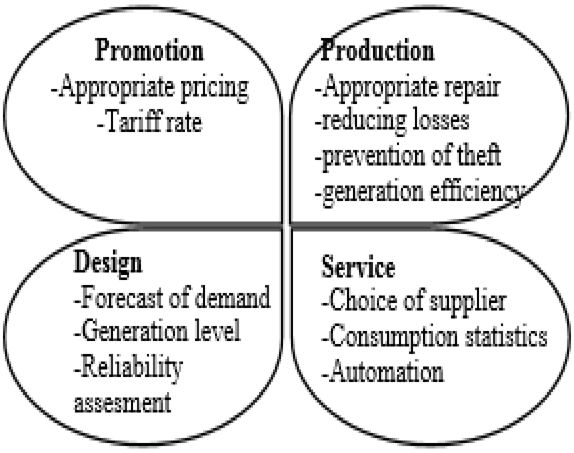

Fig. 1: Tasks of AI in Energy Industry [6]

Application of AI in photovoltaic (PV) systems improves inverter management and increases the ability to track power points [11]; [12]; [13]. Artificial maximum power point tracking (MPPT) techniques are more operational and can increase output when compared to regular MPPT processes [14]. AI systems, when correctly created, can be especially valuable for automated routine and structured procedures, allowing humans to deal with tomorrow's power concerns. The ability to provide clean, affordable energy, which is critical for sustainable development, is inextricably linked to AI [15]. AI and machine learning (ML) methods such as the Artificial Neural Network (ANN) and Random Forest (RF) are computationally efficient and accurate in forecasting energy consumption, cyber-attack, predictive maintenance, and facility management [16];[17]; [18]; [19].

Most developed countries have used artificial intelligence to grow every aspect of their economies to become world powers. Although we now live in a time when AI is taking over many jobs, almost everything in Nigeria is done manually [1]. Unstable supply and demand, inefficiency, and a lack of critical analysis essential for optimal administration pose new challenges to the energy sector [15]. Despite its relevance and progress in terms of innovation, AI has experienced several difficulties, particularly in developing countries such as Nigeria. Complex algorithms, AI human interface, cultural and religious barriers, software malfunction, and a decline in investment are some of the challenges identified by [1]. AI concerns can be solved systematically by transferring expertise from the power sector to AI software firms [15]. Some people believe that if Artificial Intelligence (AI) continues to advance unabated, it will threaten humanity. Others believe that, unlike previous technological revolutions, Artificial Intelligence (AI) will increase the risk of mass unemployment. This implies that artificial

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intelligence is involved in the project of developing machines endowed with human-like cognitive processes and attributes such as reasoning, seeking answers, or learning from previous scenarios [1]. Similarly, Artificial Intelligence can be used to shape the growth of key sectors in the Nigerian economy. Indeed, the applications of AI technology will be the best technology for boosting core sectors and assisting Nigeria in its rapid digitization [1]. According to [6], the employment of artificial intelligence in the power industry will reduce power supply interruptions. [20] underlined that numerous opportunities such as digital progression and national development by adopting information and communication technologies (ICTs).

Empirical findings revealed that [5] highlighted the AI technologies adopted in power systems. [21] investigated how artificial intelligence impacts the solar photovoltaic value chain. Research [22] in their study explored the drawbacks, future opportunities of solar energy in selected countries in Asia, Africa, and South America. [1] also studied the importance, challenges, and applications of artificial intelligence in Nigeria. [23] reviewed the relevance of Artificial Intelligence in Indian industries at present and to the future. Unlike the existing literature contributions, this paper assesses the awareness of AI in facility management and identifies the prospects and challenges of the adoption of AI in the energy sector. Furthermore, the identification of the opportunities and obstacles of using AI is presented empirically. The study further provides insights into AI's broad topic for successful facility management. This research would help build the groundwork for identifying new strategies, provide additional insight into managing complicated electrical set-ups through AI, and aid in decision-making.

2 Material and Methods

The study adopted the quantitative methodology approach. This method entails data gathering, which may be subjected to further quantitative analysis in a formal manner [24]. Furthermore, data analysis is significantly easier and less error-prone using this technique [25]. As a result, the authors used a questionnaire to collect primary data from a sample size of 384 using the Cochran's formula. This method was used since the research population could not be determined.

$$n_0 = \frac{Z^2pq}{e^2} \qquad (1)$$

Where e = .05
p = .5
q = 1 – p = .05
z = 1.96

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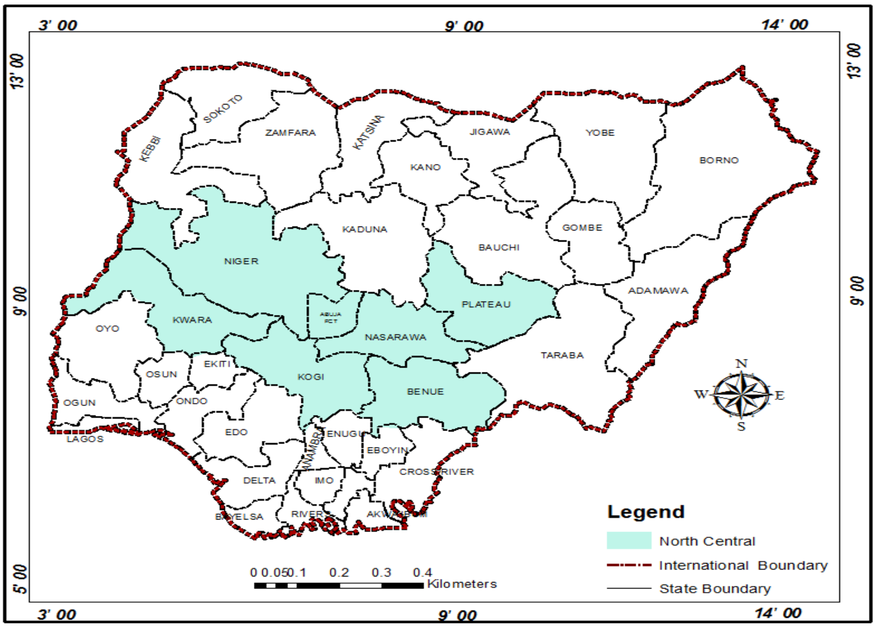
Thus

$$n_0 = \frac{1.96^2(0.5*0.5)}{0.05^2} \quad (2)$$

$n_0 = 384$

The questionnaire was administered to professionals such as mechanical, civil, electrical, and mechatronics engineers, quantity surveyors, architects, and project managers within the North-central geopolitical zone (Plateau, Kogi, Kwara, Nassarawa, Niger States, Benue, and the Federal Capital Territory (FCT) Abuja) of Nigeria (see Figure 2). These professionals work with energy-oriented organizations within the study area. The choice of the North-central geopolitical zone was motivated due to proximity, convenience, and predominant economic development of the region. Additionally, Niger state within the zone has three hydroelectric power plants which distribute power supply to neighboring states.



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The research instrument used for data collection was divided into three main sections. The first part asked respondents about personal details (such as; state, academic qualification, profession, organization category, and years of practice). The other two sections asked questions relating to the awareness of AI in facilities management and to identify the prospects and challenges of adopting AI in the Nigerian energy sector. The random method was the adopted Sampling technique, while Statistical Package for the Social Sciences (SPSS) was employed for descriptive analysis. Additionally, weighted index (WI) was further used for analysis to ascertain the level of awareness (WAI) of AI technologies and level of application. This approach was also adopted by [26] and [27].

$$WI = \frac{\sum_{i=0}^{5} aixi}{5\sum_{i=0}^{5} xi} \qquad (0 \leq \text{WI} \leq 1) \tag{3}$$

Where ai = constant expressing the weight given to a group
xi = frequency of response

A value of WI approaching 1 signifies high respondent's agreement on variable factors measured. Hence, the higher the weighted total (WT), the higher the weighted index (WI), and the higher the level of agreement among respondents for a given variable factor.

3 Results and Discussion

3.1 Background data of respondents

The data analysis was based on 287 valid responses (74.7% return rate) retrieved from 384 administered questionnaires. The high response rate indicates the willingness of respondents to take part in the survey while the remaining 97 questionnaires were either incomplete or not returned and, as a result, were disqualified. The background data of respondents is presented in Table 1.

Table 1. Background data of respondents

Profile	Frequency	Percentage
Gender		
Male	193	67.2
Female	94	32.8

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Academic Qualification		
NCE/ND	21	7.3
HND/BSC	138	48.1
MBA/MSC/M.Eng	84	29.3
PhD	44	15.3
Industry Professionals		
Project Manager	58	20.2
Electrical Engineer	62	21.6
Mechanical Engineer	47	16.4
Civil Engineers	48	16.7
Mechatronics Engineer	12	4.2
Computer Engineer	33	11.5
Other	27	9.4
Years of Experience		
1 – 5	42	14.6
6 – 10	46	16.0
11 – 15	75	26.1
16 – 20	77	26.8
0ver 20	47	16.4

The results showed that males account for 67.2% while females account for 32.8%; this implies that there are more male industry professionals in the energy sector. The survey of the educational qualifications showed that 7.3% have NCE/ND, 48.1% have HND/BSC, 29%.3 have a master's degree, and 15.3% had PhD; this indicates that the respondents have the fundamental and necessary educational credentials to offer response required to support the conclusions of this study. The respondents were further distributed as Project Managers (20.2%), Electrical Engineers (21.6%), Mechanical Engineers (16.4%), Civil Engineers (16.7%), Mechatronics Engineers (4.2%), Computer Engineers (11.5%), and others (9.4%). About 26.8% of the respondents had experience spanning 16 – 20 years while 14.6% had the least experience of 1 – 5 years. This further implies that industry professionals are experienced in their various fields and have also developed extensive expertise in handling industry-related challenges; as a consequence, the data gathered is reliable and appropriate.

3.2 Awareness of Artificial Intelligence (AI) in the Energy Sector

Figure 3 depicts respondents' understanding of the idea of Artificial Intelligence. According to the study's findings, most respondents (76%) had heard of AI, while 24%

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had never heard of the notion. The findings might be ascribed to the current understanding of the notion through the internet, social media, television shows, and seminars, among other things.

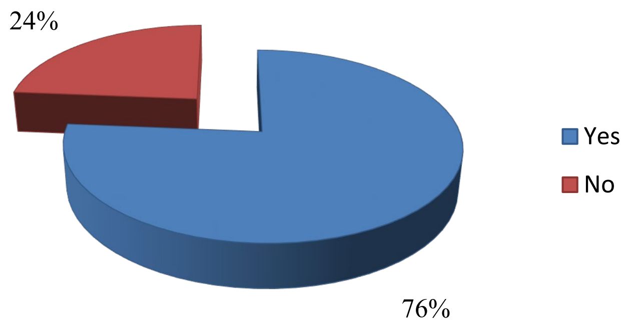

Fig. 3. Awareness regarding the concept of AI

Respondents were also asked to rate their level of awareness of a variety of AI technologies mentioned in the literature using a 5-points Likert scale, with "1" indicating the least level of awareness and "5" representing the highest level of awareness. Their level of awareness was ranked 'high' and 'low' using the respective mean score under each variable. The knowledge regarding AI technologies is presented in Table 2.

Table 2: Awareness regarding AI technologies

S/No	**AI Technologies**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Weighted Awareness Total**	**Weighted Awareness Index**	**Level of Awareness**
1	Machine Learning	36	43	69	80	59	3.29	944	0.658	High
2	Deep Learning	50	47	46	86	58	3.19	916	0.638	High
3	Neural Network	78	71	62	54	22	2.55	732	0.510	Low
4	Expert System	63	71	72	61	20	2.67	765	0.533	Low
5	Fuzzy logic	87	73	56	40	31	2.49	716	0.499	Low

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S/No	AI Technologies	1	2	3	4	5	Mean	Weighted Awareness Total	Weighted Awareness Index	Level of Awareness
6	Natural Language Processing	69	36	78	56	48	2.92	839	0.585	Low
7	Robotics	5	11	94	84	77	3.8	1030	0.718	High
8	Speech Recognition	27	47	95	75	43	3.21	921	0.642	High
1 = NA; 2 = SA; 3 = SWA; 4 = MA; 5 = EA										

Further analysis using weighted awareness index (WAI) show the existence of high awareness of AI technologies such as robotics (0.718), machine learning (0.658), speech recognition (0.642) and deep learning (0.638) while natural language processing (0.585), expert system (0.533), neural network (0.510) and fuzzy logic (0.499) all have low awareness level as presented in Figure 4.

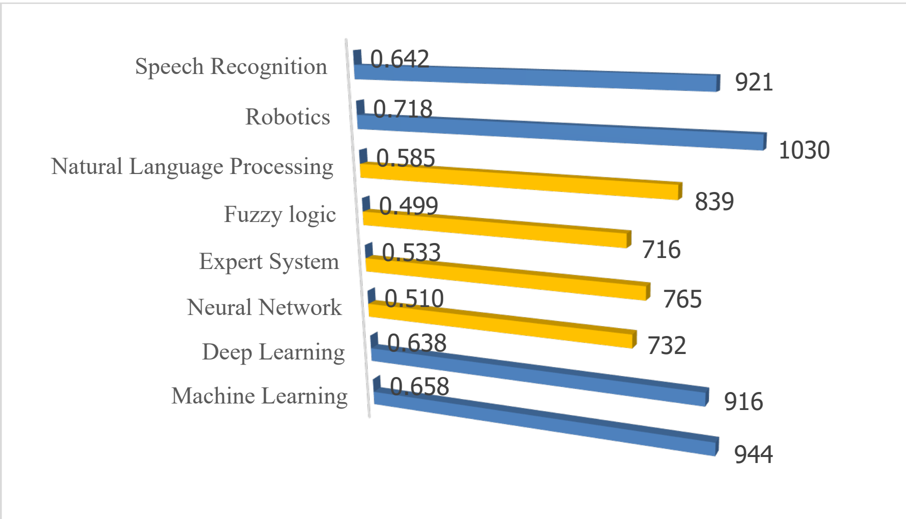

Fig. 4. Awareness level of AI technologies

To determine the level of knowledge of AI, respondents were asked to rank their level of awareness of AI applications in the energy industry. Table 3 summarizes the findings, categorizing the level of awareness as "high" or "low."

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Table 3: Awareness regarding AI applications in the energy sector

S/No	AI Technologies	1	2	3	4	5	Mean	Weighted Awareness Total	Weighted Awareness Index	Level of Awareness
1	Digitalized Power Generation	42	39	80	69	57	3.21	921	0.642	Low
2	Advanced Metering Infrastructure	25	27	53	96	86	3.67	1052	0.733	High
3	Energy Storage Analytics	52	68	71	45	51	2.91	836	0.583	Low
4	Smart Grid	28	38	81	78	62	3.38	969	0.675	High
5	Network Management	29	35	69	76	78	3.48	1000	0.697	High
6	Energy Efficiency Decision Making	39	48	77	68	55	3.18	913	0.636	Low
7	Fault Prediction and Detection	37	50	56	75	69	3.31	950	0.662	High
8	Renewable Energy Forecasting	45	55	77	56	54	3.07	880	0.613	Low
1 = NA; 2 = SA; 3 = SWA; 4 = MA; 5 = EA										

The result using weighted awareness index (WAI) shows that there is a low level of awareness in AI's application in digitalized power generation (0.642), energy efficiency decision making (0.636), renewable energy forecasting (0.613), and energy storage analytics (0.583) among the respondents while the application of AI in advanced metering infrastructure (0.733), network management (0.697), smart grid (0.675) and fault prediction/detection (0.662) all registered a high level of awareness as presented in Figure 5.

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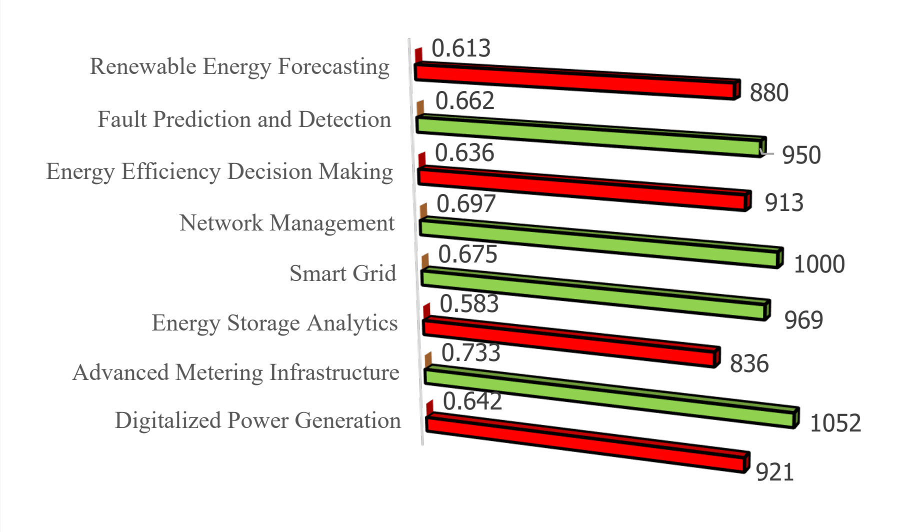

Fig. 5. Awareness level of AI Applications

The respondents were questioned if there is a personnel committed to or in charge of AI in their respective organizations. The results presented in Figure 6 showed that 86% do not have designated group/personnel responsible for AI in their organizations, while 9% have a dedicated group.

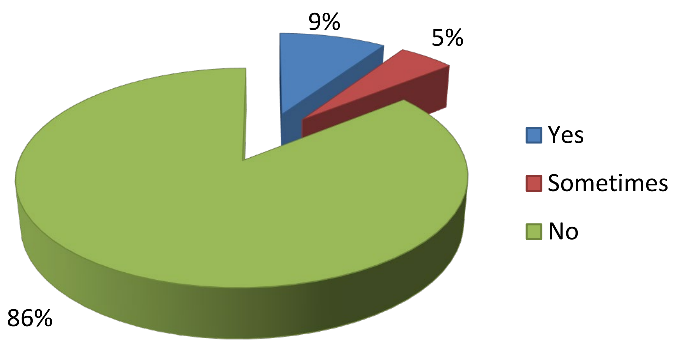

Fig. 6: Designated Group or Personnel Responsible for AI

3.3 Prospects of the adoption of artificial intelligence in the energy sector

Another objective of this research was to determine the prospects of AI in the energy sector. Extracts from the studies of [9]; [20] and [22], twelve prevailing prospects AI

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may be useful to the energy sector was drawn. On a 5-point Likert scale, respondents were requested to view their opinion. Table 4 shows the prospect of AI adoption in the energy sector.

Table 4: Prospects of AI adoption in the energy sector

Prospects	1	2	3	4	5	Mean	Weighted Total	Weighted Index	Rank
Improved energy management, efficiency and transparency	10	19	37	124	97	3.97	1140	0.794	1
Remote reading of energy meters	10	15	48	117	97	3.96	1137	0.792	2
Improved planning, operation and control of power systems	18	19	43	110	97	3.87	1110	0.774	3
Improved forecasts of electricity demand and generation	10	24	57	101	95	3.86	1108	0.772	4
Detection and Prediction of Fault	15	24	40	114	94	3.86	1109	0.773	5
Power quality monitoring and renewable energy forecasting	12	24	54	103	94	3.85	1104	0.769	6
Automation of routine and structured tasks	15	23	58	102	89	3.79	1088	0.758	7
Improved reliability, security and efficiency of electricity transmission and distribution	19	34	33	107	94	3.78	1084	0.755	8
Prevention of losses due to informal connections and energy theft	20	25	59	97	86	3.71	1065	0.742	9
Encourage and hasten the adoption of clean renewable energy sources.	23	29	49	97	89	3.7	1061	0.739	10
Lower energy waste and costs	25	33	49	97	83	3.63	1041	0.725	11
Improved assessment of damages and disaster recovery	25	32	63	95	72	3.55	1018	0.709	12
1 = SD; 2 = D; 3 = N; 4 = A; 5 = SA									

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Descriptive statistics using mean, weighted total (WT), and weighted index (WI) was used to analyse the identified prospects. According to the results, 'improved energy management, efficiency and transparency' (WI=0.794); 'remote reading of energy meters' (WI=0.792); 'improved planning, operation and control of power systems' (WI=0.774) ranked first, second and third respectively while 'accelerate the use of clean renewable energy sources' (WI=0.739); 'lower energy waste and costs' (WI=0.725); 'improved assessment of damages and disaster recovery' (WI=0.709) ranked tenth, eleventh and twelfth respectively. The results support [15]; and [14] that AI can potentially change contemporary energy systems and effective facility management in the energy sector. AI improves estimates of electricity demand and generation, allowing the demand-supply balance. Furthermore, artificial intelligence tends to minimize energy wastage, slash energy prices, and expedite the deployment of cleaner energy sources. AI may also aid in designing, operating, and controlling power systems.

3.4 Factors challenging the adoption of AI in the energy sector

Adopting and deploying AI in the energy sector presents a number of challenges. Eight common factors were identified from literature [22]; [15]; [1] to highlight the challenges associated with the adoption of AI, while others were identified via conversations with experts. The results presented in Table 5 is based on a 5-points Likert scale.

Table 5. Factors challenging the adoption of AI in the energy sector

Challenges	1	2	3	4	5	Mean	Weighted Total	Weighted Index	Rank
Outdated power system infrastructure	12	15	33	118	109	4.03	1158	0.807	1
Cellular technologies	15	19	37	113	103	3.94	1131	0.788	2
Scarcity of skilled professionals	18	20	29	115	105	3.94	1130	0.787	3
Growing threat from cyber attacks	14	24	36	112	101	3.91	1123	0.783	4
AI is dependent on electricity and internet connections	18	23	37	97	112	3.91	1123	0.783	4
Data quality issues	15	20	38	117	97	3.91	1122	0.782	6
Lack of dedicated AI policy and regulation	15	24	40	111	97	3.87	1112	0.775	7
Legal security concerns and user privacy	17	25	54	98	93	3.78	1086	0.757	8
The concept of AI models is unknown to users	18	26	54	101	88	3.75	1076	0.750	9
Integration of AI into subsystems	19	30	52	97	89	3.72	1068	0.744	10
Decentralization and diversification	25	32	57	94	79	3.59	1031	0.718	11

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Possible job loss within the energy sector	28	31	54	96	78	3.57	1026	0.715	12
Generate questions on transparency	31	40	65	86	65	3.4	975	0.679	13
1 = SD; 2 = D; 3 = N; 4 = A; 5 = SA									

Similarly, descriptive statistics using mean, weighted total (WT), and weighted index (WI) were used to analyze the identified challenges. The findings showed that 'outdated power system infrastructure' (WI=0.807); 'cellular technologies' (WI=0.788); 'scarcity of skilled professionals' (WI=0.787); and 'growing threat from cyber-attacks cellular technologies' (WI=0.783) were the major challenges identified by respondents. In addition, 'decentralization and diversification' (WI=0.718); 'possible job loss' (WI=0.715); and 'generate questions on transparency' (WI=0.679) ranked lowest. According to [14], several factors prevent broader AI adoption, such as difficulties with data quality and legal issues. The findings from the study also corroborate with that of [28] and [29] who opined that AI is reliant on infrastructures such as energy and internet connectivity. There are few datasets accessible for AI projects, and the provided data is of uncertain quality. As a result, many targeted AI and ICT initiatives fail to offer the benefits requirement to the project's sponsors owing to incorrect and inadequate data.

Furthermore, in underdeveloped nations such as Nigeria, cities, outlying areas, and villages lack regular power supplies and reliable internet coverage. The lack of these requisite infrastructures poses a significant barrier to using AI in facility management in the energy sector. Furthermore, several countries are developing legislation and regulations to support the initiation and full adoption of AI-based technology, but this is not the case in Nigeria.

4 Conclusion and Recommendations

The study's primary objective is to assess AI awareness in facility management and to identify the prospects and challenges of adopting AI in the energy sector. Based on the data, the research finds a high level of awareness regarding the notion of AI in the energy sector. Also, awareness about some selected AI technologies, machine & deep learning, robotics, and speech recognition had a high awareness level. Additionally, the study concludes that AI technologies with a high awareness level regarding applicability to facilities management in the energy sector are in advanced metering infrastructure, smart grid, network management, and fault prediction/detection. The study also concludes that improved energy management, efficiency and transparency, remote reading of energy meters, and improved planning, operation & control of power systems were the most prevalent prospects of AI adoption. The critical challenges to AI deployment in the Nigerian energy sector are outdated power system infrastructure,

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cellular technologies, a scarcity of qualified experts and data scientists, growing threats from cyber-attacks, and AI dependence on electricity and internet connections.

Hence, the study recommends the following:

1. *Improved awareness and technical know-how of energy sector personnel*
   Increased awareness through conferences, workshops, and seminars for stakeholders in the power sector will boost the knowledge and awareness of AI-based technologies. These trainings would also enhance swift adoption when necessary infrastructures are provided.
2. *Provision of adequate power system infrastructure to provide stable power supply*
   Most digital technologies, especially AI technologies, require an uninterrupted electricity supply for effective operation. Hence, unless the country is able to sufficiently address the issue of epileptic power supply, adoption of AI technologies will be impossible
3. *Provision of reliable connectivity in a rural underserved area for constant data communication*
   Just like power supply, strong internet connectivity is another essential component of operating AI. Some urban cities and most rural settlements are still characterized by weak or very poor internet services, respectively. Hence, telecommunication providers need to improve and stabilize internet connectivity for enhanced AI adoption.
4. *Funding fundamental and applied research to produce significant breakthroughs in AI theory, technology, and applications in the energy sector.*
   Adequate funding to support the massive infrastructural deficit to enable AI-technologies' active implementation and adoption cannot be overemphasized. In addition, research in the area of emerging AI technologies also requires funding to achieve breakthroughs in their applications.
5. *Setup secure platforms and databases to promote data quality and private data exchange*
   Data security through secure databases to encourage investors and other stakeholders to venture into AI technologies in the energy industry cannot be overemphasized as well. This would curb the menace of cybercrime and boost confidence in AI operations.

5 Acknowledgment

The authors wish to appreciate the energy sector practitioners across the North-central zone of Nigeria who participated in the survey. Their valid responses made the completion of the article possible.

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The Effects of Prepaid Metering Systems on Customer Satisfaction in Niger State, Nigeria

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Abstract—Energy consumers in Nigeria have long complained about Distribution Companies' unfair billing practices, exorbitant monthly electricity bills resulting from meter estimation rather than accurate meter reading. The study's objectives were to establish the relationship between the prepaid metering system and customer satisfaction; and evaluate the level of satisfaction concerning the usage of the prepaid metering system in Niger State, Nigeria. In carrying out the study, the structured questionnaire was administered to 393 randomly chosen respondents drawn from prepaid meter users, out of which 344 responded, generating a response rate of 87.5%. The data derived were subjected to spearman correlation and multiple regression models. The major findings from the study showed a significant, moderate, and positive relationship between the prepaid metering system and customer satisfaction. Additionally, three significant predictors, Affordability, Availability, and Flexibility with $p < .01$ are statistically significant. Further findings from descriptive statistics revealed that users had the highest level of satisfaction with their privacy as a result of no meter readers and no accumulated. The study concluded a positive and beneficial link between the prepaid metering system and customer satisfaction. Therefore, the study recommends good customer care units and a marketing campaign for better knowledge of the prepaid metering system.

Keywords—Prepaid metering system, Postpaid metering system, Customer satisfaction, Spearman correlation, Multiple regression model

1 Introduction

The Postpaid and prepaid systems are the two most prevalent types of electricity billing systems in use around the world [1]. Most households have predominantly been subjected to postpaid billing, and just lately, there has been a significant shift toward

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the prepaid metering system [2]. This shift is due to the fact that with a postpaid metering system, users are billed, and monthly payments are based on overall usage, which means that service takes precedence over payment[1],[3],[4]; prepaid metering, on the other hand, requires the user to purchase tokens and units before electricity usage [5]. Electricity was first provided in Nigeria through a postpaid metering system, this requires DISCO staff to manually interpret meter readings and consumers pay for the electricity that has already been used. This is a prevalent method of accounting for substantial non-technical losses resulting from immoral acts like paying bribes to waive bills for consumers who bypass meters. Users who noticed they were overcharged due to incorrect billing estimations typically attempt to recuperate their losses by paying bills late or not at all [6].

According to [1], postpaid billing difficulties include meter reading errors resulting in payment irregularities, inaccessible meter readings causing meter readers to assume and guess. Given the low electricity supply and widespread utility exploitation of customers through irregular billing, accurate consumption metering is crucial in Nigeria. More than eighty percent of the complaints received by the regulator (Nigerian Electricity Regulatory Commission) are about billing irregularities, high tariff rates in the estimated metering approach, and faulty metering infrastructure due to Nigeria's bad billing procedures [7]. The ability of a company to recognize and meet its customers' needs and desires consistently determines its success. Customer happiness is one of the most powerful weapons a business can use to get an edge over its competitors in today's ever-increasing competitive climate. Every organization that wishes to expand its market share must constantly identify and improve aspects that boost customer satisfaction and detect and avoid those that diminish consumer satisfaction [8].

As a result, most countries and cooperatives have shifted to this model (prepaid metering system) in recent years to reap the system's benefits [9]. Prepaid system is a new approach to energy billing that includes a modern electronic customer account management system. Smartcard technology is combined with metering equipment in this system. It not only delivers a service, but it also saves time and money for the company and gives clients more payment choices. It has a paperless payment system and can be used to replace any electromechanical meter on the market, reducing operational costs [10]. As a result of a high customer debt profile and revenue collection difficulties, the Power Holding Company of Nigeria (PHCN) launched the prepaid metering system in 2006 to minimize or avoid complaints of overbilling and other related issues [11]. The prepaid metering system allows DISCOs to collect fees from consumers before using it, reducing revenue lost due to power theft and consumers' unwilling-

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ness to pay their utility bills due to incorrect meter reading and payment [12]. The prepaid framework allows for socialization and socioeconomic ordering in a variety of ways, including financial, political, innovative, and technological. Using the prepaid model, consumers can effectively and easily manage their budgets, reducing wasteful and unnecessary electricity use, such as not conserving energy and leaving devices on [13]. The prepaid approach benefits municipalities and utility providers since it boosts income, reduces postpaid outstanding obligations, and improves customer relations [9]. Another overlooked benefit of DISCOs is worker's protection, which exposes staff who are supposed to read meters and visit customers' houses to dangers such as dog bites, harsh weather, and hazards, among other things, as well as the perception of invasion privacy [12]. This paper seeks to study the effects of the prepaid metering system on customer satisfaction, and the specific objectives of the study are to:

i. establish the relationship between the prepaid metering system and customer satisfaction and;
ii. evaluate the level of satisfaction concerning the usage of the prepaid metering system in Niger State, Nigeria.

2. Materials and Methods

The study used a quantitative method approach and a survey questionnaire to determine the level of customer satisfaction from respondents. The study's target population consists of prepaid meter users in Minna, Niger State, Nigeria. This group includes those who use or interact with prepaid electricity meters. Minna was chosen because it is an urban area where most residents in Niger State, Nigeria, use the prepaid metering system and are home to people from various social and economic backgrounds. Respondents for the study were chosen randomly, with each prepaid meter user having an equal chance of being selected. The survey had a sample size of 393 people and was carried out using the Slovin sampling method to determine the sample size.

$$n = \frac{N}{1+N(e^2)} \quad (1)$$

Where n = sample size;
N = sample frame;
e = margin of error/confidence level.

$$n = \frac{21734}{1+21734(0.05^2)} = 393$$

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A combination of descriptive analysis, rank order, and inferential statistics with the aid of Microsoft Excel and Statistical Package for the Social Sciences (SPSS) was used in the analysis of the data. The questionnaire was divided into three sections. The first section is made up of the background data (gender, age, educational qualification, marital status, household size, primary occupation, household income, years of meter usage, types of apartment, and mode of payment) of the prepaid meter users. The second section includes questions relating to the reliability, affordability, availability, and flexibility of the prepaid metering system. The fifth section is made up of questions on the level of customer satisfaction with respect to the prepaid metering system. Variables were adopted from existing literature [14]; [15] and respondents rated them on a 5-point Likert scale of (Strongly Disagree, Disagree, Undecided, Agree, Strongly Agree) and (Highly Dissatisfied, Dissatisfied, Neutral, Satisfied, Highly Satisfied).

A regression analysis was equally carried out in order to derive a mathematical model of the relationship between the prepaid metering system and customer satisfaction. The study adopted the multiple regression model used [14]. The components of the prepaid metering system include Reliability, Affordability, Availability, and Flexibility, resulting in the given equation:

$$CS = f\,(REL, AFF, AVA, FLE) \qquad (2)$$

Transforming into a multiple regression model;

$$CS = \beta_0 + \beta_1 REL + \beta_2 AFF + \beta_3 AVA + \beta_4 FLE + \varepsilon \qquad (3)$$

Where:
CS = Customer Satisfaction
B_0 = Constant; $\beta_1 – \beta_4$ = Regression Coefficients
REL = Reliability; AFF = Affordability; AVA = Availability; FLE = Flexibility
ε = Stochastic Disturbance Error Term

3 Results and Discussion

3.1 Background data of prepaid meter users

From the results shown in Table 1, out of 393 questionnaires administered, 344 were filled out correctly and collected, yielding a response rate of 87.5%. The high response rate of 87.5% indicates that respondents are willing to take part in the project while the

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remaining 49 questionnaires were either incomplete or not returned and as a result was disqualified.

Table 1: Questionnaire Response Rate

Response Rate	Frequency	Percentage (%)
Response	344	87.5
Spoilt/Not returned	49	12.5
Total	393	100

The background data of prepaid meter users are presented in Table 2. The findings show that males account for 77.3% (266) of the 344 prepaid meter users, while females account for the remaining 22.7%. This reveals that more male households use the prepaid metering system than females. Furthermore, most users (59.6%) are between the ages of 31 to 40 years. Users between the ages of 41 and 50 years and those between the ages of 21 and 30 years account for 17.4% and 16.7%, respectively. Users aged 51 years and above and those under the age of 20 years had the lowest representation with 5.2% and 0.9%, respectively. This implies that prepaid meters are more prevalent among youths and adults. According to the findings, 9 users have a Doctor of Philosophy (PhD), 45 have a Master's degree, with a rate of 75.3%, 259 of them have a bachelor's degree and Higher National Diploma (HND), making up the largest group, 28 have a National Diploma (ND)/Nigerian Certificate in Education (NCE), and 3 have completed secondary school. This revealed that many prepaid meter users had a higher level of education than the average secondary school student. The public/civil service employed the majority of users (37.8%), and they were closely followed by those who were self-employed (31.4%), private sector employees (24.4%), and students (6.4%). This trend showed that those employed in the public/civil service preferred prepaid electricity.

Table 2: Background Data of Prepaid Meter Users

Profile	Freq	%		Profile	Freq	%
Gender				**Mode of Payment**		
Male	266	77.3		Pay Station	132	38.4
Female	78	22.7		Online Payment	120	34.9
				Both	92	26.7

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Profile	Freq	%		Profile	Freq	%
Gender				**Mode of Payment**		
Age				**Years of Usage**		
21 and below	3	0.9		Under 2	116	33.7
21 – 30	58	16.9		2 – 4	112	32.6
31 – 40	205	59.6		5 – 7	102	29.7
41 – 50	60	17.4		8 – 10	11	3.2
51 – above	18	5.2		11 - above	3	0.9
Edu. Qual.				**Income (₦)**		
SSCE	3	0.9		Below 30000	9	2.6
ND/NCE	28	8.1		31000 – 60000	36	10.5
HND/BSC	259	75.3		61000 – 90000	105	30.5
MSC/M.Eng	45	13.1		91000 – 120000	69	20.1
PhD	9	2.6		121000 - above	125	36.3
Marital Status				**Occupation**		
Single	124	36		Student	22	6.4
Married	220	64		Public/Civil Servant	130	37.8
Separated	0	0		Private Employee	84	24.4
Widowed	0	0		Self Employed	108	31.4
Divorced	0	0		Retired	0	0
Household Size						
1 – 3	107	31.1				
4 – 6	203	59				
7 – 9	34	9.9				
10 – 12	0	0				
13 – above	0					

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3.2 Relationship between the prepaid metering system and customer satisfaction

The Spearman correlation was used in this section to investigate the relationship between Customer Satisfaction and the Prepaid Metering System. The result of the correlations between the Customer Satisfaction and Prepaid Metering System are presented in Table 3.

Table 3: Correlation between Prepaid Metering System and Customer Satisfaction

Predictor Variables		**CS**	**REL**	**AFF**	**AVA**	**FLE**
CS	Corr.	1				
	Sig.					
REL	Corr.	.332**	1			
	Sig.	.000				
AFF	Corr.	.454**	.460**	1		
	Sig.	.000	.000			
AVA	Corr.	.318**	.352**	.265**	1	
	Sig.	.000	.000	.000		
FLE	Corr.	.355**	.302**	.265**	.220**	1
	Sig.	.000	.000	.000	.000	
***. Correlation is significant at the 0.01 level (2-tailed).*						

The result shows that reliability and customer satisfaction have a significant, moderate, and positive relationship. ($r = .332$, $p < 0.01$). This indicates that the higher the reliability of the prepaid metering system, the higher the customer satisfaction. There is a significant, moderate and positive relationship between affordability and Customer Satisfaction ($r = .454$, $p < 0.01$). This correlation indicates that the more affordable the prepaid metering system, the more satisfied customers are. There is also a significant, moderate and positive relationship between availability and customer satisfaction ($r = .318$, $p < 0.01$). This correlation indicates that an increase in the availability of the prepaid metering system will lead to a corresponding increase in customer satisfaction. Furthermore, there is a significant, moderate and positive relationship between flexibility and customer satisfaction ($r = .355$, $p < 0.01$). This correlation indicates that the more flexible the prepaid metering system is, the more satisfied customers are.

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Additionally, the multiple regression analysis was further used to analyze the relationship between the Prepaid Metering System and Customer Satisfaction to obtain an accurate understanding of the relationship between them. To assure the accuracy of the regression analysis outputs, the multiple regression assumptions were closely followed.

Table 4: Collinearity Statistics

Model	**Collinearity Statistics**	
	Tolerance	**VIF**
Reliability	0.709	1.411
Affordability	0.762	1.313
Availability	0.852	1.174
Flexibility	0.878	1.139
Dependent Variable: Customer Satisfaction		

The collinearity statistics presented in Table 4 shows that all four predictors have tolerance values greater than .10 and variance inflection factor (VIF) values less than 10 in the collinearity statistic tests; this demonstrates that there is no multicollinearity between the variables.

Table 5: Model Summary

Model	***R***	***R* Square**	**Adjusted *R* Square**	**Std. Error of the Estimate**
1	.544	.596	.588	.36494

The model summary presented in Table 5 shows that there is a multiple correlations ($R = .544$) of the four significant variables with the criterion. The *R* Square of this model is .596, which means that this model explains 59.6% of the variance in customers using prepaid meter. Additionally, the adjusted *R* Square shows that the four variables account for 58.8% of the variance, contributing to higher customer satisfaction.

Table 6: ANOVA (Model Validity)

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	18.975	4	4.744	35.620	.000
	Residual	45.148	339	.133		
	Total	64.124	343			

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The analysis of variance (ANOVA) presented in Table 6 shows that the regression is significant ($F_{4, 339} = 35.620$, $P < 0.01$). This result implies that all four predictor variables (Reliability, Affordability, Availability, and Flexibility) effectively explain customer satisfaction variation. The multiple regression variable coefficients is further presented in Table 7

Table 7: Multiple Regression Variable Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.919	.187		10.240	.000
Reliability	.053	.048	.060	1.112	.267
Affordability	.263	.042	.326	6.244	.000
Availability	.127	.038	.163	3.305	.001
Flexibility	.189	.043	.214	4.408	.000

The results show that affordability has a statistically significant value of $p < .01$; hence it has a statistically significant influence on the dependent variable. Unstandardized coefficient value of .263 shows that a unit rise in affordability will cause a rise of .263 in customer satisfaction. Therefore, a rise in the affordability of the prepaid metering system will strengthen the satisfaction of customers. In explaining the standardized coefficients, the dependent variable rises by .326 standard deviations for each standard deviation of movement in affordability. Furthermore, availability has a statistically significant value of .01 ($p < .05$); hence it has a statistically significant influence on customer satisfaction. Unstandardized coefficient value of .127 shows that a unit increase in availability will cause an increase of .127 in customer satisfaction. Hence, an increase in the availability of the prepaid metering services will increase customers' satisfaction.

Regarding the standardized coefficients, for every one standard deviation of movement in availability, customer satisfaction increases by .163 standard deviations. Additionally, flexibility has a statistically significant value of $p < .01$; hence this has a statistically significant influence on customer satisfaction. Unstandardized coefficient value of .189 for this shows that a unit rise in flexibility will cause an increase of .189 in customer satisfaction. Hence, an increase in the flexibility of the prepaid metering system and services will strengthen the satisfaction of customers. In terms of the standardized coefficients, for every one standard deviation of movement in flexibility, customer satisfaction increases by .214 standard deviations while reliability has a non-statistically significant value of .267 ($p > .05$), this shows that it has no statistically significant meaningful effect on the customer satisfaction. Additionally, the value of .053 unstandardized coefficients implies that each measurement in reliability will produce a .053 change in customer satisfaction. Hence, a rise in the reliability of the prepaid metering system will strengthen the satisfaction of customers. In explaining the standardized coefficients, customer satisfaction increases by .060 standard deviations for each standard deviation of movement in reliability.

The three significant predictors (affordability, availability, and flexibility) are positively related to the criterion in the regression. Affordability has the highest standardized coefficient at 0.326, followed by flexibility with a coefficient of 0.214, and availability with a standardized coefficient of 0.163. This indicates that affordability has a stronger unique contribution in explaining customer satisfaction than flexibility and availability. However, one of the variables (reliability) has a significant value greater than 0.05, indicating that it does not contribute significantly to the model. Therefore, reliability will be excluded to improve the desirability of the regression model. Thus, based on findings presented in Table 3.6, the regression equation is as follows:

$$CS = 1.919 + 0.263AFF + 0.127AVA + 0.189FLE \qquad (4)$$

Where:
CS = Customer Satisfaction; *AFF* = Affordability; *AVA* = Availability; *FLE* = Flexibility

These findings are in agreement with earlier studies that supported that the major factors that influence prepaid metering systems and customer satisfaction were: costing; reliability; availability and flexibility. Customers also consider several factors before accepting the prepaid meter for use, including the prepaid meter's user-friendliness, durability, and access to prepaid meter vending points while also establishing a weak positive correlation between the adoption Prepaid Metering System and Customer Satisfaction [14]; [15].

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3.3 Customer satisfaction level with respect to prepaid meter usage

The prepaid meter user is satisfied when the product quality meets their expectations, and they assume the item to be of high quality; on the other hand, if it does not meet their parameters of perceived quality, they assume the product to be of low quality. Users who are satisfied complain less, speak more positively about the products they like and are more likely to remain loyal customers. The tendency of prepaid meters to provide value to customers and thus meet their needs is vital. The customer satisfaction level with respect to prepaid meter usage is presented in Table 8.

Table 8: Customer Satisfaction with Prepaid Meter Usage

Factors	Mean	%	S.D	Remark
I am satisfied because it is efficient and not easily damaged	4.38	87.56	0.645	High Satisfaction
It is easy to buy prepaid credit (tokens/units)	4.33	86.69	0.667	High Satisfaction
I am satisfied with the tariff system	2.55	51.05	1.225	Low Satisfaction
I am satisfied with the mode of payment	4.31	86.28	0.712	High Satisfaction
I am satisfied because there is no accumulated debt	4.42	88.43	0.700	High Satisfaction
I am satisfied because I can monitor my consumption	4.39	87.85	0.724	High Satisfaction
I am satisfied because I am not charged when there is power outage	4.40	87.97	0.725	High Satisfaction
I am satisfied with paying upfront before use	3.99	79.59	0.924	High Satisfaction
I am satisfied with the response anytime I encounter challenge	2.68	53.60	1.102	Low Satisfaction
I am satisfied with the privacy I enjoyed as a result of no meter readers	4.42	88.43	0.643	High Satisfaction

The results indicate that there exists a low satisfaction level with the tariff system and the response users receive whenever they encounter a problem. This is because prepaid meter users (particularly low-income earners who find it difficult to pay the previous tariff) are dissatisfied with the increase in electricity tariff. Users are also dissatisfied with the fact that when a problem is reported to the customer care unit, they tend to drag their feet and act slowly. The available customer service units are unable to effectively address customer complaints to ensure customer complaints satisfaction. There is also the issue of lateness and laziness among sales representatives and other workers who are responsible for the welfare of customers. Prepaid meter users had the highest level of satisfaction with their privacy as a result of no meter readers and no accumulated debt, with a mean score of 4.42. This is because they no longer have to rely on others to read their meters for them, and they are satisfied because they no longer have to worry about inaccurate readings or strangers posing as meter readers. On “no accumulated debts,” users are highly satisfied because they pay before consumption, and there are no bills delivered to their homes. Users also had a high level of satisfaction because they are not been charged during power outages or when the meter is not in use, they can now monitor their consumption, the meters are efficient and not easily damaged, tokens are easy to buy, and they are satisfied paying upfront. These findings are in agreement with [16], who opined that a major prominent level of satisfaction that customers enjoy from the adoption of prepaid metering system is the payment before usage, and it largely assists the user feel comfortable and get maximum satisfaction.

4. Conclusion and Recommendation

Conclusions were drawn based on the findings of the research. The findings successfully demonstrated that the prepaid metering system and customer satisfaction have a relationship and are linked. Reliability, Affordability, Availability, and Flexibility were the variables identified by the study as influencing the usage of prepaid electricity metering systems on customer satisfaction. However, Affordability has a stronger unique contribution in explaining customer satisfaction as compared to Flexibility and Availability. Residents in Minna have enthusiastically welcomed the implementation of the prepaid electric meter in the city, and they believe that the ability of the distribution company to understand customer needs is an important factor in creating customer satisfaction as well as the company’s readiness to effectively address any operational challenges or other challenges that may arise. Based on the findings and conclusion of this study, the following is recommended;

i. Good customer care service (units)
ii. Communication with meters wirelessly through mobile phones
iii. Receiving and installation of meters on time

iv. A marketing campaign for better knowledge of the prepaid meter
v. Future research work can look into the impact of utility sales on the installation of prepaid meters and increased/reduced meter tampering etc.

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Farmers-Herders Conflict and Nigeria's Quest for Food Security: The Imperative Need for Information Communications Technology

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Abstract— Although Nigeria is best known for its oil and gas production, agriculture employs roughly 70% of its workforce. Nigeria has experienced a severe farmer-herder conflict that has negatively influenced its agricultural production capacity, resulting in severe food insecurity. Tensions have risen in recent decades, with increasingly violent clashes between farmers and herdsmen sweeping the country. In recent times, many scholarly studies and inquiries into the impact of information and communication technologies, particularly with respect to promoting food security in Nigeria, have been engendered mainly by the need to ensure greater agricultural outputs among farmers and other agriculturists. However, only scant attention has been devoted to understanding the imperativeness of the use of information communications technology in the quest to proffer solutions to the incessant farmers-herdsmen conflicts that have also contributed to the unpalatable state of food security in Nigeria. The study adopts Karl Marx's Conflict Theory as a framework of analysis and elicits qualitative data through content analysis of desktop data. Hinging on this theory, this study contends that the farmer-herdsmen conflict is inevitable, like every other conflict, due to the competition for limited land resources. On the other hand, the study discovered that the failure of relevant stakeholders to leverage the capabilities of information and communications technology to address the technological gap in the conflict is one of the reasons why the farmers-herdsmen conflict has persisted, among many other factors. While further findings suggest

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that the principal causes and aggravating factors behind the escalating conflict are climatic changes, population growth, technological and economic changes, crime, political and ethnic strife, and cultural changes, the lack of the use of information and communications technology in the areas of educating both the farmers and herders, awareness creation, crime reporting, and conflict resolution further compounds the farmer-herdsman conflict. This study advocate for the proper and improved use of I.C.T. in the processes of resolving farmer-herdsmen conflicts.

Keywords—Farmers-herdsmen, Conflict, Food Insecurity, Information and Communications Technology, Nigeria.

1 Introduction

Centuries ago, roving herders habitually moved across the northern regions of modern Nigeria for grazing. However, the damage of outdated grazing lands to desertification, drought, and conversion to farmland has forced many pastoralists to rove south into sedentary farming communities or agricultural populations. The herders' movement had always been formerly seasonal, spending the dry season in central Nigeria, where there is more grazing land available for the herders, while returning back to the core north as soon as the rainy season begins. As more of northern Nigeria becomes desert, with grasses shrinking, basically, on a permanent basis, herders have chosen to wander to the south, searching for more fecund grazing land. Frequently, more than often, it resulted in clashes with farmers across Nigeria for access to land and water. Farmers frequently accuse herders of trespassing on their land, while herders frequently blame farmers or members of their host community for livestock thievery [1].

Anter [2] posits accordingly that the Fulanis have traditionally been nomadic pastoralists, following people and herding cattle, sheep, and goats over their vast desert hinterlands, keeping themselves somewhat apart from the main agricultural population. Their origins are disputed, with some researchers claiming Judaea-Syrian ancestry and others claiming a North African origin. From the Tekruur Kingdom in today's Senegal area, the clan has migrated from the Middle East through North Africa and established itself in Central and West Africa [3]. The world's largest nomadic community is said to be Nigerian herders. While most of them remain semi-nomadic herders in Nigeria, others have embraced modernity and moved to the cities. Nomadic tribes, in contrast to more integrated city dwellers, spend the majority of their time in the bush and are frequently involved in the herder-farmer conflict. These herders regularly conflict with

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agricultural communities as they herd the animals across huge distances. The problem is exacerbated by the fact that grazing reserves have been transformed into cropland, while traditional grazing paths have been obstructed by urban growth. While this conflict is essentially over land, it is becoming increasingly political along religious and ethnic lines. The herders are largely Fulani in ethnicity and practice Islam, but the majority of sedentary farmers are Christians [4]. Several participants in the herder-farmer disputes use religion to explain their acts. Although climate change and religious tensions have played a role in the rise of this conflict between herders and farmers, the lack of an effective institution and intervention capable of resolving differences and the readily available guns has caused disagreements to turn violent. The government's response to the clash includes deploying security troops to the affected areas and forming a command to look for a feasible way out. However, because of corruption and a lack of funds, its reaction has been ineffective in quelling the violence. The government's failure to provide security for local inhabitants and prosecute violent culprits has resulted in the establishment of militias equipped with machetes and modern weaponry to protect themselves against further assaults. This has exacerbated the problem. A high number of clashes have erupted between farmers and herders in Benue State, in north-central Nigeria. Because of its fecundity, the state has been dubbed the "Food Basket of the Nation," and its population and demand for agriculture have skyrocketed [5]. As a result, grazing grasslands have been converted to agriculture, and grazing routes have been blocked at a time when a growing number of herders are flocking to the region. In reaction to the closure of their traditional grazing sites, herders bring their cattle to graze on farmers' crops, causing damage to cultivated fields. Currently, the expedition to boost food security in the country is endangered by conflicts that have become tantamount not only with Nigeria but also with most West African countries. Competition over land resources has become a common manifestation between farmers and herdsmen in every part of Nigeria.

The turmoil in the Middle Belt area has expanded to other sections of the country. It has appeared in the Nigerian states such as Rivers, Enugu, Ekiti, Oyo, Ogun, Edo, Ondo, Plateau, Nasarawa, Kaduna, and Benue [6]. In Benue State, there have been harrowing clashes that have taken many lives and properties in areas including Agatu, Guma, Gwer West, Makurdi, Kwande, Katsina-ala, and Logo. Conflicts in Benue State claimed the lives of almost 5,000 people between 2014 and 2017 [7]. It has sacked over 100 towns and driven thousands of refugees into IDP camps in Makurdi, Benue's capital city. These losses have had a negative impact on farming activities as well as other related businesses and socioeconomic activities, resulting in food insecurity across the country. Because of the fear of herdsmen's attack, most farmers in the conflict's hotspots have already abandoned farms. Farming is no longer a way of life for most farmers in

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Benue and other affected states. Several farmers have been uprooted and evicted from their lands by armed individuals suspected of being herdsmen [8].

As farmers flee their farms for the safety of internally displaced person camps, their crops are being grazed upon, and their seedlings are used as cattle feed, which may prevent farmers from replanting even if they could return to their farms. Agricultural and development specialists agree that the achievements documented in the agricultural sector of the economy, particularly in food production, may suffer a significant setback due to the detrimental impacts of conflict between farmers and herders across the country. Balogun [9] revealed in his study of the causes and consequences of perennial clashes between herdsmen and farmers in Nigeria that the attacks have a significant impact on food security and have resulted in a $14 billion loss in three years. Other economic consequences of these skirmishes include hampered trade practices, reduced crop yield, farmer relocation, loss of life and property, loss of items in storage, and damage to public and private facilities, in addition to severely delaying the country's economic development. Herder-farmer clashes are expected to continue to jeopardize Nigerian food security unless farmers and herders can reach an agreement using I.C.T to develop alternatives to the never-ending fight for land resources. According to Nyong and Fiki [10], resource-related conflicts are responsible for a more than 12% reduction in per capita food output in Sub-Saharan Africa. Herdsmen have maintained a symbiotic relationship with local farmers for many decades before to Nigeria's independence, with fewer schisms. However, the relationship has deteriorated in recent years, resulting in the murders and the destruction of property [11]. According to Balogun [12], food security is a critical component of human security. By extension, if one component is harmed, the others are also harmed. The United Nations Food and Agricultural Organization (FAO) outlines four pillars of food security: availability, access, use, and stability [13]. Nonetheless, present realities have exposed a disconnect between the application of I.C.T. and food security and the settlement of farmers-herdsmen confrontations. Herders and pastoralists in the most technologically sophisticated nations have reached new heights in ranching their herds, feeding, raising, and producing using technology.

However, in Nigeria, most herders are not even aware of the presence and the imperative for using information and communication technologies in the production and rearing of their cattle. Similarly, many farmers across the country are still oblivious to the possibilities embedded in the use of I.C.T. (Information Communications Technology) in the production, marketing, and preservation of their crops and farmlands. This explains why I.C.T use among the herders and farmers remains minimal. As a result, the purpose of this paper is to highlight the implications of the herders-farmers, conflict on food security in Nigeria, and the importance of I.C.T. in

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achieving enhanced food security and reducing the occurrence farmers-herdsmen conflict.

1.1 Conceptual Explication

a. Food Security

Food is a necessity for humans. Man is thought to be incomplete without nourishment. According to Balogun [14], food has definite values that make it necessary to man. Food has biological, social, economic, and political implications for humans. During the 1974 World Food Conference, the term "food security" was coined to emphasize supply. Food security is thus defined as "the availability of sufficient world food supply of fundamental commodities at all times to enable stable growth in food consumption while offsetting the volatility in production and pricing" [15]. Demand and access concerns were added to advanced definitions of food security understanding. Food security "occurs when all people have physical and economic access to enough, safe, and nutritious dietary to fulfill their nutritional needs and food preferences for an active and healthy life at all times," according to the World Food Summit's closing report [16]. Food security is described as a state where everyone has enough food to live a healthy and productive life [17]. According to the Bureau for Africa, food security is defined as "a condition in which all people have physical, social, and economic access to adequate food to meet their dietary needs for a productive and healthy life at all times" [18]. The Food and Agricultural Organization of the United Nations (FAO) defined four food security supports: availability, accessibility, utilization, and stability [19]. The right to food was recognized by the United Nations (UN) in the 1948 Declaration of Human Rights [20], and it has since been emphasised that it is necessary for the enjoyment of all other rights [21]. Food insecurity is diametrically opposed to food security. FAO [22] defines food insecurity as a state in which individuals do not have secure access to adequate amounts of safe and nutritious food for normal growth and development, as well as an active and healthy life. It might be caused by a lack of food, insufficient purchasing capacity, incorrect distribution, or insufficient food utilization at the home level. The main reasons for low nutritional status include food instability, poor health and sanitation conditions, and inadequate care and feeding habits. Food insecurity can be long-term, seasonal, or transient. According to Balogun [23], food insecurity is a condition in which people do not have consistent physical or economic access to enough safe, nutritious, and socially acceptable food to live a healthy and productive life. According to the FAO, the leading causes of food insecurity include war, civil unrest, corruption, national policies that do

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not encourage fair access to food for everyone, environmental degradation, inadequate agricultural development, and crop pests and diseases [24].

b. Herdsmen

Domestic animals such as cattle, sheep, goats, and so on are raised by herders. They are also known as "cattle breeders" or "cattle rearers," and they often live a nomadic existence while searching for grazing places for their animals with sticks and cutlasses in their hands. The Fulani is the world's biggest semi-nomadic group, and they may be found from Senegal to the Central African Republic [25]. Some live as semi-nomadic herders in Nigeria, while others have settled in towns. According to Nwosu [26], the Fulani is sometimes lumped in with the Hausa ethnic group (thus the designation, Hausa-Fulani), despite the fact that both ethnicities are separate. In Nigeria, the Many Fulani are nomadic herders; however, some live in established areas. Because of the nature of their livelihood, they leave their base in northern Nigeria in search of greenery for their cattle in southern Nigeria. As Aluko [27] points out, the interaction of widely scattered Fulani with other communities has resulted in diverse socioeconomic patterns.

c. Farmers

A farmer cultivates the soil or raises livestock for food and raw materials. Crop farmers, poultry farmers, animal breeders, and other sorts of farmers exist. Although crop farmers and Fulani herders both work in agriculture, crop farmers may also be referred to as stockbreeders. Among the Fulani herders, some individuals practice mixed farming. This demonstrates the connections between farming and herding as a vocation in agriculture. The majority of farmers in Nigeria come from communities in the North Central and Southern regions. Farmers grow a variety of food crops, including yams, rice, maize, guinea-corn, millet, soya beans, cassava, groundnut, cotton, Irish potatoes, sweet potatoes, tomatoes, onions, cabbage, and carrots [28].

d. Conflicts

Conflicts are common in human social connections and are essential components of social life. They are commonly characterized as a dispute between two or more individuals over irreconcilable aims. They happen between people, social units, and groupings. According to Adisa [29], conflict is a persistent aspect of human social relationships. In other words, conflict is unavoidable in human social interaction due to people with a community's perception of insufficient resources. According to Albert [30], conflict is defined as an antagonism among the social units directed against one another.

Furthermore, Albert [31] defines conflict as a connection between two or more people that are seen to have opposing agendas. Albert [32] defines conflict as a situation

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in which there is insufficient or no compromise amongst social units. Personal or interpersonal conflict, intragroup or intergroup conflict, and so on. This study focuses on the intergroup conflict between farmers and herders.

2. Theoretical Explications

There are several theoretical hypotheses for the reasons and character of the Nigerian herder-farmer conflict. The disagreement is best characterized using social conflict theory. As a result, it has been adopted as a frame of analysis here. Social conflict theories highlight the importance of conflict in determining social circumstances and the dynamics of social life. In reality, when we study and engage in social life, we frequently come into conflicts or possible conflictual conditions among people, social groupings, political parties, and so on.

The concept considers social existence a struggle and focuses on the distribution of scarce resources and power, which are not distributed evenly by nature. Proponents of this theory see society as a collection of people with diverse demands and interests who have limited resources to meet those demands. Inequality ensues, resulting in social strife and, eventually, social transformation. Karl Marx is widely acknowledged as the father of social conflict theory. According to social conflict theory, conflicts for power and control in society are a major source of conflict. Conflict occurs when two or more actors oppose each other in social interaction, using social forces reciprocals in an attempt to achieve scarce or incompatible goals while preventing the opponent from attaining them. Instead of reaching an agreement, the desire for supremacy and power becomes the currency. The theory's central idea is that society is constantly competing for finite resources. This captures the rationale as to why the farmers and herders are often locked in an incessant struggle over equally desired resources. Whilst the farmers often regard farmlands as sacrosanct and imperative to their subsistence and livelihood, the herders consider the farmlands as a critical imperative for the survival of their cattle. This has always prompted a contest between these two social groups.

Again, in this case, the inadequate resources are lands, and the battle over land resources has always informed the farmers-herdsmen skirmishes in Nigeria. Even though the confrontations have taken on political, religious, and ethnic aspects, administrations at the local, state, and federal levels have been unable to resolve the competing interests between herders and farmers or aid them in reaching a solution. Regardless, the social conflict theory affords us the opportunity to understand the ‘why’ of the conflict.

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3. Thematic and Content Analysis of Findings

3.1 Farmers-Herders Conflict in Nigeria: Dynamics and Causes

Nigeria emphasizes promoting agriculture as a viable alternative to oil as a key national wealth foundation. Many individuals are going into farming, and more people are getting into livestock, including cow breeding. Attacks and retaliation by farmers and herders result in the annihilation of lives and property. According to Bello [33], attacks by Fulani herdsmen in Nigeria killed 3,780 Nigerians across the nation, omitting the injured and abducted. On the other side, farmers have slaughtered dozens of cows and Fulani ranchers in retaliation for the annihilation of farms and agricultural produce by cows. The current herdsmen drive and subsequent clashes with farmers and host towns have increased insecurity in Nigeria, particularly in the North Central region and, by extension, throughout the country. The motivation for the clashes is competition for available resources, particularly grazing land. The competition for available resources, particularly grazing areas, is the motivation behind the confrontations. As a result, grazing reserves in a neglected agricultural area were unable to be maintained. It received little or no attention from successive governments. Herders returned to their traditional and seasonal grazing routes, which had been disrupted or hampered by industry, urbanisation, demography, and other natural forces, as a last resort. As a result, clashes and violence erupted between farmers and host communities. These conflicts have become increasingly common in recent years, and they now pose one of the most serious threats to Nigeria's national security [35]. To address these issues, the federal government established a Strategic Action Committee in June 2015 to investigate the problem and make recommendations to help the government deal with it. The Miyetti Allah Cattle Breeders Association (MACBAN), a key partner in this project, determined that climate change and desertification were major contributors to annual trans-human migration from the North to the South [36]. Because climate change and other linked variables are beyond the ability of farmers or herders to solve, active efforts by the government, business sector, regional authorities, and the global community are required to address these concerns. The need to resolve the problem is even more pressing since the conflicts threaten food and agricultural security and the country's unity, peaceful cohabitation, and harmony. Climate change (frequent droughts and desertification), population growth (loss of northern grazing lands due to human settlement expansion), technological and economic changes (new livestock and farming practises), crime (rural banditry and cattle rustling), political and ethnic strife (intensified by the spread of illicit firearms), and cultural changes ((the collapse of traditional conflict management mechanisms), a dysfunctional legal regime that has endorsed crime to go unpunished and, consequently, has encouraged both farmers and herders to take laws into their own hands, as instant triggers of the incessant farmers-herders skirmishes.

a. Climate Change

Climate is a chief key in herdsmen's and farmers' operations. The changing climatic circumstances, colloquially known as global warming, are undoubtedly having an impact on the survival of herders and farmers' companies. The Saharan desert encroachment on the Sahel area and other associated climatic variables have continued to impact herdsmen's livelihoods as they push further south in search of sufficient land, pitting them against farmers and host communities [37]. This worldwide phenomenon is now affecting various world regions, with ramifications, such as the herdsmen-farmer conflict.

b. Depleting Farm Lands

Constant urbanization and demographic upheavals in the modern world have increased farmers' proclivity to go further away from farming operations. Nigeria had a population of roughly 35 million people when it gained independence in 1960 [38]. However, 58 years later, it has risen to over 180 million individuals, with the trend anticipated to continue in the foreseeable future [39]. A population rise of this scale entails a corresponding increase in the demand for food goods as a basic human requirement. This also means that farmers will be more aggressive in their search for farmland. On the other hand, industrialization and urbanization have eroded available land, leaving little or nothing for farmers' subsistence. Herdsmen have been pitted against farmers as they migrate south in search of pasture for their animals, resulting in conflict and destruction. Agriculture along the Benue River, for example, produces over 20,000 tonnes of grain per year [40]. Herdsmen can feed their cattle in this same area, which is also fertile. As a result, the movement of the herdsmen has the greatest impact on farmlands along the river's edge, resulting in a number of clashes.

c. Inattentive of Political Will

The administration at all levels has proved a near-complete lack of the necessary political will in propositioning of a long-term reaction to the challenging demands of many contributors in the ongoing conflict between herders and farmers [41]. Political leaders have failed to enact proper laws accompanied by action to specify norms and boundaries for conflict parties. At the regional level, the Economic Community of West African States (ECOWAS) has a Trans-Human Movement Protocol, but the framework has yet to be fully implemented at the state level. A lack of political will among member

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countries remains a roadblock. The lack of political will in Nigeria to implement this protocol and other frameworks such as the national ranching policy (which has been implemented in industrialized countries such as the Netherlands, Argentina, and others) contributes to the failures to control the schisms. An attempt has been made in the time past by the federal government to regulate and control pastoral activities, but it appears that appropriate political will is required to carry out some of its policies. For example, the government is sympathetic to the herdsmen's activities in some quarters, particularly by opposition parties [42]. This sharpness is most likely due to the fact that the President is Fulani, the ethnic group that controls the cattle industry. Citizens, particularly those from the worst-affected states, had expected the government to deal decisively with recalcitrant herdsmen-farmers conflicts across the state with the same zeal and determination as it had shown in dealing with similar internal security issues such as separatist movements in the country's eastern and western regions. The scourge of farmers-herdsmen, on the other hand, continues to be a recurring decimal in the country.

The fact that the President is Fulani, the same ethnic group that controls the cattle trade, is most likely to blame for the uproar. Citizens, particularly in the worst-affected states, expected the government to deal decisively with recalcitrant herdsmen-farmers conflicts across the state with the same zeal and determination it displayed in dealing with similar internal security issues like separatist movements in the country's east and west. On the other hand, the plague of farmers-herders is still a recurring theme.

3.2 The Farmers-Herders Conflict Implications/Consequences on Food Security in Nigeria

The majority of Nigeria's population lives in rural regions. Because agriculture is the primary concern of the rural people, communal violence or disputes have major ramifications for food supply and availability. The major economic activity of the inhabitants is crop agriculture and livestock keeping. As a result, communal conflicts have major consequences for the food chain. Warring tribes or groups frequently use manipulation to get access to food and cattle. As a result, food insecurity has become a side consequence of communal strife [43]. Communal strife is linked to food insecurity and, in most cases, reduces cash crop and livestock productivity and revenue. This decrease in output and revenue has major consequences for food security, potentially weakening the coping ability of individuals who rely on food resources for a living.

The Fulani herders are undeniably important contributors to Nigeria's economy. They are the primary cattle breeders, meat producers, and the most readily available and

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affordable source of animal proteins for Nigerians. The Fulani own over 90% of the cattle population in the country, accounting for one-third of agricultural GDP and 3.2 percent of total GDP [44]. The Fulani also significantly impacts the local food system and national food security. Furthermore, Abughdyer [45] reported that between 2010 and 2014, farmers and herdsmen crises in Benue state damaged 664.4 hectares (56.4 percent) of farmland in the three local governments of Agatu, Guma, and Logo. This poses a significant risk to food production in Nigeria, as the state is the country's food security focal point. The conflict's attendant consequences can also be seen within the prism of human, societal, economic, and security effects. In general, farmer-herder disputes have tremendous humanitarian consequences. The conflict between locals and nomads usually ends in death, population displacement, human harm, and loss of livelihood [46]. In this aspect, violence is capable of not only murdering people but also of rendering them homeless, displaced, and poor. In addition to the deaths by nomads and retaliation assaults by indigenous peoples, some people have become widows, widowers, orphans as a result of the hostilities, while other victims have been crippled or disabled. As a result of the violence, people become internally displaced, particularly women, who opt not to travel to the remote farm for fear of being attacked by nomads [47].

Citing the case of the Southern Kaduna between 1999 and 2017, no less than eighty-five (85) assaults were conducted, killing about one thousand three hundred and thirteen (1,131) individuals and badly injuring sixty-nine (69) [48]. Many houses were set on fire, and many properties were damaged. In a nutshell, farmer-herder disputes result in the death of farmers, the destruction of their homes and assets, and the displacement of farmers. According to Alli [49], the social consequences of farmer-pastoralist conflict endangers peace and serenity among diverse communities. In their work on herdsmen-farmers disputes, Okoli and Atelhe [50] argued that such clashes frequently produce stressful and volatile inter-group connections among the various communities. There is currently a strong manifestation of mutual mistrust and enmity between host communities and Fulani herders. As a result, the herders regard the natives as enemies to their collective survival, and they believe that the conflict fosters mutual suspicion and perpetual tension, endangering peaceful coexistence, security, and the stability of society [51]. Threats and intimidation have also resulted from the conflict, forcing both farmers and herders to flee their conflict-prone settlements. The fearful relationship impacts the level of cooperation, agricultural activities, and economic exchanges between the two groups in this regard.

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3.3 A Review of Government's Strategic Response to the Herdsmen-Farmers' Conflict in Nigeria

3.3.1 Establishment of Grazing Reserves in 1965

In 1965, the northern regional administration launched one of the country's first initiatives to address the herdsmen-farmer dispute [52]. The grazing reserves designated huge land areas for herders to raise their cattle on. On the other hand, the grazing reserve system was not well supported. Before natural processes such as population growth and other associated repercussions such as urbanization and migration encroached on these designated regions, the government was still working on laws to legalize the grazing reserves, reducing herder chances of accessing the reserves.

3.3.2 The Establishment of National Commission for Nomadic Education (NCNE) in 1989

The Nigerian legal system backs the NCNE, which the federal government founded in 1989. The program's main goal was to help nomadic pastoralists integrate into society by providing them with mobile basic education and skill training. The program aims to integrate them into society through education.

3.3.3 The Armed Forces deployment to Curb Internal Security

The participation of the Nigerian Armed Forces, as provided in the Constitutional mechanism, is one of the federal government's urgent actions to handle farmers-herdsmen disputes [53]. For example, in Plateau state, the government established (STF-OSH) Operation Safe Haven in 2001 to combat the instability caused by herdsmen-farmers clashes. OSH has recently been expanded to replace the Southern Kaduna State Operation Harbin Kunama II, which serves a similar purpose to that of the Plateau OSH [54].

3.3.4 The National Grazing Reserve Bill of 2016 Initiative

In 2016, the Nigerian legislature sponsored a National Grazing Reserve bill to alleviate herdsmen-farmer tensions. Due to resistance from several stakeholders, the Bill did not pass. They antagonized the Bill based their disapproval on Bill's provisions requirements of the Land Use Act of 1978, vesting in the state governors all responsibilities pertaining to the regulation of ownership, administration, acquisition,

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and management of the lands in Nigerian [55]. Thus, unless modified, the Land Use Act is a National Assembly Act and, by extension, binding law. State administrations and their parliamentary members have traditionally been vehemently opposed to forming grazing reserves under their authority. They see it as an infringement on their constitutionally mandated powers [56].

3.3.5 2018 Cattle Ranching System Proposal

In response to rising tensions and mass deaths caused by seasonal pastoral migrations, the government adopted National Livestock Plan in 2018, a 10-year plan to cost the FGN around 179 billion Naira. The initiative would snowball to the development of the 94 Ranch throughout the federation's ten pilot states [57]. Again, state administrations, particularly in the South and North Central regions, opposed the concept, citing that their states do not have as much land as their counterparts in the North [58].

3.3.6 Prohibition of Open Grazing Legislation

As part of efforts to address the ongoing conflict between herdsmen and farmers in several regions, state governments have begun enacting legislation restricting open grazing. This, they think, would lessen the possibility of herders destroying farmlands and causing disputes. States, including Benue, Ondo, Oyo, Akwa Ibom, and Taraba are leading the opposition by implementing state laws forbidding open grazing. On May 22, 2017, the state of Benue passed the Open Grazing Prohibition and Ranches Establishment Law (2017), which went into effect on November 1, 2017 [59]. The states of Ekiti and Taraba have also passed legislation restricting open grazing. As a result, open grazing in any form is illegal in many states and punishable by law. The conclusion is that because the security of people and property is the duty of government at all levels, and because the Nigerian Constitution appropriately places land use within the jurisdiction of the states, additional states may accept the open grazing prohibition.

3.3.7 The Federal Government' Great Green Wall Agency

In 2013, the federal government established the Great Green Wall Agency to combat desertification. This was in response to the African Union's Great Green Wall Initiative, which began in 2007 and encouraged member countries to plant 8,000 kilometers of trees in the Southern Sahel to combat desertification [60]. The seasonal movement of herders from one location to the next in search of water and greenery for livestock

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grazing is a key factor driving desert expansion in the Sahel as a result of climate change.

4. The Imperative for Information and Communications Technology towards Food Security and the Resolution of the Farmers-Herdsmen Conflicts

Nigeria continues to be one of the least secure countries in terms of food production, security, and long-term sustainability. The recurring issue of farmers-herdsmen clashes is at the heart of this uneasiness. Apart from the recurring agricultural conflict between farmers and herdsmen over land possessions, several agriculturally-induced crop production glitches, such as biotic stresses, abiotic stresses, lack of water obtainability, soil toxicity, post-harvest loss, precision prediction inability by the farmers on how and when to farm, absence of information on healthy diets, and others, have all contributed significantly to Nigeria's unpalatable state of food security. Rather than seizing the emerging potential of information and communication technology, appropriate parties, most notably the government, have yet to overhaul the food production system through upgraded technologies. Enhanced technological techniques and practices capable of bringing improved food security in Nigeria are yet to be fully embraced by relevant stakeholders, the farmers, and the herdsmen. Pest-resistant crops and diseases, eggplant that is pest-resistant, pesticides, rust-resistant wheat varieties, spatial repellent for on-farm pests, herbicides, tilling machines, enhanced agronomic practices, salt-tolerant crops (for instance, potato, quinoa), climate-resistant crops, tissue culture and micro-propagation, conventional breeding, marker-assisted breeding, cutting-edge genetic engineering, low-cost extension workers, diagnostic toolkit for liquid nitrogen and low-cost alternatives for animal semen conservation, low-cost diagnostic toolkits for livestock veterinarians, tissue engineering for laboratory-grown animal products, low-cost veterinary pharmaceuticals (ideally thermostable), water storage technologies (subsurface water technologies, aquifers, ponds, tanks, low-cost plastic water tanks, natural wetlands, reservoirs), canal irrigation, micro-irrigation technologies, water lifting (solar-power irrigation pumps and hand-powered mechanical pumps, treadle pumps, , hydrogen-powered pumps, electric and fossil fuel pumps), fungal seed and plant treatment for water-related stress, irrigation forecast systems and decision-support systems, planting technology for increased water efficiency, water-buffering technology, rainwater harvesting mechanisms, desalination water technologies, portable sensors for groundwater detection, fruit preservation technologies, thermal battery-powered milk chillers, nanotechnology, improved genetic variations, seed and grain drying, storage and aeration know-how, biowax coating system, hexanal formulations, rice parboiling technology, processing efficient technology for pulses, rice-drying technology, grading, cleaning, and packing technology, off-grid refrigeration, low-cost solar dryers, low-cost refrigerated vehicles, vacuum or hermetic sealing, dissemination of nutrition information through health mobile applications or technologies, weather-forecasting technologies, infrared sensors to detect crop stress, hyperspectral imaging, drones based technology and satellites and other innovative technological mechanisms and imperative in food production system that can help guarantee considerable level of food security are mostly non-existent in Nigeria.

Similarly, the lack of technological invention in the quest for a peaceful resolution of the persistent fame-herdsmen conflict has aggravated the conflict. In many cases of farmland infringements by herdsmen, farmers can only recourse to walking several miles to make reports at the police station. The implication is that before the officers arrive at the crime scene, the offender may have scampered away. Rather than relying on the predominant counterproductive practice, a mobile telecommunications application or software could have been designed primarily for the farmers and the herdsmen to make fast and direct complaints of crimes to the police for immediate intervention or investigation.

Furthermore, it is quite disdainful to have found that most farmlands across the Nigerian state do not possess unique recording cameras for safety and security monitoring. While the practice of installing remote recording cameras (CCTV) in most private and public properties in developing countries is rife, Nigeria and other developing countries have not made it a priority to ensure the installation of security cameras in pricey properties such as farmlands and others. The implication is that many dodgy herdsmen may be tempted to commit acts of trespass, violence, and grazing of the cattle of farmers' farmlands in the hopes of not getting caught, especially when there are no security cameras installed on the farmland. Hence, to deter potential aggressors amongst the herdsmen, the installation of security, telecommunications cameras, or CCTV has to be imperative in light of the increasing conflict between the growers and herdsmen.

Again, to date, here in the study area, no official database for the herdsmen across the Nigerian state. Coupled with the influx of herdsmen from all over Africa, especially neighboring West African countries, local herdsmen in Nigeria remain largely unaccounted for and digitally uncaptured. This increases the risk of criminals infiltrating the ranks and files of the herdsmen due to the lack of a digital database that would harbor the personal and professional data of the herdsmen.

5. Conclusion

Food is an essential aspect of a man's life because it helps to support his growth and well-being. The farmers-herders' conflict remains a major food security threat, especially in Nigeria, with a growing population estimated at around 170 million. The findings of this study have shown that conflicts between farmers and herdsmen account for a decline in food production. According to the UN Agriculture Agency [61], notwithstanding, the robust global food supply, flooding, localized drought, and lingering farmer-herdsmen conflicts have excruciated and increased and perpetuated food insecurity in the country. Thus, succeeded in slowing down, retarding, and even stopping some major economic activities in most parts of the country is this menace. The damages to the properties and even loss of lives, the declining and diminution in agricultural produce, unemployment, loss of revenue, etc., have let loose fear, animosity, and hatred among the people and have also increased rural-urban migration, poverty, and social problems. These and many other factors remain Nigeria's topmost challenges to meaningful food security and an enduring peaceful resolution of the farmers-herdsmen conflict. The apparently-visible lack of ICT usage in the quest to find an enduring solution to the farmer-herdsmen conflict that has negatively affected Nigeria's food security objects has also become a key factor as to why the conflict has remained never-ending. The installation of security cameras across farmlands and other public spaces; the official establishment of a digital database for all herdsmen; and the use of crime reporting and emergency call applications and software for both the herdsmen and farmers are some of the many mechanisms recommended in this study for the nominal and enduring resolution of the lingering farmer-herdsmen conflicts for the actualization of the goal of improved food security in Nigeria.

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Modelling the Impacts of Climate Change on the Yield of Crops

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Abstract - This study shed light on the impact change(s) experienced in our climate system will have on the level of crop productivity in the immediate period and the nearest future. Nigeria was used as a case study. An observed climatic dataset was obtained and utilized alongside 20-year Cassava, Rice, and Soybean yield data to develop models applied in this study to estimate future crop yield. Four (4) statistically downscaled and bias-corrected Global Climate Models (GCMs): National Oceanic and Atmospheric Administration (NOAA), Japan Agency for Marine-Earth Science and Technology (MIROC5), Irish Centre for High-End Computing (ICHEC), and Norwegian Climate Centre (NCC) performed simulations for the period 1985–2100 under the Representative Concentration Pathway (RCP8.5). These were modeled to predict future yields of Cassava, Rice and Soybean in 2020-2050 and 2070-2100 for the 36 states in Nigeria and the FCT. Eighty-nine (89) empirical models were developed to estimate the yields of the three crops earlier mentioned across Nigeria, with their coefficient of determination (R^2) ranging between 15% - 99%. The result showed an increase of 3.91% ($P<0.001$), 0.08, 1.79 ($P<0.1$), and a decrease of 0.93% for cassava yield for ICHEC, MIROC, NOAA, and NCC, respectively. It also projected an increase in yield of 8.88% ($P<0.001$), 7.77% ($P<0.001$), 6.62% ($P<0.001$), and 8.85% ($P<0.001$) for Rice yield using climatic data from ICHEC, MIROC, NOAA, and NCC respectively. Soybean increase in yield is 2.81% ($P<0.01$), 5.84% ($P<0.001$), 11.38 ($P<0.001$), and 9.06% ($P<0.001$) for ICHEC, MIROC, NOAA, and NCC, respectively.

Keywords: Climate Change, Empirical models, RCP8.5, Yield, Food Security, Crop production

1. INTRODUCTION:

Climate change is defined as an observable, significant, and long-term change in weather patterns that occurs across timescales, which can range from tens of years to probably millions of years. It could be a shift in accustomed conditions of the weather or its distribution around the accustomed conditions either positively or negatively. Many such shifts could also be seen locally or globally [1].

Knowing how climate varies historically and in the future is very important in developmental studies, especially in crop and water resources, as these affect the socioeconomic state of an area. [2, 3]. Climate change studies show that crop water use, efficiency, and yield are likely to change. Although there are drought-resistant crops, rainfall deficit or lack of it or its unpredictability, which has been noticed in recent research, does not help. These rainfall fluctuations tend to promote temperature rise, which can also influence the outbreak of crop diseases that can negatively impact yield [4]. Crops can adapt to mean climatic variations but in some instances react negatively to extreme climatic conditions. These reactions to harsh or extreme conditions are usually more severe than reactions to mean climatic variations [5, 6, 7, 8].

Climate change's impact on food production, water resources, crop development, and productivity has been widely documented in numerous parts of the globe. The critical issues impacted by the changing climate, such as crop production and food security, have gotten a lot of attention they deserve, with studies forecasting possible future impacts on agricultural productivity using crop models in conjunction with climate models [9].

In accordance with IPCC (Intergovernmental Panel on Climate Change) 2007 report, Global climate change will result from increased anthropogenic greenhouse gas emissions. This change is expected to increase global temperature, change precipitation patterns and quantities. It will also increase the frequency and intensity of significant natural hazards such as droughts, heatwaves, floods, and fires [10], keeping in mind that living organisms, including crops, rely on water availability for survival [11]. Therefore, more extensive impact analyses are needed, with probabilistic output from ensembles of climate models to represent better uncertainty and clear communication of what we know and don't know about how regional climate may change [5, 12].

Dependency on rainfall has also become a critical hindrance for developing countries' long-term food production programs [13, 14]. Crop production in the region is mainly subsistent and sensitive to climate with little coping or adaptive strategies [15]. Climatic scenarios, a significant player in crop production, can hardly be controlled, and projected deviations from historical means might likely affect production level and capacity [16].

In studying how climate change impacts our environment, the Intergovernmental Panel on Climate Change (IPCC) has developed scenarios with distinct predicted

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environmental conditions for the future. Various aspects of our environment can be analyzed using these scenarios. The climate change research community has developed four (4) new tools for studying climate change called scenarios, designated Representative Concentration Pathways (RCPs), for the IPCC's Fifth Assessment Report [17]. Details of this report which describes each of the four (4) scenarios hereafter referred to as RCP can be found in the IPCC 2013 reports.

The effects of climate change on crop yield are frequently linked to its effects on water productivity and soil water balance. Temperature and rainfall will be affected by global warming, directly impacting soil moisture levels and groundwater levels. [18].

Food production is influenced by more than just rainfall and temperature fluctuations. At regional and global dimensions, population growth and economic development trajectories will influence future climate change impacts and, at the same time, agricultural responses to changing climate circumstances. [19, 20]. Recent research has also posited that the effects of these climatic changes in some places of the United States and Canada are not wholly negative.; greater agricultural outputs are projected as CO_2 levels rise and the length of the growing season lengthens [21, 22]. Similar studies carried out in the Ondo State region of Nigeria through empirical evidence strongly showed that climate variability and climate change, among other factors, negatively affected primary fruit, tuber crops' outputs, and cropping acreage [23].

Studies in Indonesia also found out that rice production in Indonesia is vulnerable to changing climate, and it creates the need to implement strategies to adapt to these changes [24]. Africa, unfortunately, having the little adaptive capability, is one of the most sensitive continents to climate change and climate parameter fluctuation. Africa's weak adaptation capability has been exacerbated by development constraints such as endemic poverty, complex governance and institutional features; restricted access to capital, including markets, infrastructure, and technology; ecological degradation; and complex disasters and conflicts, increasing the continent's vulnerability to projected climate change [25].

Agricultural Production is a vital source of income and employment for numerous Nigerian households and a vital source of food. As previously stated, climate change poses a significant threat to this industry. If this concern is not addressed, it could result in increased unemployment, food scarcity, and even hunger among small-scale farmers. The Agro-allied industry is an integral contributor to the Nigerian economy, and farmers' incapacity to grow crops in sufficient amounts can translate to severe ramifications for people's livelihoods and economies. As a result, it is necessary to; Increase crop producers' per capita income by facilitating the adoption of effective adaptation mechanisms to cope with climatic unpredictability in light of current and

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likely worsening climatic conditions and also, maintaining while improving crop production levels in light of current and likely deteriorating climatic conditions.

This research aims to take a look at the consequences of climate change on Cassava, Rice, and soybean. It further seeks to determine the likely effects of these future scenarios on future yields of these crops, allowing us to devise adaptive approaches to maximize results' value.

2. Methodology

2.1 Area of study

The country Nigeria is considered for this research. The region is found between 4ºN and 14ºN latitudes and 2ºE and 15ºE longitudes (Figure 1)

The country's southern region is defined by a coastline that runs from the southwest to the southeast and includes Africa's largest delta, the Niger delta. It has a tropical rainforest environment with annual precipitation ranging from 60 to 80 inches (1524mm to 2032mm), with saline water in the south section of the rainforest zone, which is known as the mangrove swamp forest due to the proximity of a large amount of mangrove within the zone. A freshwater wetland and the rain forest are located to the north. This region is characterized by uneven, steep terrain that stretches from the west to the Benue Mountains in the east.

The Savannah Zone, located north of Nigeria's tropical timberland region, represents the start of Northern Nigeria, with approximate annual precipitation ranging from 500mm to 1600mm. The Guinea Savannah, with long grasses, trees, and a humid environment, is followed by the Sudan Savannah, with shorter grasses and more scattered, drought-resistant trees like the baobab, tamarind, and acacia. The third, known as the Sahel savannah, is found in the country's far north and has a desert environment with annual precipitation of less than 500mm. The northern part of Nigeria's geography is lowland, with a relatively level terrain that stretches from Lake Chad to the Sokoto lowlands.

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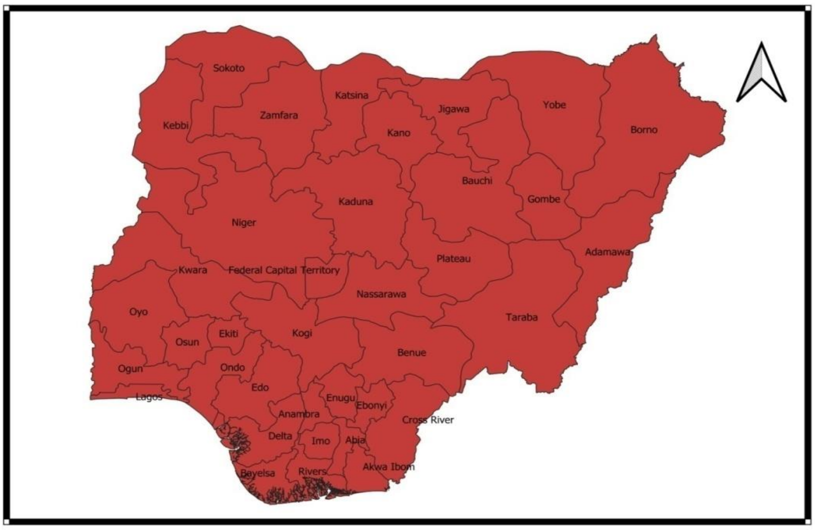

Figure 1: Map of Study Area

2.2 Materials:

The records of the crops', i.e. **Cassava, Rice, and Soybean** yield covering 20 years, were sourced across the 36 states of Nigeria and the FCT through the Agricultural Development Project (ADP). The three crops were selected based on their level of consumption, production, cultivation, commercial value, and data availability in Nigeria.

Climatic data for this research was in two datasets. One dataset was used to observe the present-day climate and the locations where crops are grown across Nigeria. The second was climate modeled data (statistically downscaled at the weather station level), usually called GCM (Global Climate Models). The observation dataset was the 0.5° × 0.5° resolution monthly precipitation, minimum and maximum temperature gridded dataset from January through December for 1985 to 2100 collected from the Climate Research Unit, University of East Anglia [26]. The GCMs from the IPCC's RCP 8.5 scenario was used as a basis for the calculations and analyses for this research. (RCPs are a set of scenarios developed by the IPCC working groups based on emission and radiative levels by 2100. The data were bias-corrected to make model estimates/simulations closer to the observed values [27, 28]. There are 4 RCPs, the minor emission/radiative

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level is RCP2.6, and the highest emission/radiative level is RCP8.5). The GCMs are detailed below;

Table 1: List of GCMs applied in the study

Modeling group	IPCC Model ID	Resolution
Japan Agency for Marine-Earth Science and Technology	MAROC	1.4^0 x 1.4^0
Norwegian Climate Centre	NCC	2.5^0 x 1.9^0
National Oceanic and Atmospheric Administration (USA)	NOAA	2.5^0 x 2.0^0
Irish Centre for High-End Computing (Europe)	ICHEC	1.25^0 x 1.25^0

The data for this research covered three time-periods: i) past/present (2000), (average values between 1985 - 2015), ii) intermediate (2050) (average values between 2020-2050) and, future (2100) (average values between 2070-2100).

2.3 Methods:

Among empirical models, multiple linear regression (MLR) models are tools used in carrying out analyses regarding climate and soil conditions to determine their effects on crop yield. [29, 30]. This method was applied in this study in developing models to estimate Cassava, Rice, and Soybean yield in Nigeria.

2.3.1 **Regression Analysis** – Multiple Linear Regression **(Development of Crop Yield models).**

The development of crop yield models was done using this medium. With the exception that numerous independent variables are utilised in the model, multiple linear regression analysis is quite similar to simple linear regression analysis. Multiple linear regression is mathematically represented as:

$$Y = a + bX_1 + cX_2 + dX_3 \quad (1)$$

Where:

Y – Yield; X_1, X_2, X_3 – Climatic variables; *a* – Model Constant; *b, c, d* – Model Coefficients

2.3.2 Temporal/Trend Analysis

The Mann – Kendall test is a non-parametric one, usually deployed to detect and quantify trends in datasets. This technique was deployed to estimate the significant trend in the observed yield of the crops through the periods which the research work covered. The trend analysis was carried out on a monthly and annual basis. The value of the trend was obtained by using Sen's non-parametric test, an integral part of the Mann-Kendall software. The procedures are as outlined by [2], [3] and [31].

3. RESULTS AND DISCUSSIONS

3.1 Developed Crop models

Numerous models were developed, and the models with the best Coefficient of determination and incorporating the highest numbers model variables were selected for each crop and State to give reasonable estimations. Selected models were used to estimate the yields of the three earlier mentioned crops across Nigeria, with their coefficient of determination (R^2) ranging between 15% and 99%.

3.2 Crop Yield Changes under ICHEC Climate Scenario

Applying climatic data downscaled from the Irish Centre for High-End Computing (ICHEC) in estimating the yield of Cassava, Rice and Soybean across Nigeria, between the periods as described in the methods, the output from the analysis showed that the yield of Cassava is significantly on the increase in most of the states of the except Abia, Adamawa, Bauchi, Bayelsa, Benue, Borno, Delta, Ebonyi, Edo, Rivers Sokoto, Taraba and Zamfara states which presented a significant decrease in their case. This scenario presented itself in [32], where the study reported that future climate changes positively benefitted parts of the United state. This positive benefit was mainly in The Pacific North-West and Northern Great Plains. On the other hand, the southeast coastal regions were severely affected by expected climate changes. Also, [33] and [34] projected an increase in Cassava and Oil Palm yield in Nigeria from 2020 beyond due to the effect of climate change on temperature and precipitation.

The yield of Rice was also projected to significantly reduce in nine (9) states, namely Adamawa, Bayelsa, Borno, Kaduna, Kebbi, Lagos, Ondo, Oyo, and Yobe, with three

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(3) others experiencing a non-significant reduction in yield. However, twenty-one other states were projected to experience an increase in rice yield. [33] reported that the yield of cereals might reduce due to climate change impacting temperature and precipitation, which is in line with results obtained in this study regarding Rice.

In the projection for Soybean yield, there were also instances of significant increase and decrease. A study by [35] projected that rising temperatures would lower global wheat yields by 6.0%, rice yields by 3.2%, maize yields by 7.4%, and soybean yields by 3.1%, with outcomes highly variable across crops and geographical locations, with some positive impact estimates.

The increase in Cassava yield ranged between 1.71% and 11.35%, while the decrease was between 3.11% and 11.82%. For Rice, the growth is between 0.12 and 11.74, reducing between 0.64% and 9.77%. In the case of Soybean, the yield increase is between 0.59% and 12.35%, while the decrease ranged from 0.87% and 11.58%. These projected changes in yield are most significant ($P<0.001$), as shown in Table 2.

3.3 Crop Yield Changes under NOAA Climate Scenario

In using the climate data from National Oceanic and Atmospheric Administration (NOAA), the yield of Cassava showed a significant decrease in Abia, Adamawa, Bauchi, Bayelsa, Benue, Borno, Delta, Ebonyi, Edo, Kaduna, Kogi, Nassarawa, Rivers Sokoto, Taraba, and Zamfara states, agreeing with [23], where climate change harmed the yield of tuber crops, while the other Nineteen states and the FCT showed a marked and significant increase in yield. [36] Showed that the impact of changing climate patterns on crops using wheat and maize as case studies with respect to two (2) Representative Concentration Pathways (RCP4.5 and RCP8.5) projected both an increase and decrease in yield. These projected changes in yield are significant ($P<0.001$) except in Kaduna, Kogi, and Plateau State. The growth is from 0.69% to 11.33%, while the decrease ranges between 0.17% and 11.69%.

Rice projections exhibited a significant decrease in Adamawa, Bayelsa, Borno, Ekiti, Kaduna, Kebbi, Ondo, Yobe, and Zamfara with FCT (3) others Gombe and Oyo, experiencing a non-significant reduction in yield. In contrast, the other states predicted an increase in output. The observed increase ranged from 0.5% to 11.39%, whereas the decrease was between 0.47% and 10.39%.

Ekiti, FCT, Gombe, Kogi, Lagos, Niger, Oyo, and Sokoto returned a projected decrease between 1.18% and 10.71% for Soybean. In comparison, the other twelve (12) states with Soybean production predicted significant increases ranging from 0.94% to 11.86%. These expected changes are significant ($P<0.001$), as shown in Table 3.

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3.4 Crop Yield Changes under MIROC Climate Scenario

The yield projection using climatic data from the Japan Agency for Marine-Earth Science and Technology (MIROC) mirrors results from NOAA yield analysis. Cassava yield is predicted to increase as the years go by in twenty (20) states, with the increase projected to be between 0.86% and 10.98%. In contrast, there will be a reduction in Abia, Adamawa, Bauchi, Bayelsa, Benue, Borno, Delta, Ebonyi, Edo, Kaduna, Kogi, Nassarawa, Rivers, Sokoto, Taraba and Zamfara states between 0.41% and 11.33%.

There are observed changes in the yield of Rice as follows, projected 9.28% decrease in Adamawa ($P<0.001$), 1.10% decrease in Anambra (not significant), 6.98% decrease in Bayelsa ($P<0.001$), 3.04% decrease in Borno ($P<0.01$), 2.22% decline in Ekiti ($P<0.05$), 1.41 decline in Gombe (not significant), 8.80% decrease in Kaduna ($P<0.001$), 8.72% decline in Kebbi ($P<0.001$), Lagos decreased by 4.03% ($P<0.001$), Ondo went lower by 4.23% ($P<0.001$) and Yobe decreased by 0.95% (not significant). The remaining states predicted an increase in Rice yield, which is significant ($P<0.001$), with the boost ranging from 0.55% to 10.94%.

A projected increase in Bauchi, Benue, Ekiti, Kaduna, Kano, Katsina, Kwara, Ondo and Taraba State for Soybean yield is observed. In contrast, a decrease is projected in Adamawa, FCT, Gombe, Kogi, Lagos, Nasarawa, Niger, Oyo, Plateau, and Sokoto State. The changes are significant ($P<0.001$) and range from 3.89% to 11.09% and 2.82% and 10.85% for the projected increase and decrease in yields. These details are contained in Table 4.

3.5 Crop Yield Changes under NCC Climate Scenario

In the application of climatic data from the Norwegian Climate Centre (NCC) to model climate change's impact on yields of Cassava, Rice, and Soybean in Nigeria, the following were observed; for Cassava, twenty (20) States projected an increase in their yield (Table 6). This increase is between 1.06% and 11.01%, significant ($P<0.001$). The other sixteen (16) states projected a decline in cassava yield with the observed decrease predicted to range from 1.17% to 11.52%, also significant ($P<0.001$).

In the case of Rice yield, Twenty-one (21) States produced an increase in their yield, while twelve (12) had decreased. 0.32% to 11.39% for the increased yield while 0.10% to 9.70% for the decline. Most of these predicted increase or decrease in yield is significant ($P<0.001$).

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Soybean yield also projected a similar result to those presented above under the NCC climate scenario. Eight (8) States had an increase in yield projected, with these increases going between 4.80% to 12.23%. All of the projected increases were significant (P<0.001). The decrease projected is observed in ten (10) states, with them being significant (P<0.001) except for Ekiti and Akwa Ibom State that are not. The decrease ranged from 0.57% to 10.78% across these 10 states.

3.6 Observation on Crop Yield Changes

The ensemble means of the climatic parameters obtained from the four (4) Global Climate models (GCMs) were used to estimate the yield of Cassava, Rice, and Soybean across Nigeria, and the result showed that there would be an increase in crop yield in some states. In contrast, some states will experience a decrease.

This scenario presented itself in [32] study. The study reported that future climate projections will positively benefit the united state and negatively affect other regions. Also, [33] and [34] projected an increase in Cassava and Oil Palm yield in Nigeria from 2020 beyond due to the effect of climate change on temperature and precipitation.

Overall, the national average yield of Cassava is projected to increase to 11.23 $tonnesha^{-1}$ in 2050 and 12.60 $tonnesha^{-1}$ in 2100; rice yield has a projected increase to 2.80 $tonnesha^{-1}$ in 2050 and 3.45 $tonnesha^{-1}$ in 2100, and the yield of cowpea to 0.92 $tonnesha^{-1}$ and 1.18 $tonnesha^{-1}$ in 2050 and 2100 respectively. This portrays that the national average yield of Cassava will increase by 0.07 $tonnesha^{-1}$ in 2050 and by 1.43 $tonnesha^{-1}$ in 2100; rice yield to grow by 0.42 $tonnesha^{-1}$ in 2050 and 1.08 $tonnesha^{-1}$ in 2100 while the national average yield of cowpea to improve by 0.15 $tonnesha^{-1}$ in 2050 and 0.41 $tonnesha^{-1}$ in 2100. The state by state change in crop yield is shown in figure 2.

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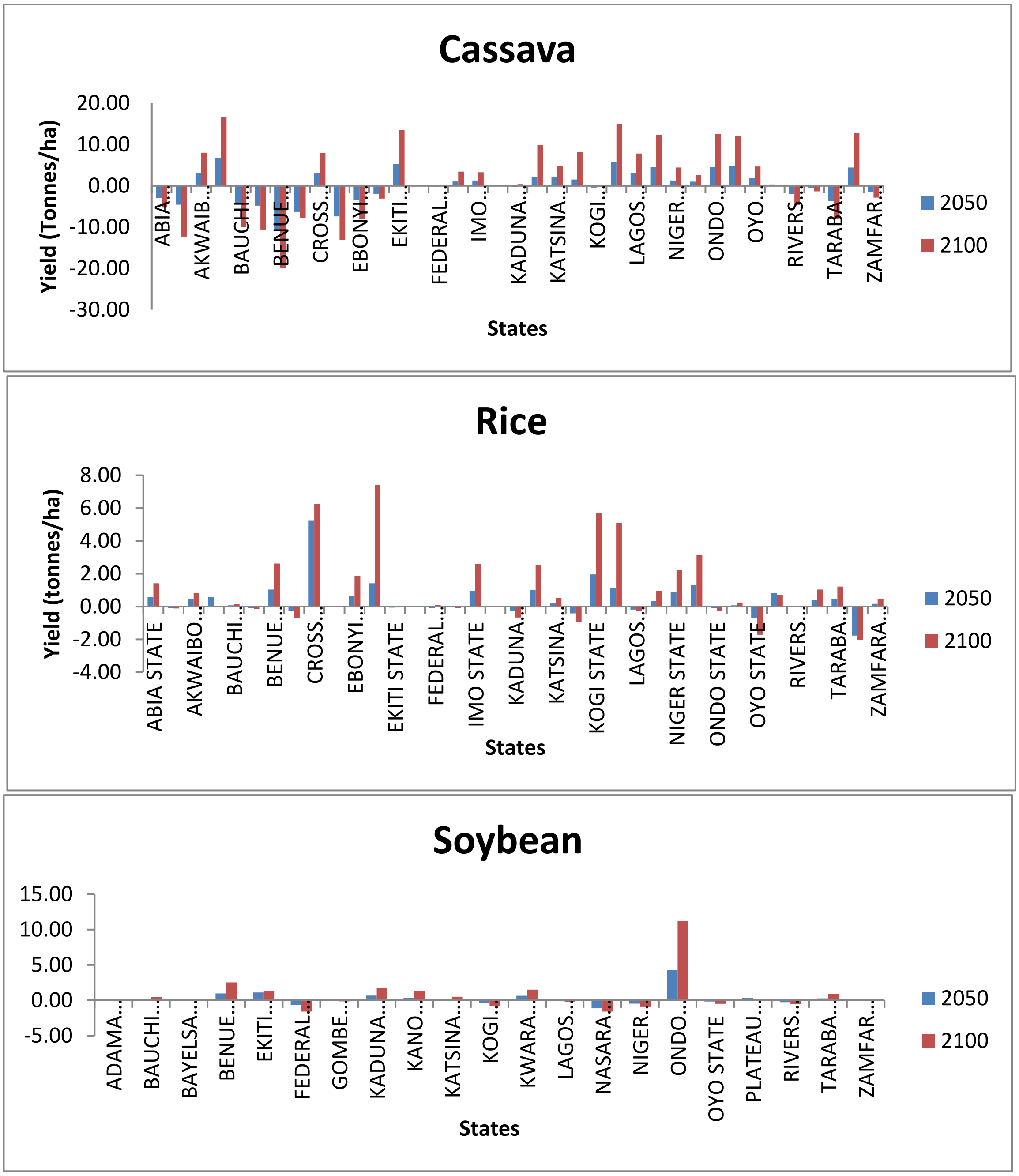

Figure 2: Change in yield of Cassava, Rice and Soybean by the years 2050 and 2100

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From the four (4) scenarios produced using the different climate models, it was observed that in some regions of the country, Nigeria, an increase in crop yield would be experienced as the years go by, while in the other areas, a decrease will be experienced. Studies from different parts of the globe also painted a similar pattern to what was reported above, with [23] postulating a negative impact on crop production due to climate change while [36] reported both an increase and decrease in crop yield as noted in this particular work.

Similarly, [37], including [1], reported that in Europe, climate change would most likely bring about an increase in crop production in future due to a predicted increase in atmospheric carbon dioxide (CO_2) while on the other hand, agricultural production especially crop production and crop suitability to cultivation are going to experience a decrease where precipitation decreases significantly.

Therefore, we can agree that the issue with climate change is a two-pronged reality activity that comes with both positive and negative effects depending on how extreme it is and what aspect of the climate is more affected.

Table 2: Trend details of crop yield between 1985 – 2100 for ICHEC

STATES	**Cassava**		**Rice**		**Soybean**	
	% change	**Significance**	**% change**	**Significance**	**% change**	**Significance**
Abia	-4.87	***	9.13	***		
Adamawa	-5.86	***	-9.28	***	-4.94	***
Akwa Ibom	9.89	***	8.41	***		
Anambra	10.69	***	-0.64			
Bauchi	-10.02	***	0.12		5.19	***
Bayelsa	-8.94	***	-5.59	***		
Benue	-8.66	***	10.94	***	11.56	***
Borno	-11.82	***	-4.80	***		
Cross River	10.33	***	9.50	***		
Delta	-11.56	***				
Ebonyi	-8.04	***	9.78	***		
Edo	-3.11	**	9.42	***		
Ekiti	11.13	***	-1.18		-0.87	
Enugu	3.56	***				
FCT	3.61	***	1.90	+	-11.58	***

Gombe	8.61	***	-1.36		-5.98	***
Imo	10.66	***	10.60	***		
Kaduna	1.71	+	-9.77	***	12.35	***
Kano	9.07	***	11.74	***	9.56	***
Katsina	5.13	***	9.95	***	7.91	***
Kebbi	8.92	***	-9.59	***		
Kogi	3.18	**	7.41	***	-11.35	***
Kwara	10.24	***	11.20	***	9.03	***
Lagos	9.26	***	-5.31	***	-3.26	**
Nasarawa	10.76	***	10.54	***	-10.32	***
Niger	6.00	***	7.34	***	-9.40	***
Ogun	11.14	***	8.59	***		
Ondo	10.82	***	-5.84	***	10.96	***
Osun	11.35	***	4.98	***		
Oyo	10.49	***	-3.28	**	-6.72	***
Plateau	2.81	**	3.13	**	0.59	
Rivers	-8.95	***				
Sokoto	-5.54	***	8.95	***	-10.16	***
Taraba	-8.43	***	9.06	***	9.47	***
Yobe	8.95	***	-1.74	+		
Zamfara	-8.13	***	8.95	***		

Level of significance: * 0.001, **0.01, *0.05, +0.1**

Table 3: Trend details of crop yield between 1985 – 2100 for NOAA

STATES	Cassava		Rice		Soybean	
	% change	**Significance**	**% change**	**Significance**	**% change**	**Significance**
Abia	-3.13	**	7.66	***		
Adamawa	-8.29	***	-10.19	***	0.94	
Akwa Ibom	7.14	***	6.00	***		
Anambra	9.32	***				
Bauchi	-8.92	***	2.75	**	7.92	***
Bayelsa	-9.23	***	-2.86	**		

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Benue	-8.17	***	10.37	***	10.31	***
Borno	-11.69	***	-10.39	***		
Cross River	9.09	***	7.88	***		
Delta	-11.06	***				
Ebonyi	-4.17	***	9.64	***		
Edo	-2.88	**	6.95	***		
Ekiti	9.75	***	-1.71	+	-1.36	
Enugu	2.86	**				
FCT	4.15	***	-0.47		-10.68	***
Gombe	8.50	***	-0.62		-5.09	***
Imo	9.23	***	10.54	***		
Kaduna	-0.17		-7.87	***	11.86	***
Kano	8.57	***	11.39	***	8.80	***
Katsina	3.70	***	9.27	***	4.80	***
Kebbi	8.09	***	-8.99	***		
Kogi	-1.22		7.37	***	-10.36	***
Kwara	8.61	***	10.16	***	8.41	***
Lagos	7.88	***	0.50		-1.18	
Nasarawa	-10.96	***				
Niger	6.59	***	7.17	***	-8.64	***
Ogun	11.33	***	6.84	***		
Ondo	9.83	***	-4.54	***	10.93	***
Osun	9.95	***	4.43	***		
Oyo	8.35	***	-0.55		-4.21	***
Plateau	0.69		4.19	***	1.85	+
Rivers	-8.75	***				
Sokoto	-4.69	***	10.25	***	-10.71	***
Taraba	-7.74	***	8.31	***	8.45	***
Yobe	11.31	***	-2.89	**		
Zamfara	-6.46	***	-5.97	***		

Level of significance: * 0.001, **0.01, *0.05, +0.1**

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Table 4: Trend details of crop yield between 1985 – 2100 for MIROC

STATES	Cassava		Rice		Soybean	
	% change	**Significance**	**% change**	**Significance**	**% change**	**Significance**
Abia	-4.87	***	9.13	***		
Adamawa	-5.86	***	-9.28	***	-4.94	***
Akwa Ibom	9.58	***	4.14	***		
Anambra	8.87	***	-1.10			
Bauchi	-10.21	***	2.34	*	4.57	***
Bayelsa	-8.74	***	-6.98	***		
Benue	-8.11	***	10.38	***	9.86	***
Borno	-11.33	***	-3.04	**		
Cross River	9.22	***	8.07	***		
Delta	-10.89	***				
Ebonyi	-7.21	***	8.21	***		
Edo	-3.13	**	9.95	***		
Ekiti	9.66	***	-2.22	*	3.89	***
Enugu	3.85	***				
FCT	-1.23		0.81		-10.61	***
Gombe	7.24	***	-1.41		-5.65	***
Imo	9.14	***	10.25	***		
Kaduna	0.86		-8.80	***	11.09	***
Kano	8.71	***	10.79	***	9.34	***
Katsina	4.74	***	9.41	***	6.12	***
Kebbi	7.73	***	-8.72	***		
Kogi	-0.41		6.22	***	-10.85	***
Kwara	6.66	***	8.99	***	7.37	***
Lagos	10.26	***	-4.03	***	-2.93	**
Nasarawa	8.52	***	10.12	***	-9.05	***
Niger	3.53	***	4.96	***	-7.37	***
Ogun	10.98	***	8.49	***		
Ondo	7.21	***	-4.23	***	10.58	***
Osun	9.93	***	1.53			
Oyo	8.39	***	0.55		-6.66	***

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Plateau	-0.99		4.72	***	-2.82	**
Rivers	-8.52	***				
Sokoto	-6.69	***	10.07	***	-8.95	***
Taraba	-6.53	***	9.70	***	10.15	***
Yobe	10.72	***	-0.95			
Zamfara	-5.45	***	10.94	***		

Level of significance: * 0.001, **0.01, *0.05, +0.1**

Table 5: Trend details of crop yield between 1985 – 2100 for NCC

STATES	Cassava		Rice		Soybean	
	% change	**Significance**	**% change**	**Significance**	**% change**	**Significance**
Abia	-3.34	***	8.06	***		
Adamawa	-7.37	***	-9.70	***	-1.26	
Akwa Ibom	7.21	***	3.16	**		
Anambra	9.36	***				
Bauchi	-9.63	***	3.00	**	6.49	***
Bayelsa	-7.42	***	-6.77	***		
Benue	-6.05	***	11.39	***	10.77	***
Borno	-11.52	***	-7.68	***		
Cross River	10.28	***	8.07	***		
Delta	-10.98	***				
Ebonyi	-7.30	***	9.09	***		
Edo	-2.59	**	5.02	***		
Ekiti	9.13	***	-2.68	**	-0.57	
Enugu	1.67	+				
FCT	-1.40		1.12		-10.78	***
Gombe	8.83	***	-0.10		-3.32	***
Imo	9.90	***	9.09	***		
Kaduna	1.06		-8.34	***	12.23	***
Kano	9.20	***	10.98	***	7.69	***
Katsina	2.41	*	9.57	***	4.80	***
Kebbi	8.47	***	-8.88	***		

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Kogi	-1.17		6.48	***	-9.80	***
Kwara	6.11	***	8.83	***	8.27	***
Lagos	8.45	***	-1.52		-5.14	***
Nasarawa	7.96	***	8.18	***		
Niger	2.40	*	4.09	***	-8.33	***
Ogun	10.09	***	7.46	***		
Ondo	8.29	***	0.32		10.36	***
Osun	9.38	***	6.59	***		
Oyo	10.07	***	-2.09	*	-6.38	***
Plateau	-2.25	*	4.71	***	-1.67	+
Rivers	-6.85	***				
Sokoto	-3.04	**	9.72	***	-10.24	***
Taraba	-7.34	***	8.36	***	8.70	***
Yobe	11.01	***	-1.93	+		
Zamfara	-6.40	***	-5.04	***		

Level of significance: * 0.001, **0.01, *0.05, +0.1**

3.7 National Mean Crop Yield

Climate change's impact on Cassava, Rice, and soybean yields was further modeled on a National basis against the state-by-state basis presented in Tables 2 – 5. The result is shown in Table 6.

Table 6: National Mean Crop Yield Trend between 1985 - 2100

	Cassava		**Rice**		**Soybean**	
Model	**% change**	**Significance**	**% change**	**Significance**	**% change**	**Significance**
ICHEC	3.91	***	8.88	***	2.81	**
MAROC	0.08		7.77	***	5.84	***
NOAA	1.70	+	6.62	***	11.38	***
NCC	-0.93		8.85	***	9.06	***

Level of significance: * 0.001, **0.01, *0.05, +0.1**

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Results presented showed an increase of 3.91% (P<0.001), 0.08, 1.79 (P<0.1) and a decrease of 0.93% for cassava yield from 1985 – 2100 using climatic data from ICHEC, MIROC, NOAA, and NCC, respectively. It also projected an increase in yield of 8.88% (P<0.001), 7.77% (P<0.001), 6.62% (P<0.001), and 8.85% (P<0.001) for Rice yield under the period from 1985 – 2100 using climatic data from ICHEC, MIROC, NOAA, and NCC respectively.

In the case of Soybean, an increase in yield is predicted using the four (4) climatic scenarios. The rate of increase are 2.81% (P<0.01), 5.84% (P<0.001), 11.38 (P<0.001) and 9.06% (P<0.001) for ICHEC, MIROC, NOAA and NCC respectively.

These projected changes are still well below acceptable global standards to achieve food security. The above finding agrees with [38], where it was reported that due to the predicted increase in food demand worldwide by 2050, there must be incremental yield, needing more to be done to meet the targeted approximate 20% increase in the yield of crops to tackle food sufficiency. Research [34] also concluded that the net impact of climate change on oil palm yield in the Niger Delta region of Nigeria is positive, in line with the positive effects of climate change on the yield of crops considered for this study. The impact of temperature and solar radiation on the decrease in rice yield has been widely reported as the decades go by [39]. This study appears to negate the finding, although the study was carried out at a regional scale while this study was on a national scale.

4. Conclusion

The impact of climate change on crop yield in Nigeria has been modelled using Cassava, Rice, and Soybean over three time periods, applying climatic data from four (4) GCMs in the process. It was shown how climate change positively impacted the predicted yields of these crops in the future; in some regions or states in the country, the crops will experience an uptick in yield as opposed to the downward trend observed in some regions of Nigeria. In all, the research showed that as the years go by, the yield of Cassava, Rice, and Soybean in Nigeria is projected to increase; this outlook portrays a swing in the right direction as regards the attainment of food sufficiency and security in the country. However, this positive result did not consider how other factors necessary for crop production, such as management practices, planting area, crop species, and cost of security, will impact yield. Further work can also be done to determine how water use will affect the production of these crops in the future over this same study area.

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This study also demonstrated how the use of empirical models to estimate and model the future yield of crops can be relied upon based on the similarities the results from this study, largely, has with results from other studies that modeled the impact of climate change on crops using different approaches. These studies applied approaches different from the one used for this study to model the impact of climate change on crop yield across the world. Therefore, the knowledge provided here can assist policymakers and researchers to adequately enact policies and birth plans that can be implemented to improve crop production.

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Assessing Theoretical Frameworks, Human Resources Management Implications and Emerging Technologies on the Water, Energy and Food (WEF) Nexus

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Abstract: Water, energy, and food (WEF) resources are three vital resources needed for human wellbeing; however, there exists an interaction among the resources. The interactions of water, energy, and food resources resulting in the WEF nexus thinking have been conceptualized as an integrated framework to achieve the security of the three vital resources. However, there are some gaps in WEF nexus research, which constrains the understanding and actualization of the nexus. Hence, this review paper aims to assess theories, human resource management implications, and emerging technologies' effect in understanding the nexus for its actualization. The research employed a qualitative research methodology to achieve the research objectives. The research findings revealed six (6) significant theories that can aid the understanding and actualization of the WEF nexus. The research also revealed that human resource management is strategic, highlighting the need for nexus thinking among human resources. Furthermore, the study revealed the three major emerging technologies of Artificial Intelligence, Big data analytics, and Internet of Things (IoT), which are shaping the WEF nexus through innovations and shaping the nature of the nexus. The study concluded that there is an interaction between the theories and human resources management for attaining the WEF nexus, which affects the extent of the sustainability of the innovations introduced by the emerging technologies. The study recommended quantification of the theories, training on nexus thinking of the current human resource in the WEF sectors, and capital investment on emerging technologies in the WEF nexus.

Keywords: Water, Energy, Food, Theories, Human Resources, Emerging Technologies.

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1. Introduction

Water, energy, and food resources are indispensable in sustaining humanity, poverty reduction, and ensuring that development is sustainable. However, Botai, et al., [12], Leck, et al., [63] and Hoff [53] researches show that there exist interactions, interlinkages, and interconnectedness among the three resources, leading to the idea of a WEF nexus. According to the authors, this is evident in the fact that the actions of one sector of the WEF resources, directly and indirectly, affect the other sectors' activities. According to Ghodsvali, et al., [45], these inevitable effects among the three sectors are somewhat competitive and can result in conflict. This is because of the usefulness of one resource in producing another resource, as opined by Endo, et al., [36]. The World Economic Forum [142] averred that the WEF nexus is about securing the individual resources and managing their tradeoffs, in terms of accessibility, affordability, availability, stability, and productivity, given their sectoral security. According to UNESCO [131] and UN – WATER [129], water security is "*the capacity of a population to safeguard sustainable access to adequate quantities and acceptable quality of water for sustaining livelihoods, human well-being and socio-economic development for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability".* The International Energy Agency, IEA [55] opined that energy security is "*an uninterrupted availability of energy sources at an affordable price while respecting environmental concerns."* In addition, the United Nation [128] defined energy security as "*access to clean, reliable and affordable energy services for cooking, heating, lighting, communication and productive uses".* The Food and Agriculture Organization, FAO, [40] defined Food security as "*the availability and access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life".*

Moreover, the growing demand and consumption for WEF resources lead to scarcity in natural resources and global warming, climate change, extreme weather conditions, droughts, and floods, which indirectly damage water infrastructure, electrical systems, and food crops. The nexus management of natural resources such as water, energy, and food (WEF) has been proposed to meet these issues confronting humankind. The WEF nexus is a global response for concurrently assessing how the various approaches of achieving the security of water, energy, and food, can be operationalized.

However, several researchers have worked on the concept of WEF nexus, developing several conceptual frameworks but lacking theoretical frameworks. To the best of the

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researchers ' knowledge, there is a shortage of research on comprehensive theories underpinning the nexus of the three resources. This is a significant gap in the integrated framework, considering the importance of theories in research, which this paper fills. According to Pigott [97], theories aid in understanding the underlying relationships and principles guiding a concept. The author further opined that theories aid the planning of data analysis, as theories aids researchers accountable to data. Anfara & Mertz [4] earlier posited the same perspective, that theory clarifies relationships between abstractions to understand a phenomenon. To Lederman and Lederman [64], a combination of theories or one theory constitutes a theoretical framework. According to Bradbury – Jones, Taylor, and Herber [14], they are mostly used in qualitative papers, such as the concept of WEF nexus. According to Collins and Stockton [25], a theoretical framework uses theories in research that provide an articulated lens or signpost on how the study in view will process new knowledge. According to the authors, a theoretical framework entails the connection of prevailing knowledge about a phenomenon, a researcher's epistemological dispositions, and the approach for research.

To Grant and Osanloo [47], a theoretical framework is a blueprint for a research inquiry, providing structures and vision for the research. Meleis [83], as cited by Bradbury – Jones, et al., [14], a theory is "*an organized, coherent, and systematic articulation of a set of statements related to significant questions in a discipline that are communicated in a meaningful whole." It is a symbolic portrayal of aspects of reality that are discovered or invented for describing, explaining, predicting, or prescribing responses, events, situations, conditions, or relationships. Theories have perceptions that are related to the discipline's phenomena. These perceptions are associated with each other to form theoretical statements*." The WEF nexus concept, since its popularization by Hoff [53], have been viewed from different perspectives but lacks a theoretical framework which is a qualitative research problem in the concept, which is most common to qualitative research as lack of identification of significant theories and articulation of the theories of a major hurdle in qualitative research [85, 27]. In the view of Leeming [65], theories aid the understanding of research findings, thereby boosting knowledge development. This was corroborated by the findings of Mueller and Urbach [88] that theories are a reasoning process that enables researchers to draw conclusions from research and make appropriate predictions. Hence, this paper makes available a theoretical framework for research entailing the water, energy, and food nexus, by proposing several theories for proper understanding of the phenomenon and institutions for the integrated concept. The theories will also give researchers, policy

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makers, and economic experts on how to manage the three resources and the nexus of the resources.

Moreover, as the theories of the WEF nexus guide its implementation and understanding of its depth, it highlights a human resources management lacuna in the integrated concept. There is also no research on the implications and effects of human resource management on the nexus of the three resources. Human resource administration generally entails procuring, utilizing, and rewarding human resources. This is especially needed considering that the WEF nexus requires integrated thinking that needs human resources in the WEF sectors with a nexus thinking approach than the current prevailing silo thinking prevailing in the three sectors [72]. According to Armstrong [5], human resource management is a premeditated, coherent, and integrated methodology to the employment, wellbeing, and development of work force working in an organization. It is a process by which management builds an organizational workforce by creating the human performances that the organization needs [13]. To Storey [124] cited in Osinbanjo & Adeniyi [94], human resources management is "*a distinctive approach to employment management which seeks to achieve competitive advantage through the strategic deployment of a highly committed and capable workforce, using an integrated array of cultural, structural and personnel techniques."* In the research of O'riordan [92] and Armstrong & Taylor [6], human resources management goals include the following;

- **a.** Supporting organization objectives via developing and implementing human resources strategies integrated with business strategy.
- **b.** Contributing to developing high – performance culture.
- **c.** Ensuring that talented and skillful people are in the organization.
- **d.** Creating an environment of mutual trust between management and employees
- **e.** Encouraging the application of a principled approach to public's administration.

Therefore, it is of utmost importance to comprehend human resources management's implication in the WEF nexus, considering labor laws, sectoral employment procedures, skill development & training, compensation arrangement, interdepartmental collaboration, and inter-sectoral coopetition.

Furthermore, while the theories and human resource management aid in a better understanding of the WEF nexus, emerging technologies will shape the actualization of the WEF nexus. Emerging Technologies such as Big data analytics, the Internet of Things (IoT), and Artificial Intelligence, among others, are shaping the intersection of the three resources and providing a structural framework for managing the tradeoffs and synergies of the resources, considering different geographical scales. According to Halaweh [50] research, emerging technologies are science-oriented innovations that have the likelihood to transform a current industry or build a new industry, which is often a product of research. Daniel, et al. [29] stated that emerging technologies are not common but commercially available but could be common in the next five years.

Hence, emerging technologies are technologies that are just arising out of research procedures or being tested for commercialization in different research fields. This is highly necessary for the water, energy, and food space considering the interaction, synergies, and tradeoffs of the resources will require different technology arrays, which according to Coles and Hall [24], is a significant challenge nexus thinking. Hence, it is imperative to empirically analyze and identify the emerging technologies in the water, energy, and water nexus to actualize the nexus, which this paper tends to achieve.

Succinctly, in contributing to ensuring the proper management, governance, regulation, and interaction for the actualization of the nexus, this research seeks to empirically make available a theoretical framework for WEF Nexus, identify human resources management implications and examine the emerging technologies that will knit the theories and human resources together for the nexus. This will bridge the existing gap in the literature regarding the attainment of the WEF nexus integrated framework to achieve water, energy security, and food security.

2.0 Methodology

This research is a review paper based on qualitative research methodology. This methodology entails analyzing empirical literature to contextualize opinions and juxtapose concepts, aiding a researcher to have in-depth insights into a phenomenon [2]. According to Snyder [120], reviewing literature as a form of methodology aids research finding synthetization in uncovering research areas that need more details in understanding. Therefore, this paper did a structural, logical, and strategic review of relevant literature in top-ranked journals, editorials, book chapters, and publications.

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3.0 Discussions

3.1 Theoretical Framework of Water, Energy, and Food (WEF) Nexus

The water, energy, and food (WEF) nexus is a multifaceted concept that gives the individuality and complexity of the three energy, agriculture, and water sectors, which are all indispensable in human endeavors. However, the efficiency and Modi operandi of the nexus is established on some theories. This paper proposes the following theories as theories to be understood in ensuring the nexus of the three resources; Secularization theory, Game theory, Malthusian theory of population, and Institutional theory deals with the process of WEF nexus, while Technology Acceptance model theory and the Innovation Diffusion theory deals with the output of WEF nexus. Hence, the theoretical framework for WEF nexus as established from relevant literature, are explained succinctly.

a. Secularization theory

The security of the three resources was brought forward as a security issue at the Bonn2011 Conference [53], echoing the security views of the 2030 water resources group and US national intelligence council. As a matter of expediency, the US's National Intelligence Council [90] predicted that poor nexus management would lead to social, dire geopolitical, and economic repercussions. In showing the expediency and the securitization of the WEF security nexus at the Bonn 2011 conference, there were contributions from the German Government, the International food policy research institute (IFPI), World Economic Forum, world wide fund for nature (WWF), Stockholm International Water Institute (SIWI), Stockholm Environment Institute (SEI), Food and Agriculture Organization (FAO), the World Business Council for sustainable development (WBCSDI), and the Energy and Resources Institute (TERI), which were all consolidated at the United Nation Conference on Sustainable Development (UNCSD) on the 21 of June 2012.

The securitization of the WEF nexus is grounded on the historical facts that the world has crossed at least three of the nine planetary boundaries of climate change, aerosol loading, species extinction, ocean acidification, ozone depletion, changes in land cover, freshwater usage, usage of chemical, and nitrogen – phosphorus cycles disruption [38; 102]. In addition, the WEF nexus is seen as a security phenomenon because of the projected increase in resource utilization compared to resource availability. According to Hoff [53] and the World Economic Forum Water Initiative [141], about one billion persons worldwide do not have accessibility to drinking water that is clean and not polluted, more than one billion people are suffering from hunger, and about 1.3 billion do not have access to electricity. This is as the world's population is anticipated to grow geometrically, and by 2030, the world population will need 40% more energy, 30% additional water, and 50% supplementary food [90].

According to Leese and Meisch [66], the WEF nexus is a security issue, influenced by the securitization theory of Weaver [135] of the Copenhagen School of security studies. This was also confirmed by the study of Staupe – Delgado [121], which also opined that the security of the three resources is based on the securitization process of the securitization theory. This concept of securitization theory has been applied beyond the traditional military field into different areas of human endeavor like nuclear proliferation [15]; HIV/ AIDS [80]; Environmental degradation [41]; Drug Trafficking [117]; and Government stability [138].

The securitization theory was initiated by the Copenhagen School of security studies, originally named Copenhagen Peace Research Institute (COPRI), through the research of Weaver [136], Weaver [135], and Buzan, et al., [17] in their book titled, "Security: A new framework for analysis", and the re-conceptualized research of Balzacq [8]. The securitization theory is how issues are seen and constructed as an "existential threat" [17; 71]. Mclnnes and Rushton [80] stated that the securitization theory is not limited to military threat alone, but issues that affect the core existence of human beings and their survival can be tagged as security issues.

According to Charrett [19], the securitization theory by the Copenhagen school is premised on three principles, which are;

i. The observation of existential threats in five distrusted yet interconnected sectors includes; military sector, environment sector, economic sector, social and political sector. The water, energy, and food nexus threats cut across four of the five sectors.
ii. Security studies should also focus on the interlinking security dynamics or regions.
iii. There must be a social constructivist consideration of security issues through a securitization process of a speech act through this goal in Buzam, et al., [17] – "based on a clear idea of the nature of security, securitization aims to gain an increasingly precise understanding of who securitizes, on what issues (threats), for whom (referent objects), why, with what results and, not least, under what conditions (what explains when securitization is successful)".

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The securitization theory by the school was borne out of the discontent towards the inflexibility of the realism theory, where military aspects and only state are considered matters of security and this discontentment was further stimulated by the Economic agendas and intercontinental environment agendas of the 1980s and 1970s [117]. Hence, Buzan, et al., [17] stated that issues are classified as security issues because security "takes politics beyond the established rules of the game and frames the issue either as a special kind of politics or above politics," where an issue can be classified as politicized, non – politicized or securitized. Buzan, et al., [17], as cited by E Silva & Pereira [117] opined that this process is the securitization theory process, which is explained in the following concept;

a. **Non – politicized Issue:** A matter is not politicized when the government is not involved directly in dealing with the matter, whereas there is no public sentiment regarding the matter or issue.
b. **Politicized issue**: An issue is politicized when it necessitates the intervention of government, which sometimes culminates into public policy.
c. **Securitized issue:** An issue is securitized when the matter is seen as an existential threat, requiring exigent action, and there is a justification of measures beyond the normal political process.

Furthermore, Buzan, et al., [17] emphasized that the securitization of an issue depends on three (3) indispensable components: identifying and classifying a threat as existential; legitimizing the suspension of laws, and adopting emergency actions. Moreover, according to E Silva & Pereira [117], the securitization theory has three operational categories, which are;

a. Referent object: This unit is under threat (i.e say WEF resources).
b. Securitizing agent: This is the actor who proposes there is a threat and justifies how it is an existential threat to the referent object (i.e the actors at the Bonn 2011 conferences)
c. The functional actors: these actors are involved in the security of the referent object but are playing a unified role than the securitizing agent (i.e, researchers, international organization, etc).

However, in conformity with democratic traits, the securitization process is seen as a danger to democracy; hence, Waever [135] canvass for desecuritization process of the securitization theory, whereby security issues are handled within a regular operation,

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whereby the emergency measures are subjected to the normal policy framework. Waever [135] stated that desecuritizaion involves three strategies; i) the threat should not be addressed as an existential threat, ii) prevention of securitization from becoming a spirally effect and iii) ensuring the issue is seen within the scope of public policy. Hence, depending on the severity of the existential threats, securitization theory, involves securitization process and de – securitization process.

Therefore, the WEF nexus is a security issue that operates under the securitization theory, as the non – availability of these resources is an existential threat to the world. Therefore, world leaders, governments, international bodies, and researchers must follow both the securitization process and de – securitization process, depending on the resources needed in a geographical area.

b. Game Theory

The water, energy, and food nexus entail collaborations and compromises among the three sectors [53], which brings the interactions among stakeholders in the sectors to the limelight. The interaction among stakeholders in successfully achieving a nexus for the overall benefits of the geopolitical space of the resources is a strategic and systematic endeavor. Hence, the game theory optimizes the nexus's interactive decision-making process. According to Madami, Darch, Parra & Workman [74], the game theory can solve the WEF nexus complex socio-economic, ecological, and socio-political factors interconnected with the three resources. The authors further stated that this theory is necessary, as it becomes the decision-making process of the nexus, which is complex due to its multi-sectoral, limited understanding of the interdependencies, multi–objectives, competing factors, and multiple stakeholders with their objectives. Madani, et al., [74] further stated that the game theory provides essential insights into the strategic behaviors of WEF resources stakeholders and the analysis of the socio-political dimensions of making WEF nexus-related policies. The authors also stated that in making policies associated with WEF nexus, the game theory helps in the following dimensions;

a. Facilitate internal decision-making and cooperation about priorities within government bodies, civil services departments, and institutions.
b. Strengthen the approaches and outcomes of negotiation among geopolitical spaces and within WEF resources domain.
c. Seeks solutions to specific questions on resource management at different geospatial scale.

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d. Reconcile multiple long-term aims of different related WEF nexus resources.
e. Provision of robust strategies across different stakeholders with different interests.
f. Management of multiple actors who strategically interact to achieve their objectives is self – optimizing and often divergent.

Moreover, Madani [73] stated that game theory is necessary for resolving conflicts relating to water management, especially in water quality & quantity, as the theory provides a strategic framework in studying the actions of individual decision-makers in developing acceptable broad solutions. The author further opined that game theory applications in the administration of water resources cover areas such as water locations, water classification, water cost/ benefit analysis, water quality management, ground water management, water allocations among Trans – boundary users, and cooperative bargaining solutions in negotiations revolving energy optimization. This was further corroborated by Wei [137], where he analyzed the operationalization of game theory in the management of water resources. The author stated that game theory had been used in solving the following water resources problems;

a. The cost of distributing joint water resources projects, especially in the wastewater treatment and disposal.
b. The allocation of water rights.
c. Pollution of Transboundary River and intra- Country River, analysis of water policy – making and water dispatch compensation.

In addition, Li & Zhou [68] analyzed the implication of game theory between government and farmers, who are stakeholders in optimizing farmlands. The author analyzed the three main stakeholders in land optimization: local government, farmers, and central government, where the game theory was utilized in maximizing the different interests of the stakeholders. In analyzing the nexus in energy generation and management, Garcia [44] opined that game theory is needed in supporting decision-making. The author stated that the theory gives valuable insights in designing policies on complex energy – environmental issues, thus supporting the WEF nexus agenda in the following areas;

a. Facilitation of a better knowledge of the dynamics of policies under ambiguity by assessing the interactions of diverse objectives in energy resources-related institutions.

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b. Understanding different agendas from different departments during policy designs increases accountability and risk-sharing mechanisms among the departments.
c. Assess different energy–environmental policy mechanisms across different political agendas and institutions.

According to Madani, et al., [74], games are defined as a mathematical framework, which consists of some players, strategic moves, and payoffs of players (utilities) for a possible mishmash of the outcome of the game, whereby the player's decisions in the game is fueled by their potential gain. According to Scharpf [109], games are a state where the actions of the actor (individual or groups) are interdependent and collaborating, and the choices of all players affect the outcomes. Also, Tesfatsion [127] stated that a game entails of a gathering of decision-makers, named players; some information on each actor during decision making, the assemblage of different promising moves (in terms of actions decision, , plays) by each player that they can play, a procedure and rules determining moves choices of all players, that can collectively determine the outcome of the games, and the preferences of the players. Based on these foundations, the game theory is built upon how players make decisions. Madami [74] stated that the game theory is a mathematical study of cooperation and competition, illustrating how players' tactical interactions lead to outcomes specific to their preferences. According to the author, Game theory predicts how people behave, follow their interests, and conflict occurrence among people on their varying interests, where the players (decision-makers) with their objectives try to outsmart each other. It is a set of systematic tools premeditated to model interdependent or interactive circumstances, whereby the rational performance of a player can mark his gain or loss and other players [137].

In a bid to solve gambling problems among the idle nobles of French, Mathematicians in the seventeen century came up with the game theory. This led to the 1913 publication of Ernst Zermebo, proving that "*every competitive two-person game possesses the best strategy for both players, providing that both players have complete information about each other's preferences and intentions.*" However, several proponents and contributors to the game theory emerged, such as James Waldegrave, Pierre de Montmort, Nicholas Bernoulli, Isaac Todhunter, and Emile Bore. However, the 1941 scholarly work of Von Neumann and Oskar Morgenstern cemented the concept of game theory in "Theory of Games and Economic Behavior."

According to Wei [137], Mathematically, a game theory is represented thus;

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G_T = {N, A, P, I, O, E}

Where;

G – A game

N – Set of players.

A – Players moves or set of actions, which is also a variable of his decision.

P – Payoff or utility, which is the value of the outcome of players, based on costs & benefits of actions and outcomes of each player. It could be either actual or expected payoff.

I – Information set, which is the understanding a player has about other players, such as actors profile, characteristics, and payoff utility in the game.

O – Outcome of the game is a strategy summary eroding from the moves/ actions combination chosen by all the actors at the end of a game.

E – Equilibrium or equipoises, each player can exploit his payoff.

According to the author, NAPI is acknowledged, as the guidelines of the game and OE are the results of the game, which are subject to the following;

a. Players in the game models are regarded as "intelligent and rational." A rational player means that each player will choose a strategy or an action, which can maximize his expected utility given, he thinks what act other players will choose. In contrast, an intelligent player means that each player understands the situation and knows that others are intelligent and rational.
b. Each player considers his behavior and knowledge, and others while pursuing exogenous arms.
c. Each player has more than one choice or plays.
d. All possible combinations of choices or plays result in a well–defined outcome: lose or win, or mutual losses and gains.
e. The players know the rules of the game and the options of other players, but they do not know the real decisions of other players in advance, whereby every player has to choose options based on the assumption of what other players will choose.

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f. Each player knows that his actions can affect others, and the actions of others affect him.
g. Each player makes the best possible move, knowing that his opponent is also making the best possible move.

According to Raoof and Al – Raweshidy [99], in game theory, games are categorized into different aspects, which are briefly explained below;

i. Non – Cooperative and Cooperative (coalition) games: It is a type of game, whereby the players are driven by self-interest where the actions of each player are assumed selfish, seeking to improve their payoff, without considering other players. While a cooperative game is a kind of game, those players, through mutual agreements, play to achieve some payoffs, thereby allocating benefits and costs depending on the circumstances, where group or individual contribution depends on other players' actions in the game. For the WEF nexus to succeed, a cooperative game is the best approach, where all players are involved.
ii. Strategic and extensive Game: A strategic game, also called a static or normal game, whereby players decide on some personal decision at the beginning of the game, without having prior material facts about the actions of other players. In extensive games, on the other hand, players have information about other players' choices, thereby players making decisions during the game for appropriate reactions to the actions of other players.
iii. Zero-sum Game: This is a payoff structure, where one player's gain is another player's loss.
iv. Games with Perfect and Imperfect Information: A game with perfect information is when the decision or action of a player is influenced by the knowledge of preceding decisions of other players. Whereas, a game with an imperfect decision is when the player has no facts about the actions of other players during their decision-making.
v. Games with complete and incomplete Information: A game with comprehensive information is when all the elements of the game, the strategies, payoff s, and decisions of each player are common knowledge to all players, which is often seen as an efficient, perfectly perfect competitive game. While a game with incomplete information is when players do not have sufficient information about other players in the game, making predictability difficult.

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c. Malthusian Theory of Population

Rising population people in the world has been a significant driver in most of WEF nexus conceptual frameworks seen in Hoff [53], World economic forum [142], Bizikova, et al., [10] of the Institute of sustainable development and Mabhaudhi, et al., [72] for South Africa. This is because of the perceived disparity between rising population and WEF resources utilization and depletion. This has also being echoed in the work of Meadows, et al.,[81] about planetary boundaries being crossed by the increasing world population and their activities. These concerns support the views of the Malthusian theory of Population.

The Malthusian theory of population is a philosophy of exponential growth of people (1, 2, 4, 8, 16, 32) and arithmetic food supply (1, 2, 3, 4, 5, 6, 7). According to Gupta (2012), the theory is used to plan environmental degradation and poverty rate matters. As Unat [130] cited, the Malthusian theory of population was propounded by Rev. Thomas R. Malthus in his seminal work – "An essay on the principle of population", published in 1978. The theory is premised that food production will increase at an arithmetic progression, while the population will be at a geometric sequence and will be doubled every twenty–five (25) years if not checked. As cited in Chowdhury & Hossain [22], Malthus opined that according to the reducing yields law, there is decrement for food per capita when there is an increase in population. Rahman [98] explained the two mathematical sequence, which is the pillar of the theory, as follows:

a. Arithmetic Progression (AP): It is a mathematical rule of 1, 2, 3, 4….., where the difference between consecutive terms is constant. According to the Malthusian theory, it is term slow sluggish progression when applied to food production. Hence, if there is an increase in food production at the rate of 1, 2, 3, 4,5 , when population doubles (according to the theory), the added population food demand will not be met.
b. Geometric Progression (GP): It is a mathematical rule of 1, 4, 8, 16, where the difference between consecutive numbers is in a ratio of multiplication form, unlike the AP, which is in addition form. Per the theory, the population takes the GP rate. Hence, if there is a 10% increment in population in two years, then there wouldn't be an increase in food for the excess population but will increase the demand by 10% for food.

Rahman [98] furthered posited the Malthusian theory of population using this Illustration "Suppose 1 Million metric tons of Rice is required daily for a country's population. If the country's population increases one–fold after five years, then the demand for food will increase two-fold, requiring 2 million rice metrics for a one–fold population. But it is not possible to produce more food rather than the population".

The Malthusian theory of population by T.R Malthus is based on the following facts, as inferred from Sakanko & David [108]:

a. The population will always increase due to the natural instinct of sex of human beings, making it grow at a faster rate.
b. The workings of the law of diminishing returns, which posits that adding an additional factor of production results in smaller increases in output.
c. The assumption of a fixed quality of land for production of food and as population gains more land to build houses and other endeavors, thereby depriving the land of agricultural activities or cultivation.

Moreover, as cited by Sakanko & David [108], Rahman [98], and Seth [116] and Chand [18], Malthus, in his theory, proposed two checks to control population growth, to balance up with food production rate. They are:

a. **Preventive check**: this check deals with controlling the birth rate through late marriage, celibacy, family planning, abstaining from birth control, procreation, and homosexuality.
b. Positive or natural checks: This check deals with the increase in death rates, which will occur if preventive checks are not in place. The positive checks include; war, diseases, and famine. In complementing this natural check, as cited by Rahman [98], Malthus wrote explicitly – "*Famine seems to be last, the most dreadful resource of nature. The power of population is so superior to the power of the earth to produce subsistence for man that premature death must visit the human race in some shape or other. The vices of humankind are active and able ministers of depopulation. They are precursors in the great army of destruction and often finish the dreadful work themselves. But should they fail in this war of extermination, sickly seasons, epidemics, pestilence, and plague advance in a terrific array and sweep off their thousands and tens of thousands. Should success*

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> *be still incomplete, gigantic inevitable famine stalks in the rear; and with one mighty blow levels the population with the food of the world.*"

Furthermore, Rahman [98] stated that a Malthusian catastrophe would occur whenever there is an increment in population and a decrease in food production. In addition, the author opined that whenever either the preventive checks or positive checks occur, there is a monetary balance between population and food supply, but this is a cycle called the Malthusian cycle.

Moreover, the Malthusian catastrophe, the hallmark of the Malthusian theory of population, emphasizes the growing demand for resources, especially water, energy, and food. Hence, WEF nexus, which is majorly about managing the synergies and tradeoffs of the resources for resources security in line with resource demand and expected population increase, is a solution to wade off the prediction/ prophecy of the Malthusian theory of Population. The pessimistic theory is now an environmental management stimulus in ensuring that population growth and the existing population have enough resources to cater to their wellbeing. This is also in line with the concept of sustainable development, which emphasizes ensuring that resources are craftily managed in catering for today's population and tomorrow's population, which is the fear of the Malthusian theory. The theory also highlights that in avoiding the predictions of the possibility of the positive checks of the theory, stakeholders, government and population must ensure effective resource leadership, which the WEF nexus represents. This is because of the critical role water and energy plays in ensuring food production and supply.

The theory has been used for the relationship between income and population from 17 OECD countries by Madsen, et al.,[76]; between per capita growth and population in India by Chowdhury and Hossain [22]; the relationship between fertility and poverty rate in Turkey by Ozturk [95]; and the relationship between development, and population growth in Sub – Saharan African countries by Eren [37]. All these empirical studies show the relevance, importance, and validity of the possibility/ effect of the Malthusian theory of population, as all relate to resource optimization.

However, as Okunola, Nathaniel and Festus [93] stated, the Malthusian theory has been heavily criticized, whereby some of the criticism is aiding the WEF nexus. These criticisms are summarized as follows;

a. The wrong mathematical form of the theory as there are no empirical proofs.

b. Malthus failure to foresee opening of new areas in Australian, United States of America and Argentina, where there is extensive farming of virgin land, unlike his local area of England.
c. Failure to see unprecedented increase in scientific knowledge, Agricultural inventions and technological breakthroughs in Agriculture.
d. Malthus neglected the Manpower aspect of population, that an increase in population means an increase in Manpower for agricultural activities.
e. The Malthusian theory rest on a weak relationship between food supply, and population, as population is more related to total wealth.
f. Empirically, it has been proven that population growth is a function of the level of per capita income, because when per capita increases, it lowers fertility rates and the rate of population growth therefore declines.

d. Institutional Theory

The water, energy, and food nexus is an integral method that cuts across different complex sectors, thus necessitating the application of various policies, rules, procedures, regulations, and norms. The nexus entails the management of the different institutions, their actions, and policies. Scott [114], in his research on the governance of the WEF nexus, opined that the nexus is about how policies and actions in one sector can stimulate constraints by overlooking their impact in the other two sectors, as this integrated approach requires harmonization on public polices, coordination and the alignment of strategies, incentives and regulations. The author further opined that the WEF nexus approach requires the processes and institution of governance. Also, Stein, Barron, and Moss [122] opined that the interconnected challenges of WEF resources, which necessitated the nexus, need the alignment of policies for sustainable development due to the different resource systems, actors, and policy domains that are interconnected. According to the authors, the WEF nexus is about the inseparable relationships between people (who are actors) and their perceptions. Furthermore, the research of Foran [42] had suggested that in the optimization of the WEF resources nexus, the nexus has to be viewed from a social science perspective, considering their historical, socio-political, and cultural dimensions. In addition, the author opined that an understanding of the WEF nexus entails synthesizing fundamental concepts, discourses, interests, and institutions.

These researches: Scott [114], Stein, et al., [122] and Foran [42] have shown that the efficiency and governance of WEF nexus can be attained by factoring in the role of

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Institutions, which is what the institutional theory centers on. According to Scott [113], "*Institutions comprises of regulative, normative and cultural – cognitive elements that, together with associated activities and resources, provide stability and meaning to social life"*. Furthermore, according to Scott [113], as cited by Comyns [26], the three elements of Institutions are briefly explained. The regulative pillar of Institutions deals with establishing, monitoring, and enforcing rules and regulations. The normative elements entail the definitions of goals and how to pursue those goals, while the cultural–cognitive support highlights individual responses to the peripheral world shaped by cultural frameworks. Jepperson [59] stated that Institutions are developing, higher-order factors above the level of individuality but constraining or constituting actors' interests and political participation without repeated authority to achieve regularities.

Institutions are informal or formal procedures, conventions, routines, norms, moral templates, cognitive scripts, and symbols systems in an organizational structure [51]. In addition, Scott [112] and Berthod [9], institutions are rules, roles, beliefs, and symbolic elements that can affect the methods or structure of an organization without resource flow and technical requirements. Paul [96] averred that institutions help in the coordination of actions between diverse actors in a society without the necessity for centralization, which limits. Friel [43] research highlighted scholars' views that institutions govern the actions of individuals and define their preferences and power in a society. Furthermore, according to Williamson [139], Institutions exist at four (4) levels in society. The first level is customs, traditions, religion, and norms, which are subject to change over time but have a lasting impact on the conduct of a society. The second level is the formal rules, consisting of laws and constitutions, which materialize partially out of an evolutionary process and partially out of design. The third level is governance, which entails the conception of contracts and agreements between groups in a society or institutions, which set the basis for mutual benefits and reduction/ avoidance of conflicts. The fourth level of institutions' existence in society is resource allocation.

Institutional theory emphasizes on the activities, relationships, and regulations of institutions over time. Slimane, et al., [119] emphasized how actors in institutions are willing to institutionalize new practices and how organizations within an institution can manage environmental pressure. This management of ecological pressures is a result of institutional practices, which, according to Dimaggio & Powell [33], are done through Isomorphism. The author stated (as cited by Comyns, [26]) that Isomorphism in institutional theory is in three processes: Mimetic Isomorphism, Coercive Isomorphism, and Normative

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Isomorphism. Coercive Isomorphism entails responding to government regulations due to formal or informal pressure, whereas Mimetic Isomorphism is a process whereby organizations mimic or copy others within the same institutions. Normative isomorphism entails professionalism in the institutions.

Moreover, Lewis, Cardy, and Huang [67] study opined that Institutional theory foreground the complexity of institutions and help skilled actors influence and navigate the social constructions of institutions themselves, which serves as a toolkit in managing the three process of isomorphism. According to the authors, the concept of institutional theory emanates from the scholarly works of Meyer and Rowan's [84] in their study titled – "Institutionalized organizations: formal structure as myth and ceremony" and Dimaggio & Powell [33] in their research titled – "The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields." Meyer and Rowan [84] opined that Institutional theory entails understanding the decision-making process of organizations, which are usually motivated by their environment/ Institutions rather than their efficiency, which often leads to Isomorphism (where organizations in an environment or institutions begin to resemble each other). Starting from where Meyer and Rowan research work stops, Dimaggio & Powell [33] expanded the Institutional theory by researching Isomorphism and providing mechanisms on how it works in institutions. The authors formulated three processes of Isomorphism as stated earlier, which includes;

a. **Coercive Isomorphism**: This is a type of Institutional resemblance that occurs due to formal expectations (laws or regulations), informal expectations (corporate social responsibilities and ethics); and the penalties/ sanctions that occurs when these expectations are not met, which includes loss of legitimacy, bans, fines, etc.
b. **Normative Isomorphism**: This entails codifying rules, norms, routines, and values when different organizations in the same institution become professionalized. These are seen in Institutions such as Education, professional associations, etc.
c. **Mimetic Isomorphism:** This occurs when organizations within the same institutions tend to reduce search costs in the face of uncertainty and accept Institutional practices by default due to the diffusion of those practices, whereby failure of adoption or copying results in penalties. This also occurs due to environmental uncertainty and the organization's ambitious goals that lead organizations to imitate one another [125].

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Succinctly, Institutional theory entails how groups and organization within an institution secure their situations and affirms the legality by compatible to rules (such as laws, governmental agencies, regulatory structures, professions, scripts, and other environmental pressures) and norms [46; 33; 84; and 112]. Also, Jennings & Zandbergen [58] and North [91] opined that Institutional theory studies how an organization in an institution seeks legitimate practices in the views of other stakeholders due to pressures from social, economic, and political environments influences on their decision-making ability.

The theory provides a theoretical lens for identifying and examining internal and external factors that influence the survival and legitimacy of organizational practices, whereby the influencing factors are social environment, culture, regulations, tradition, history, economic incentives, and resources. Institutional theory is also because organizations within the same institutions adopt initiatives in gaining acceptance or legitimacy within society, which helps them access scarce and important resources [23].

Furthermore, Schmidt [110], as cited by Friel [43], in his contribution on Institutional theory, suggested that there are four (4) types of Institutional theory approaches, which shapes actors (organizations or players) in an institution, which includes;

a. **Rational choice Institutionalism** entails that institutional actors have static preferences and therefore act rationally to maximize their preferences. It is a simultaneous influence exerted on each other by both actors and institutions in maximizing their preferences (for actors) and legitimizing practices (for institutions). March and Olsen [78] opined that the fundamental logic of the rational choice approach is that institutions are arrangements of incentives and rules, where members of Institutions, that is organization and players, behave in response to them, whereby institution influences the actors through rewards for their actions and reduce the uncertainties of their actions.
b. **Sociological Institutionalism**: This examines how and the extent to which institutional actors follow the norms and rules, assuming that culture and identities are the causes of interest for individuals. It emphasizes how institutions model actors and not how actors form institutions.
c. **Historical Institutionalism**: It focuses on the development of institutions over time, as they are sets of regularized practices. It is also because the structural and policies made by an institution during inception will have a long-lasting influence over its practice during the course of its existence [123].

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d. **Discursive Institutionalism:** This examines the generation and legitimization of ideas by actors through a rationality of communication, focusing on the collaborative process through which concepts are produced.

Therefore, in applying Institutional theory to WEF nexus, it is a mix of different players from both public and private sectors in each of the institutions of water, energy, and food/ Agriculture sectors. The norms, regulations, culture, governance, and environmental pressure are nexus. Hence, Institutional theory underpins the nexus on how the integration of different institutional practices can be achieved, simplified, and sustained over time to create the nexus. This has to do with identifying patterns in each sectoral institution for the internationalization of processes and managing conflicting rules and procedures.

e. The Theory of Technological Acceptance Model

The Water, Energy, and Food nexus, due to its complexity and heterogeneity with other fields and sectors of the economy, the integration of Technology is inevitable. Technology remains the core optimization of the nexus, and the integration between the three resources can only be possible by technology. Several authors have researched the technological aspect of WEF nexus. Martino, et al., (2021) designed a technological aspect of WEF nexus by designing a reverse Osmosis desalination in South Central Texas to decrease water scarcity and meet local water demands in the area. Emmanouil, et al., [35] designed an environmentally friendly renewable energy micro grid for a village in Ethiopia for a sustainable irrigation system for pumping, lighting, and cooking. Endo, et al., [36] also analyzed different methods and tools for achieving WEF nexus, which the bottom line is Technology. Technology, the application of science, is inevitable in achieving WEF nexus for different WEF resources needs or objectives.

However, in designing a technology-oriented WEF nexus, the technology acceptance model theory dealt with the acceptability of such new technology. Davis [30] propounded the Technology Acceptance Model (TAM) theory on how readily people will accept new technology. He demonstrated it at the Massachusetts Institute of Technology (MIT) in the 80's, on the acceptance of an IBM product [118]. According to the authors, TAM focuses on why users will accept or reject technology and the improvement on the acceptance or rejection. According to Deslond and Becerra [32], TAM predicts the level of technology acceptance and usage, categorized into perceived usefulness and Perceived ease of use. The authors opined that perceived ease of use (PEU) is the degree to which a user believes that

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using a particular technology would require minimal or easy efforts. In contrast, perceived usefulness (PU) entails the extent to which technology enhances job performance.

Furthermore, Wingo, Ivankova & Moss [140] stated in their research, as seen in figure 1, that five (5) factors contribute to the perceived usefulness of a technology. The first one is the subjective norm, which entails how the users believe other people's perceptions of the technology based on their experience and whether the technology usage is mandatory or voluntary. According to Jaradat & Almashaqba [57] research, the subjective norm is defined as “the degree to which an individual perceives that most people who are important to him think he should or should not use the system.” The second factor, image, is how the technology used will affect the user. According to Moore & Bensasat [87], image entails “the degree to which an individual perceives that use of an innovation will enhance his or her status in his or her social system.” Job relevance, which is the third factor, deals with how the user-perceived that the technology would help accomplish the job's significant goals. In further explaining job relevance, Venkatesh & Davis [132] defined job relevance as “the degree to which an individual believes that the target system is applicable to his or her job and the effect it has on the job.” The fourth factor is the output quality, demonstrating how the quality of the technology will influence the applied task. Venkatesh & Davis [132] opined that output quality is “the degree to which an individual believes that the system or technology performs his or her job tasks very well” The fifth factor, demonstrability, entails the perceived tangible outputs and benefits of the technology. Moore & Benbasat [87] defined demonstrability as “the degree to which an individual believes that the results of using a system are tangible, observable, and communicable”.

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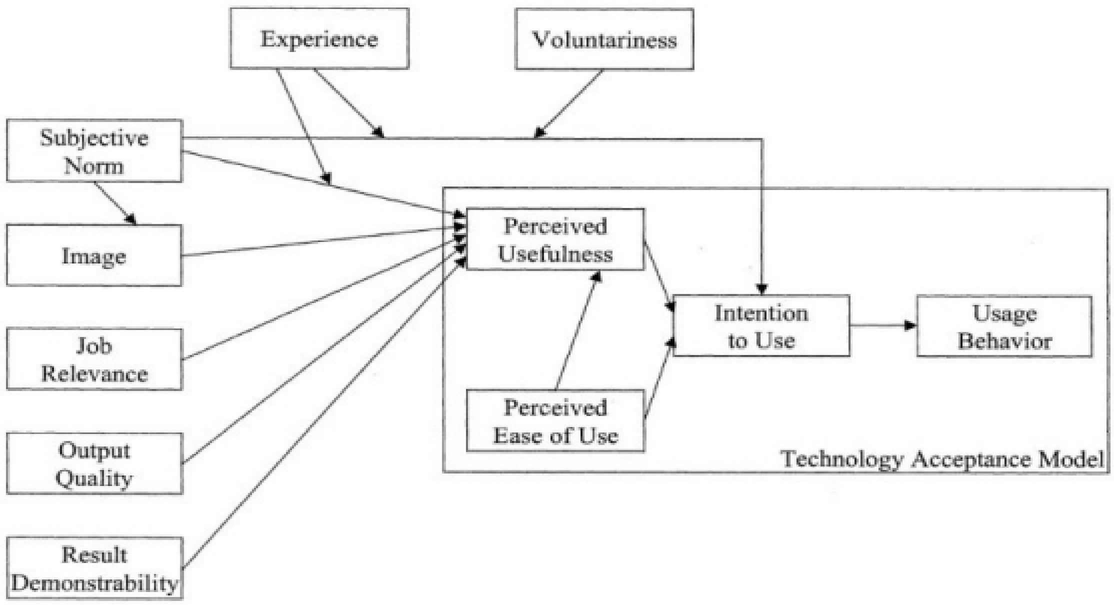

Figure 1: Technology Acceptance Model [140].

Therefore, the use and application of the technologies on the water, energy, and food nexus will be subjected to the acceptance of the technologies grounded on the theory of the Technology Acceptance Model. Users of the WEF nexus will observe the technologies' perceived usefulness and ease of use of the technologies. This, therefore, entails that WEF nexus stakeholders, policy makers, researchers, and project managers should focus on simplifying technologies for easy usage and highlighting the importance of speeding up the acceptance of the technologies.

f. Innovation Diffusion Theory

Products of the individual three resources of water, energy, and food are innovations at inception; they are produced to bridge a gap or satisfy human needs. Likewise, products from the WEF nexus are innovations, considering their newness and purpose. Robertson [101], as cited in Ja Kim, Lee & Contractor [56], defined innovation as "a process whereby new thought, idea, behavior or thing is conceived and brought into reality." Mytelka [89]

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also opined that innovation is a procedure by which an organization masters and implement the design and manufacturing of goods & services that are new to their organization, regardless of whether they are new to their competitors, market, customers, or the world. Therefore, considering the inevitable processes, designs and production, and technological innovation in the three most crucial resources and their nexus, there is a need to understand how these innovations will flow and be sustainable. Rogers [104] defined diffusion as "the process by which an innovation is communicated through certain channels over time, among the members of a social system." Hence, the IDT application to the WEF nexus deals with how the nexus products will be readily diffuse for acceptance or rejection.

Rogers propounded Innovation Diffusion Theory (IDT) in 1962 in his book titled "Diffusion of Innovation", explaining how innovation or technology spread and is accepted among a population. Jwaifell & Gasaymeh [60] opined that innovation diffusion theory describes the process whereby innovation is adopted among a population. Citing Rogers (2003), the authors opined that in the adoption of technology and experience, it is effective in their activities before accepting or rejecting the technology. Hence, according to Rogers [105] cited by Choe & Noh [21], IDT is defined "as the process by which an innovation is communicated through certain channels over time among members of a social system".

Rogers [105] stated that the adoption and spread of innovation is determined by five (5) qualities, which are;

a. **Compatibility**: this entails the perceived consistency with values, needs and experience of possible users & adopters.

b. Relative advantage: this connotes that the more incredible, easier, and quicker technology adopters realize the benefits, merit, and importance of technology, the fast its rate of adoption.

c. **Trialability**: this is the extent to which the exploited technology can experiment on a limited basis.

d. **Simplicity and ease of use**: this is based on the effortlessness of usage and application of the technology. People will quickly adopt an easy-to-use technology than a technology that requires new skills and knowledge.

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e. **Observable results**: the quicker and easier potential technology adopters see the benefits and results of using technology, the faster it is adopted.

Furthermore, according to Rogers [105] and Sahin [107], there are four (4) main elements in the diffusion of innovation, which comprise creation, time, communication channels, and social systems.

a. **Innovation**: This is a project, idea, or practice that is professed as new by an individual, even if the innovation has been invented for a long time.

b. **Communication channels:** This is the process whereby participants produce and share information with each other or among themselves to reach a conclusion or mutual understanding. According to Rogers [105], the communication channels in the IDT entails 5 channels shown in figure 2, consisting of knowledge (this is the why, what and how of the innovation); Persuasion (this is the formation of favorable & unfavorable attitude towards the innovation based on the degree of uncertainty); Decision (at this stage, the user decides to either accept or reject the innovation); Implementation (the user is putting the innovation to practice) and Confirmation (the user has decided to use the innovation but needs further support to cement their acceptance decision or uncertainty attitude).

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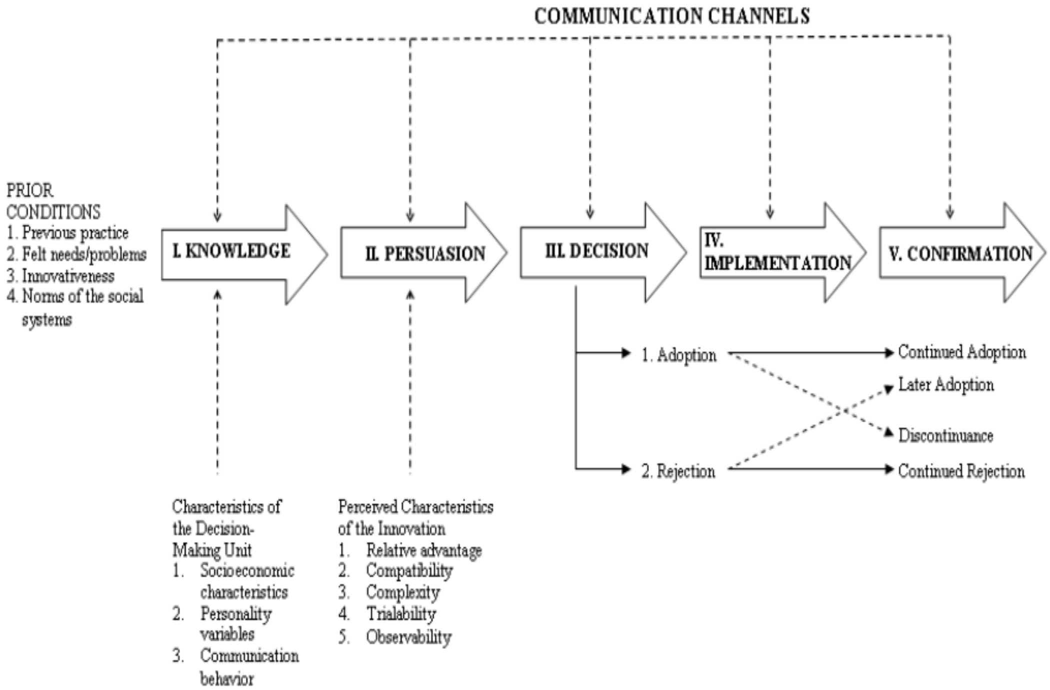

Figure 2: IDT communication channels [105; 107].

c. **Time:** this entails the period by which people adopt the innovation. According to Rogers [105] and Dearing & Cox [31], the period of innovation is in accordance with 5 categories of adoptions, which are innovators (2.5%), early adopters (13.5%), early majority (34.0%), late majority (34.0%) and Laggards (16.0%). This is shown in figure 3.

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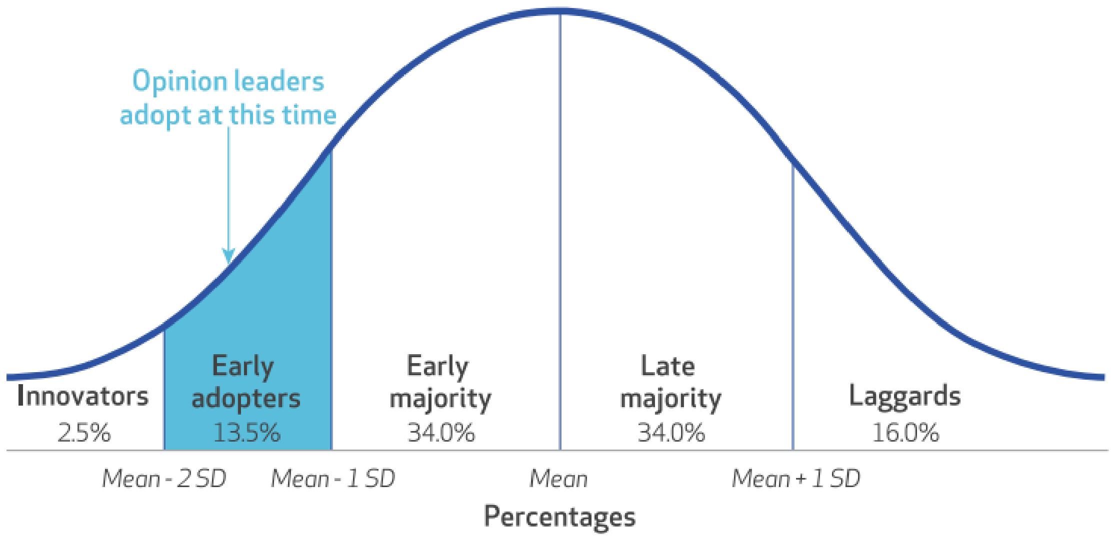

Figure 3: IDT Time of adoption [31].

d. The social system is a set of interconnected units engaged in solving a problem to achieve a mutual goal, which is often influenced by a social structure.

Therefore, the applications of the innovation diffusion theory to the innovation arising from the water, energy and food (WEF) nexus entails that before the acceptance of those innovations, they must be applied in stages and not in a forceful attempt. This will ensure quick acceptance of the innovation and the marketing mechanism and, most importantly, their sustainability. Relevant stakeholders in WEF nexus policy decision-making process must appraise the innovation based on the five (5) communication channels of IDT and the five (5) qualities of the theories.

3.2 Human Resource Management Implications on WEF Nexus

The WEF nexus theories have shown the crucial role of human resource management, which is a lacuna in nexus management. The securitization theory introduced by Weaver [135] of the Copenhagen school of security studies has shown that the security of the resources needs human resource managers that will always view the insecurity of the three resources as an existential threat. This lay emphasis on the vision and foresight of the leadership in Human resource management. As opined by Zhao, Liu, Zhu, and Liu [144], the administration has an intrinsic value in ensuring the performance of an organization through the utilization of human resources of the organization. Hence, in ensuring the security of the three resources, which is the ultimate aim of the WEF nexus, human resources must be coordinated in channeling their capabilities to view the unavailability of the resources as an existential threat. The Game theory popularized by Madami, et al., [74] revealed the importance of stakeholder engagement and management in making resource management decisions, a key aspect of human resource management practices. To effectively utilize human resources to achieve organizational goals, stakeholders' engagement must be a human resource strategy. This was optimized by Li & Zhou [68] in maximizing and integrating various stakeholders' interests to achieve food productivity. Therefore, the WEF nexus must utilize this human resource strategy in managing the synergies and tradeoffs of the resources, which involves multiple stakeholders. Stakeholders in the WEF nexus thinking includes WEF resources policy makers, employees in the three sectors, managers in the three sectors, business leaders, corporate organization, researchers in the WEF spaces, and government officials across different tiers/ level of government. In addition, other stakeholders include interest managers from ancillary services such as transportation, community managers, urban & rural planners, and managers of other WEF drivers like climate change, environment/ ecology, economy, population growth, etc.

Moreover, the Malthusian theory of population introduced by Malthus [77] described the relationship between population growth and food supply, directly and indirectly, emphasizing human resources productivity. This paper opined that the productivity level of human resources in the association between population growth and food supply determines the extent of food supply and diminishes the effect of population growth. Hence, irrespective of the introduction of money, materials, machine, and method, as Hameed [52] stated in an endeavor, until man, which is the human resource, make it work, the efforts will end in a stalemate. Therefore, accentuating the strategic role of human resource productivity will ensure the supply of WEF resources in terms of accessibility, affordability, availability, and stability. However, as Mojelan, Satari, Soleimani & Daryani [86] stated, human resources must be managed well for optimal productivity. Hence, the WEF nexus security depends on the productivity of human resources, which has formed part of the criticism of the Malthusian theory in ignoring the human resource productivity of population growth.

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Moreover, institutions in the Water, Energy and Water sectors must be strong to ensure human resource productivity. Human resources efficiency and productivity depend on rules and governance structures. This is the hallmark of the Institutional theory, as shown by Scott [114] on policies and regulations alignment that must be followed in the three sectors of water, energy, and food. Therefore, for institutions to be strong and work for intended purposes, there must be an understanding and collaboration between rules and human resources, as rules can't be followed without human resources. The Technological Acceptance model introduced by Davis [30] and the Innovation Diffusion Theory postulated by Rogers [104] bring to the limelight that technologies' optimal performance depends on the acceptability rate of human resources. Therefore, introducing technologies to achieve the nexus of the three resources, especially at the National and geographical scale, requires human resources' buy-in. This shows the importance of human resource engagement for the technology to thrive.

Furthermore, the introduction of the importance of human resources in the theoretical framework of WEF nexus emphasized the utilization aspects of human resource management but was silent on the procurement, compensation, and rewarding aspects. This highlights the importance of recruiting human resources with nexus thinking, which can optimally drive the WEF goals regarding WEF security, climate change management, economic sustainability, environmental sustainability, social sustainability, and sustainable sustainability economy. Lack of nexus thinking among managers of the WEF nexus has been the bane of the nexus. Citing Leck, et al., [63], McGrane, et al., [79] posited that the nexus aims to break down silo mentality among the three resources, acting as a barrier to achieving the nexus of WEF resources. The authors lamented that the translation of "Nexus thinking" into "Nexus doing" has not yet materialized. Hence, this paper believes that for a transition of nexus thinking to nexus doing, human resources in the three sectors must have a nexus thinking, thereby enabling them to study the effect of the policy of one sector on the policy of the sectors. These three resources, mainly under the government's control, require civil servants in charge of policy formation and require a WEF Nexus thinking. It should be an issue of expediency that recruitment into the three sectors should factor in the understanding of the imperative of the interrelationship between one resource to other resources.

Moreover, system mapping of the various linkages of the WEF resources proposed by Terrpon – Pfaff, et al., [126] requires productive human resource managers with nexus thinking. These human resource managers would ensure efficient coordination of the management of the interlinkages beyond the occasional input of academics, thereby ensuring the sustainability of the resources. Hence, for the nexus to be translated into the policymaking process, system-level thinking is highly needed, which cannot be achieved with a human resource without nexus thinking. Mabhaudhi, et al., [72]) of the South African Water Research Commission stated the lack of nexus thinking among human resource managers in the energy and Agriculture sector of Mpumalanga and Limpopo provinces of South Africa. Also, Rasul and Sharma [100] opined that lack of nexus thinking among human resources of WEF sectors leads to over-allocation of resources during policy formation.

Furthermore, Gywahi [49] highlights the compensation aspect of human resource management in the WEF Nexus. The author opined that internal rewards by leaders in powerful positions corrupt nexus thinking and enthrones a silo mentality among the WEF resources. Hence, an appropriate compensation and reward system should be introduced to propagate a nexus thinking among human resources of the various departments and agencies of the WEF sectors.

Therefore, this paper advocate for consideration of WEF nexus thinking in the recruitment policy of the sectors of the three resources. This will aid prompt and efficient management of the three resources' interdependencies, synergies, and tradeoffs. Moreover, for the actualization of the WEF nexus, existing human resources of the sectors can be trained on its importance, as training offers employees new perspectives on an issue, stimulates their understanding, and gives them technical knowledge – how of WEF security. In addition, the compensation and rewarding system should be efficient in the sectors, emphasizing the management of WEF resources tradeoffs, cutting of wastes, and identification of innovation synergies. This will further ensure the attainment of the goals of Human resource management, as stated by Armstrong [6], which will enable the private sectors to have a good synergy with the public sector.

3.3 Effect of emerging technologies on management of Water, Energy, and Food (WEF) Nexus

The extent of operationalization of the theoretical framework of WEF nexus and productivity of human resources depends on the effect and influence of emerging technologies. Several technologies support the management of water, energy, and food (WEF) nexus, such as water-efficient energy systems. These technologies are at various research, demonstration, development, and deployment stages. There are wide ranges of technologies optimizing the various nexuses in the water, energy, and food space, like the water-energy nexus, water – food nexus, energy-water nexus, food-water nexus, energy – food nexus, and food–energy nexus.

Moreover, Zaidi et al., [143] addressed that water-energy nexus problems and alternatives can be solved using machine-learning contexts of Artificial Intelligence. Furthermore, in optimizing Ethiopia Renewable Energy sources for WEF nexus, Emmanouil, et al., [35] designed a micro grid of solar and small scale hydropower for irrigation water pumping, using the technology of Hybrid optimization of multiple energy resources (HOMER) software and simulations of MODFLOW unsaturated zone flow package. Zhang, Li, Huang & Ma [144] also designed a copula-based stochastic fractional programming (CSFP) method to solve risks related to arable land, hydropower generation, and water resources, which will help in planning food production, water allocation, and energy generation, used for five (5) countries in Central Asia, Uzbekistan, Tajikistan, Kazakhstan, and Turkmenistan. In addition, Ahmad, Ahmad, Zaindin, and Adhami [3] used a technological novel method called interactive neutrosophic programing approach (INPA) to solve WEF nexus environmental and socio-economic objectives of electricity conversion, optimal energy supply, food production, CO_2 emission control, and water resources allocation.

Furthermore, in applying technology to WEF nexus for different wheat intensive agriculture, Fabiani, et al., [39] used the Variable Rate Technology (VRT), which combines digital and physical technologies such as farm machinery, drones, satellites, artificial intelligence, machine learning, and hyper spectral imaging for the automation of materials like fertilizers, chemical sprays and seeds to land. The Integration of technological innovations into the water – energy and food nexus has steered several technological concepts within the sectors. This includes concepts such as Precision Agriculture and Precision farming [34], vertical farming, hydroponic & Aquaponics systems [106], Smart grid [133], water reticulation [54], and post-harvest technologies, Irrigation & Drainage Engineering and Agro-processing [61].

Furthermore, Mekonnen, Burton, Sarwat, and Bhansali [82], in exploring the relationship between the Internet of Things and the WEF nexus, opined that the Internet of Things (IoT) is highly vital in understanding the interdependency of WEF resources, where the authors used wireless sensor networks (WSN) to create real-time data for smart farming. The sensor networks will aid farmers to forecast their agricultural yields, enhance water utilization via smart irrigation control and precisely know when to harvest, which will diminish labor &

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energy input. This will safeguard environmental sustainability, as farming will be based on precision and efficiency, for more yield, without negative effects on the environment. The authors avowed that IoT would help collect data, whereby the data are analyzed using different algorithms of neural networks, support vector machines (SVM), linear regression, and Artificial neural network (ANN) to make informed decisions in the WEF systems. Using an IoT technology, the authors built a smart farm bed consisting of an off-grid PV panel, smart irrigation, a distributed WSN, and data infrastructure to exploit vegetation yield, diminish the environmental effect, and minimize energy consumption. The advent of IoT technologies helped enhance the effective utilization and integration of data across the WEF resources, making nexus possible effective, and applicable. The management of WEF data is an integral component of ensuring sustainability, especially on operations and delivery of the resources (Etzion & Aragon – Correa, 2016).

According to Kumar, et al., [62] in the WEF nexus system, IoT is essential, with the following benefits; enabling the user to practice efficient measures, water quality monitoring, enable consumers to become energy & water efficient, ensures asset performance & management, ensures food security, water sustainability, energy sustainability, and food sustainability. The authors highlighted the application of IoT in the various WEF components. In the water subsystem of the WEF nexus, IoT applications comprise water quality monitoring, water safety, quality control in water reserves, wastewater management, water transport, monitoring the drought locations, leakage detection in water flow paths, efficient & systemic water management, and monitoring the water consumption patterns. In the Energy subsystem of WEF nexus, IoT applications include advanced metering infrastructure (AIM), control & operation of energy-consuming devices (Co – ECD), Battery Energy Management (BEM), Micro Grid (MG), Control of electrical energy system and utility (CEESU), Nano Grid (NG), and Energy system reliability & stability (ESRS). Other applications are Fault maintenance in energy systems (FMES), Decrease in Energy Downtime (DED), Energy and Performance Optimization (EPO), Hybrid Energy system intelligent control (HES – IC), energy storage & Analytics (ESA), Predictive maintenance (PM), and Smart Grid (SG). It also includes Smart Inverters (SI), Hybrid Electric Vehicle Intelligent Control (HEV – IC), Remote monitoring and Reliability (RMR), Supervisory Control and Data Acquisition (SCADA), and Safety & Security (SS). In the Food Subsystem of WEF nexus, utilization of IoT technologies consist of; storage and handling of food products (SHFP), Food packaging, Food transport, Freshness and quality monitoring of food products that are originated from plant species & animal meat, and intelligent packaging & delivery (IPD). Others are Food delivery monitoring & Alert, vegetable washing systems, removing dried and damaged leaves from the food material from the plants, food safety & security, cereals & pulses drying at controlled temperature, sorting of vegetables, packed food products & fruits, online payment of food bills and food safety & security.

Abe, et al., [1] posited that data science is needed to analyze WEF nexus datasets and the functionality of WEF subsectors technologies, especially in spatial computing, whereby the unavailability of data has become an encumbrance in nexus management. Pitts, et al., (2020) opined that big data. Analytic technology is a technique for modeling the WEF nexus, where there are no reliance or underlying assumptions between variables, and data is the foundational input in the model. This makes it less prone to error and uncertainty, quick to develop, and shows tradeoffs in the nexus, thereby highlighting areas that will adversely affect sustainability issues in the nexus.

Therefore, the significant effect of emerging technologies is the emergence of innovations in the water, energy, and food space, thereby shaping the nature of the nexus. Moreover, the Artificial Intelligence (AI), Big data analytics, and Internet of Things (IoT), are the significant technologies steering the water, energy, and food space.

4.0 Conclusion and Recommendation

The paper explained the various theories aiding the WEF nexus, such as Institutional theory, Malthusian theory of population theory, Game theory, Securitization theory, Innovation Diffusion theory, and Technology Acceptance Model. The theory revealed the intrinsic nature of the WEF resources and their interrelationship with human activities. The theoretical framework shows that human activities will continue to shape the three resources' nexus and determine the extent of security of the three resources. Moreover, the theories highlight the significance of human resources for actualizing the WEF nexus. The paper also highlights the importance of recruiting human resources in the WEF sector with a nexus thinking to mitigate against silo mentality in the WEF sectors. Furthermore, the research revealed how Artificial Intelligence (AI), Internet of Things (IoT), and Big data as emerging technologies shape the WEF nexus interactions with innovations. Conclusively, there is an interaction between the theories of WEF nexus and Human resources management of the nexus, which will affect the extent of the innovations introduced by emerging technologies.

Therefore, it is recommended that there be a quantification of the theories introduced in this research to know the extent of application and magnitude of effect. Moreover, there is a need for periodic and consistent training of current human resources in the water, energy, and food sectors on WEF nexus thinking. In addition, there is a need for capital and human resource investment on emerging technologies shaping the WEF nexus for mass commercialization and customization of innovations introduced in the water, energy, and food space.

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The Design and Performance Evaluation of a Wireless Sensor Network Based Irrigation System on Different Soil Types

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Abstract— In the Nigerian economy, agriculture plays a significant role, and most of its people depend on it for their livelihood. Agricultural practices in the country are still mainly based on conventional, traditional methods of farming which usually result in wastage of water resources and low production of crops to meet the country's demand. There is a need to transform farming from the traditional way to a more efficient method with optimum water utilization. Irrigation is an assistive measure to salvage the problem of inadequate water for dry season farming. Irrigation requires a lot of water and time, and it must be completed on time. Overwatering and soil underwatering are two issues that the controlled irrigation system helps to solve. This research proposed an Arduino-based smart irrigation system using a wireless sensor network to overcome the problem of overwatering, underwatering, and efficient time utilization in farming. The system is implemented using Arduino IDE, Proteus Simulation Tools, and Blynk Platform. The effect of the four-mobile network: MTN, GLO, Airtel and 9mobile on response time for Gidan- Kwano area was evaluated. Testing carried out on the system resulted in a response time of 0.75 seconds for the Glo 2G network and 0.45 seconds for the Glo 4G network. Less than 1sec in the worst-case scenario. Also, 0.72 and 6.073 seconds respectively was achieved for loamy soil average response time and average saturation time. Average response time of 0.85 seconds and 4.906 seconds for saturation time, while 0.77second and 6.366 seconds as average response time and saturation time for clay soil. This makes the system effective in terms of time response, thereby eradicating the time wasted by manual system operation to irrigation scheduling. Also, the appropriate soil moisture content is maintained, whether it rains or not. This reduces excesses and ensures healthy plant growth, increasing agricultural productivity, and cultivating crops are made possible throughout the year. The system will also help drive agricultural innovation through the use of IoT.

Keywords— IoT, ZigBee, WSN, Wi-Fi Module, Arduino, Irrigation System

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1 Introduction

Agriculture has a significant economic impact on Nigeria. Agriculture, along with crude oil, is the backbone of the Nigerian economy. The bulk of the freshwater resources available is used for agricultural purposes [1]. Nigeria's population is expected to exceed 300 million by 2050, and the currently available food is not adequate for the increasing population. As a means of subsistence, most of the population relies on agriculture. To date, the majority of farmers do use conventional farming techniques. This may be the reason behind the decline in the production of crops and the country's food shortage. Nonetheless, few farmers have used an irrigation system that operates manually with high water waste.

For as long as humans have grown seeds, irrigation has been around. Irrigation procedures rely mainly on the availability of water [2]. Irrigation is essential in semi-arid and arid areas for food, pasture, and fiber production [3]. To increase food security while saving water, irrigation methods around the world are evolving. Developed and developing countries are moving from pure supply to a system centered on a demand-based model [4]. In a nation like Nigeria, where water supplies are manually regulated and managed, and water is unevenly distributed in time and space, demand-based practices are not feasible. Due to limited sweet water supplies, an efficient and cost-effective way of irrigation has emerged as the need of the hour, especially in countries severely affected by a lack of sweat water reservoirs. Most water is lost due to insufficient plant irrigation [5]. The efficient use of water in agriculture is one of the most important agricultural challenges that modern technologies are helping to address [6]. Agriculture is one of the most water-intensive businesses on the planet. Due to a lack of updated technology, more than 80% of water resources are squandered in this business. The efficient use and management of water are one of many countries' major challenges today. Irrigating 25% of the world's crops, which provide 45 percent of the world's food, is predicted to require around 70% of the world's freshwater. Industrial and domestic water usage accounts for roughly 20% and 10% of total water consumption, respectively [3,7]. As a result, by conserving water and managing plant development conditions at the same time, a low level of water consumption can be attained.

Freshwater demand is rising, and this trend is expected to continue as the world's population grows, resulting in higher food and fiber demands, as well as a predicted negative influence on climate change. The need to have enough water to support other ecological functions is becoming more well recognized [3]. To practice smart farming, it is vital to combine new technologies with agriculture [8].

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A Wireless Sensor Network (WSN) is a wirelessly connected collection of spatially dispersed sensor nodes (motes) [9]. WSNs consist of several small sensor nodes networked by a low-power wireless communication scheme and are adopted for data extraction and transmission [10,11]. WSN is adopted for a wide range of applications, ranging from continuous patient monitoring in healthcare to environment-connected vehicles in transportation and even smart irrigation in agriculture [12,13]. Due to water scarcity and drought being faced in the agricultural sector, WSN is being adopted in smart irrigation to foster the efficient utilization of resources, resulting in minimization of human labor, improved yields, and profits [14,15,16].

As a result of this study, an Arduino-based smart irrigation system with a wireless sensor network was built to address the issues of overwatering, underwatering, and efficient time utilization in agriculture. This improves the system's response time by eliminating the time spent preparing irrigation for manual system service, such as present irrigation systems that need farmers to irrigate crops in the field manually. System automation enables remote agricultural monitoring and effective resource utilization, saving time and energy for farmers [17]. The suitable soil moisture content is also preserved with the assistance of weather prediction, whether it rains or not. This reduces surpluses and ensures healthy plant growth, increases agricultural productivity and makes it possible to grow crops throughout the year. The system would also help fuel and push agricultural innovation by using the internet of things (IoT) system.

2 Related Work

Agriculture must discover strategies to make efficient use of this finite resource as the demand for water continues to grow [18]. Water is commonly considered to be the most critical resource for long-term agricultural development. Irrigated lands will develop in the next years, while agricultural freshwater supplies will be redirected to satisfy rising residential and industrial demands. Furthermore, irrigation efficiency is low, as the crops only use about 65 percent of the water applied. In dry places, irrigation water sustainability is a top problem for agriculture.[19]. Several prototypes have been developed to address these problems, some of which are presented, and analyses in this section range from the application of IoT, WSN, and weather prediction models.

Their research employed an automated watering system with a wireless sensor network and a General Packet Radio Service (GPRS) module [20], which included a unit with a dispersed wireless network of soil moisture and temperature sensors in the plant's root zone.

On the other hand, a gateway device was in charge of sensor data, actuators, and data communication with a web application. To measure the amount of water, an algorithm

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was developed with temperature and soil moisture threshold values that were encoded into a microcontroller-based gateway. Photovoltaic panels were used to power the device. Their work was distinct in that it was wireless and trackable. Similarly, [21], Developed a smartphone app that expanded the use of a team of Colorado State University Researchers' Water Irrigation Scheduling for Efficient Application (WISE) scheduling tool. Users could easily monitor and operate their irrigation projects using the smartphone application. This software can track soil moisture deficits and weather data and input and compute the amount of irrigation needed. However, the app is limited by its underutilization of WISE's full capabilities, which allowed users to create field boundaries using a web browser and a base map layer. Furthermore, the software was exclusively available for iOS users. In addition, the YL-69 sensor technology was used as a data input in [22] to monitor the land's humidity. An ESP8266 module, which served as a Wi-Fi network server, was used to process the data. The humidity data was sent to a web server over a Wi-Fi network, where it could be accessed using a web browser. The ESP8266 module served as a microcontroller and also a transmitter through the Wi-Fi network. It used wired sensors, which could cause wire crowding in the farmland. Real-time control could be added to the system to be more dynamic and efficient. The sensors could also be made wireless using wireless sensor networks.

The authors in [23] designed an architectural structure and performance evaluation of a sprinkler irrigation robot using two assemblies of ZigBee technology to enhance prototyping efficiency. ZigBee technology covered a larger communication area. The robust design could not carry more than 5litres; this may not be recommendable for a large farm. Adding an automation system would further enhance system performance. Weather forecasting was added to the authors' automated irrigation system for more efficient use of water resources (AISWP) in [24], which was an improvement over the previous system' automated irrigation system with partitioning system for efficient irrigation of small farms' (AISPF). The proposed model was able to address the AISPF Process issues using a weather forecast, and the water supply efficiency was increased by 20%. It isn't as efficient. The device may become more functional after the Wireless Sensor Network is established. Using a wireless sensor network and GPRS module, the automated irrigation system in [4] used soil water balance concepts to plan irrigation levels and duration. To receive ETo data, these controllers employed a wired (phone) or wireless (cellular or paging) interface. The challenge with this research is that the data provided might not be accurate. Their concept might be expanded by including XBEE / Bluetooth technology, which would allow data on the state of the water pump to be transferred to a smartphone or XBEE transceiver unit when the pump is turned on or off. The authors of the study [25] looked at the necessity for perfect uniformity in plant watering, which led to the development of an automated irrigation system. The

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irrigation system operated in a way that if one part had its requirement met and other parts were over watered or under watered, technologies that existed should indeed give the water level and detect the water required by the plant in a specific area. The proposed system provided many benefits, like operation with less workforce, due to the transfer of water directly to the root zone of plants. It had two nodes and a central node that coordinated the information provided by the sensors in each node. The resulting analysis showed that it was insufficient, and there was a need for the system to be more robust.

The authors in [22] used a moisture sensor to determine the level of the water content of the soil and turned on the pumping motor when detecting a level of moisture content of the soil. Their project had a simple design and not too much complexity, but also, cannot make an efficient prediction. Compared to an automated system, it was less efficient. In this type of project, more environmental conditions could be accessed for proper investigation and precise irrigation, such as using a rain sensor to determine when rain is falling. The researchers designed a metering network using GPRS and backend server services to report flow discharges (water discharged) in real-time. An analytical roster was created by comparing the acquired water distribution data. It had the advantage of having a large number of smart eater meters with high sampling and transmission frequencies deployed on a huge scale. More features, such as the use of weather prediction to predict rainfall could be added to the system to make it more robust and efficient, assisting in regulating the system's operation. In [27], the authors introduced a model-based method for determining seasonal irrigation regimes that are sub-optimal. According to their findings, Re-computing the sub-optimal solution minimized the detrimental impact of faulty weather forecasts. Wireless sensor network technology could be used to improve its efficiency.

The fundamentals of several irrigation schemes utilized by Indian farmers to nurture their crops were presented in detail in [20]. A multitude of irrigation technologies are utilized around the world to protect the plant's thrust, including surface, sub-surface, sprinkler, drip, and sophisticated smart irrigation. The typical procedure had not been effective enough, creating eater logging and salinity problems. Deficient utilization of weather is vital for productivity sustainability. This article presented a substantial disparity between irrigation systems. The researchers employed MQTT and HTTP in their work in [28] to keep the user up to date on the present agricultural situation from a faraway place. They used a neural network to supply the device with the essential intelligence. Its intelligence, low cost, and portability gave it an advantage. [29] To achieve a smart energy system, they applied approaches in their system. They created a software framework to improve the system's intelligence. This technology had an advantage in that it used renewable energy sources. A wireless sensor network could help

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them optimize their system even more. [30] They deployed a wireless sensor network in their suggested concept to optimize crop watering. Hardware, a web application, and a mobile app were all utilized. The component employed data mining to estimate optimal temperature, humidity, and soil moisture for future crop development control. Weather forecasting technology could help the system improve even more.

3 Materials and Methods

A built-in system for autonomous irrigation monitoring and control is included in this study. A wireless sensor network is used in this project to monitor, detect, and regulate an irrigation system in real-time. When the sensor goes below the process's limit at the root level of the crop, this technique maintains consistent water use on agricultural land and prevents water waste. The system then turns on the pump's motor. When a standard level is reached for a particular soil, it automatically turns off. The sensor data was acquired by a ZigBee system and sent to another ZigBee setup. Using the Arduino-interfaced open-weather.org API, the irrigation system also serves as a weather prediction for the area, allowing the system to be more conservative with the usage of available water. Irrigation is crucial in producing delicate plants such as tomatoes, peppers, and various vegetables. Because these plants are shallow-rooted, they require frequent irrigation, particularly when frost is a threat. About 100-110cm of irrigation is needed for a thriving plantation. Irrigation of Nigeria's plain fields must be done every four days during the dry season and every 10-15 days during the rainy season.

Table 1. Percentage of Dry-Weight of Soil [31]

Soil	**Field capacity (%)**	**Permanent wilting point (%)**	**Available Moisture (%)**	**Dry Density (kg/m3)**
Sand	5	2	3	1500
Sandy Loamy	12	5	7	1400
Loamy	18	10	8	1350
Silt Loamy	24	15	9	1300
Clay Loamy	30	19	11	1300
Clay	40	24	16	1200

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3.1 Irrigation Planning

Irrigation planning calculates the amount of water to apply and the interval at which it should be used based on the soil's Available Water Holding Capacity (AWHC) and the crop's evapotranspiration (ET) need. The depth of water applied was calculated using Equation 1[31].

$$d = AWHC \times pw \times dr \quad (1)$$

Where d is the applied water depth in centimeters, AWHC is the soil's available water holding capacity in centimeters, pw is the percentage of wetted soil, and dr is the root zone depth in centimeters (cm). Soil conditions, discharge, and emitter spacing all influence the percentage of soil wetted. The wetting diameters of two neighboring emitters must not overlap by more than 60%. The empirical equation for WD was utilized in Equations 2, 3, and 4 [31].

$$WD = 3.936 + 74.456_{qe} \text{ for fine soil} \quad (2)$$

$$WD = 2.296 + 81.90_{qe} \text{ for Medium soil} \quad (3)$$

$$WD = 0.984 + 89.34_{qe} \text{ for coarse soil} \quad (4)$$

Here in equations 1-4, *qe* is the discharge of an emitter, while WD is the wetting diameter

3.2 Field Capacity

The maximum moisture that the soil can hold after gravity water has been drained is known as field capacity. The field capacity of the soil refers to the amount of water that remains in the soil. Large, non-capillary pores are filled with air, whereas small, capillary pores are filled with water at field capacity moisture content, which is the amount of water available to the plant's root zone. Equation 5 gives the Field Capacity (FC), while equation 6 gives the Available Moisture (Aw) [31].

$$FC = \left(W_s * 100\right) W_w \quad (5)$$

$$Aw = \frac{W_s}{W_w}\left(FC - \text{permanent wilting}\right) \quad (6)$$

Where W_s is the weight of the soil while containing moisture and W_w is the dry weight of the soil.

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3.3 Mathematical Approach

Some calculations will be required by a control system that will perform irrigation depending on the factors used to adjust the soil moisture content in the present and future states. In this computation, some parameters are employed, such as the Minimal volume of water moisture maintenance and the Mean soil moisture decay rate [32]. Various parameters must be considered before the magnitude of the above variables can be determined. These equations are meant to cover all irrigation areas.

$$d = a_1x_1 + a_2x_2 + a_3x_3 \cdots a_nx_n \quad (7)$$

$$d = \sum a_1x_1 \quad (8)$$

Where X_1 = predicted parameter affecting d, and a_1 = Coefficient attributed to each parameter.

Imprecision in parameters such as humidity, pressure, temperature, and so on is considered for various climatic scenarios. Affect the amount of water that the soil loses, i.e., its moisture content. Irrigation is carried out to compensate for losses. Equation 9 gives the total volume of water lost in 24 hours Wd:

$$W_m = p\left(\omega_{op} - < \omega > Ah \times 24\right) \quad (9)$$

Where Wm denotes the minimum volume of moisture maintenance; h denotes the effective depth (where water is available to the roots); and = Soil Moisture Average for the Previous 24 Hours.

3.4 Integration of WSN

Climate variables such as temperature, humidity, and other factors influence plant water requirements. Various sensors in a WSN will detect these parameters. Any irrigation management system that is designed must start with such components. Using Zigbee technology, the XBee s2c module networks the sensor parameter for the required action.

3.5 Data Collection Level (Router)

Different sensors can be used to acquire environmental data. The gateway sends the data received by the sensor nodes to the controller, which helps the controller decide on an irrigation operation. If the measured temperature or humidity falls below predefined criteria, it initiates the irrigation system. The Zigbee 802.15.4 interaction mechanism is employed in this case. It is the most appropriate communication protocol for

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this type of application. It allows for the transmission of small amounts of data (environmental data) over vast distances with minimal power usage. A smartphone, PC, or tablet can be used by the irrigation system user or management to operate the irrigation operation.

3.6 Control Level (Coordinator)

At this point, the microcontroller compares the sensed data to pre-defined threshold values. Assume the microcontroller determines that the measured values are less than a certain threshold. The auto irrigation system will be activated in that situation. Otherwise, the system will be turned off until the opposite outcome is achieved.

3.7 Gateway Level

The esp8266 and an Arduino Mega for control are found on the gateway level, which delivers sensor data to the internet and waits for a control signal from the internet via a mobile app. The central Arduino Mega esp8266 is used to accomplish this.

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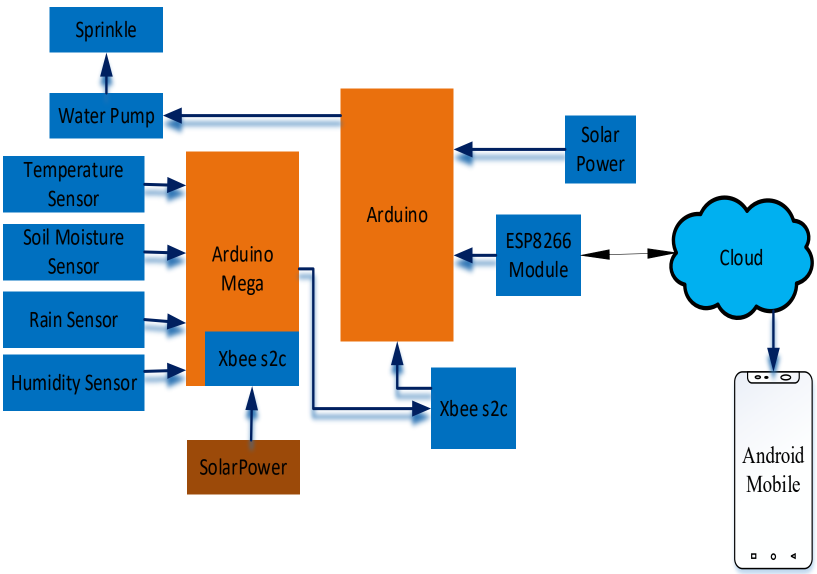

Fig. 1. Block Diagram of Arduino Based Smart Irrigation System

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The system connection is depicted in Figure 1 by a block diagram in which the router module is wirelessly connected to the coordinator node using the ZigBee connection protocol. The entire sensor is connected to one component of the system and wirelessly transmits data to the other portion for decision-making. The purpose of using WSN is to eradicate the problem of wire crowding in the farmland, especially on a large farm. The flowchart in Figure 2 depicts the actions that take place in the router module. The microcontroller takes sensors data. The gathered data is compared to the threshold that is predefined in the router microcontroller. If the threshold is meant, the data is sent to the coordinator via the XBee device. Figure 3 shows the operation of the coordinator module; the data sent by the XBee attached to the router module is collected by the XBee s2c attached to the coordinator module. The system checked for a reached packet on the XBee serial, extracted the data and compared it to the predefined threshold in the coordinator module using the gathered weather data to operate the system.

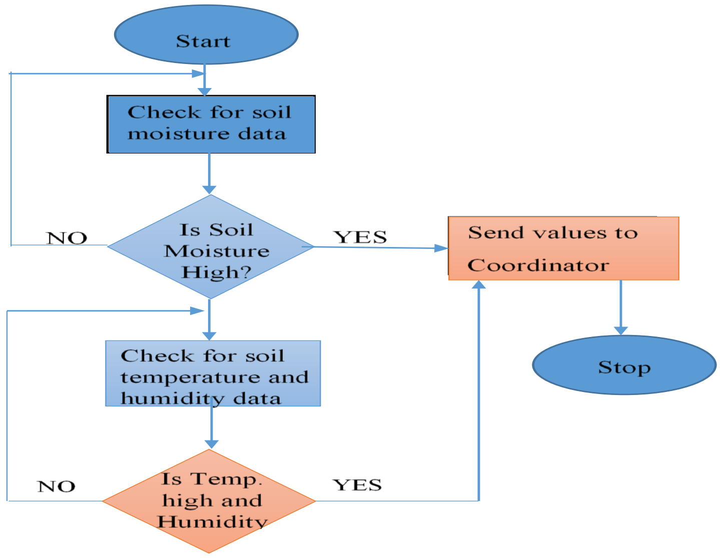

Fig. 2. Operation of the Router Module

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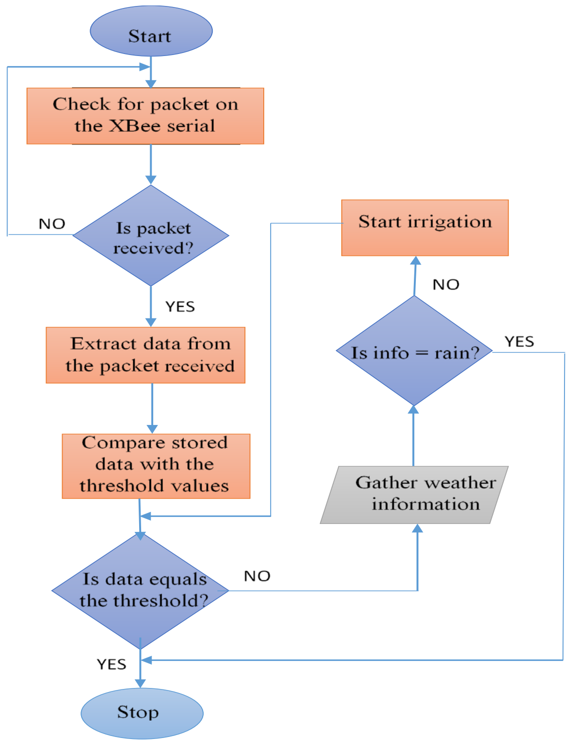

Fig. 3. Operation of the Coordinator Module

3.8 Design and Overview of the System

The system connection is depicted in Figure 1 by a block diagram in which the router module is wirelessly connected to the coordinator node using the ZigBee connection protocol. The entire sensor is connected to one component of the system and wirelessly transmits data to the other portion for decision-making. The purpose of using WSN is to eradicate the problem of wire crowding in the farmland, especially on a large farm. The system overview in Figure 4 shows the physical representation of the system integrated into farmland. The system is networked to form a smart farm where the user can monitor and control the activities going on the farm through the use of the internet. Remote monitoring and management software can also be used to manually turn on and off the water supply. Figure 5 shows the flow of operation that happens within the system. The user has control over the operation of the system. And the system administrator has access to the code controlling the system and inputting the necessary updates.

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Figure 6 shows the model of the entire system; the model describes the activities involved in each of the three segments of the system. Segment 1 represents the coordinator module which serves as the main brain of the entire system. Segment 2 represents the end node module, where the sensor data is read and transferred to the coordinator module for the necessary action. Segment 3 represents an android mobile platform, where the user can easily monitor and control the event on the field.

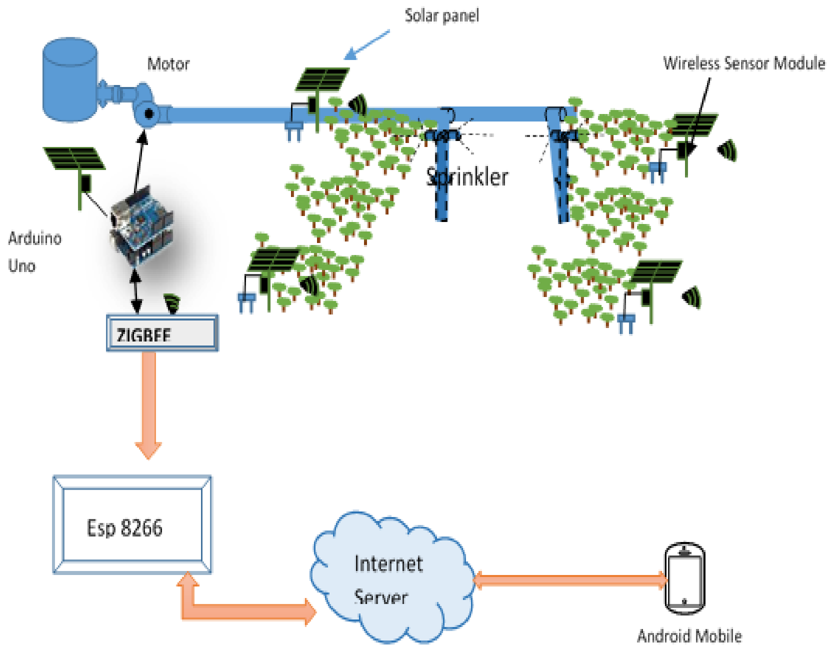

Fig. 4. System Overview

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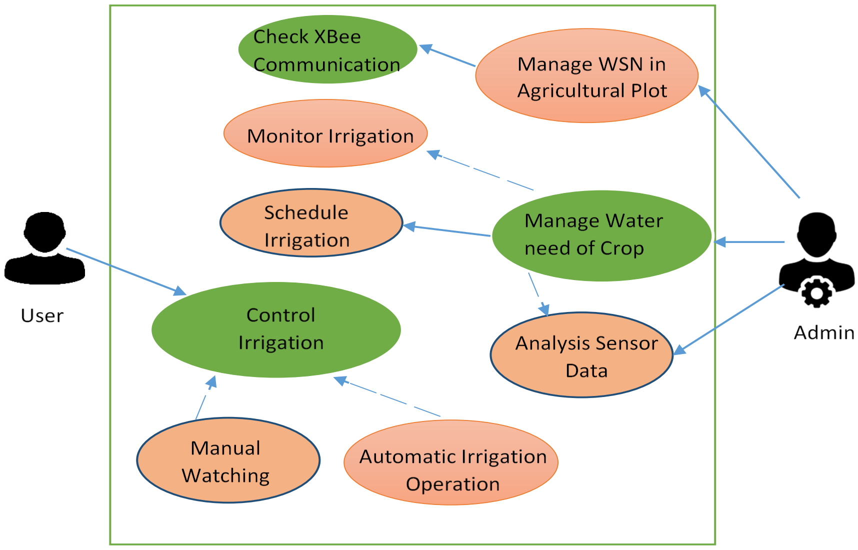

Fig. 5. Use Case Diagram to Show the Operational Process of the System

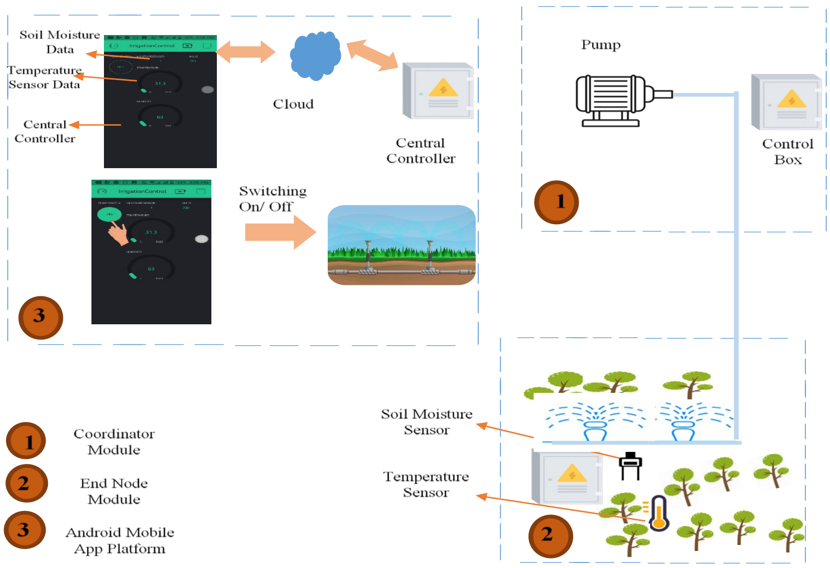

Fig. 6. The Model for the System Setup

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3.8 Performance Evaluation Metrics

The performance of the system was evaluated based on its Response time and Saturation time of the soil. The response time is used to determine the length of time taken by the system to react to events, commands, and subjection to a change in the input signal. It is necessary to know the amount of water at the right time to increase irrigation efficiency. The saturation time of each type of soil used in the test was determined to see how effective the system is to different soil types [31].

$$T_{response} = T_{think} \tag{10}$$

T_{think} is the thinking time of the system (in seconds).

$$\text{Average Response Time} = \frac{\sum \text{Response Time}}{\text{Total Number of Trials}} \tag{11}$$

Saturation time = Time taken for soil moisture to be at 60% in sec

$$\text{Average saturation Time} = \frac{\sum \text{Saturation Time}}{\text{Total Number of Trials}} \tag{12}$$

4 Result and Discussion

As stated in the methodology, the sensor data collected at the location is communicated via a router module to a coordinator module via a wireless sensor network protocol. The coordinator module will compare this information to a specified value stored in the microcontroller. The esp8266 node MCU is used to make the prediction, and the information obtained is shown in Figure 7. The Android app also shows a live readout of the moisture sensor for remote monitoring and control.

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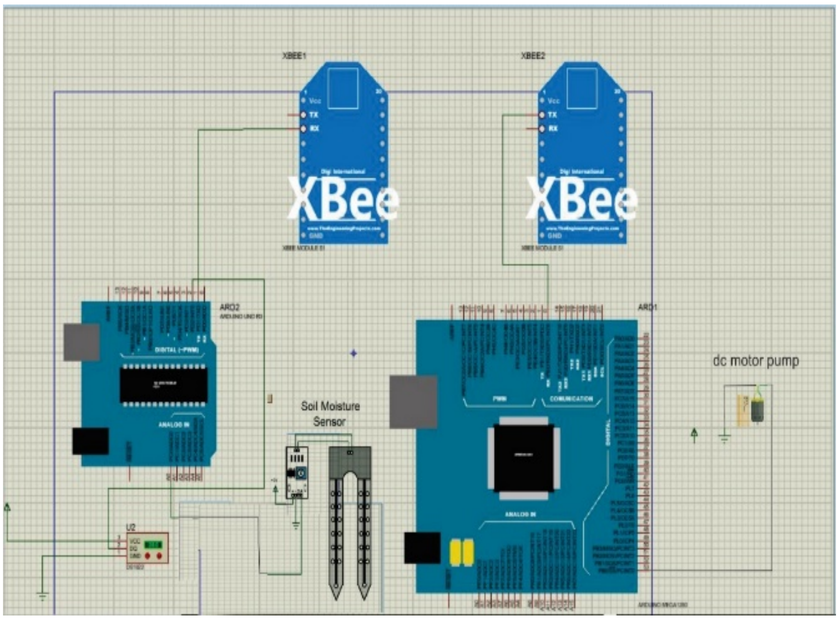

Fig. 7. Simulated Work on Proteus

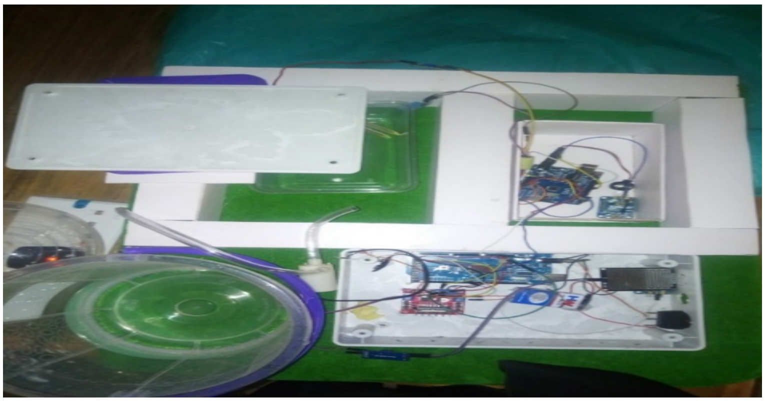

Fig. 8. Working Prototype

Figure 8 depicts a working system prototype. It is also possible to manually turn on and off the water supply using Android software, which can be accessed from anywhere on the planet. Sensor data will be collected and delivered to a microcontroller for processing, as well as to a Wi-Fi module, which will send the data to a web server and allow the user to interact with the data by sending a control signal back to the Wi-Fi module, which will then send the data to the microcontroller. The simulated work on Proteus is shown in Figure 7. Proteus is used to simulate the irrigation system to confirm

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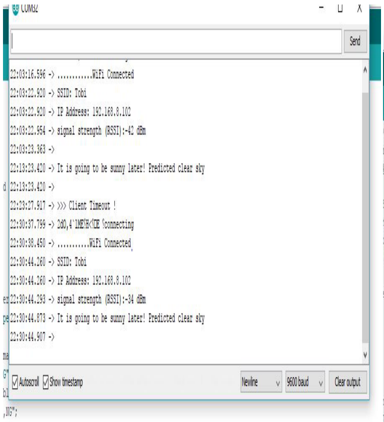
that it is operating properly. Also, to make the process of connecting the entire system and verifying communication and synchronization between the two modules easier. The benefit of simulating the system before fully implementing it is that you may get a sense of how it will act in real life and ensure that the system will work well for full integration of the subsystems and components.



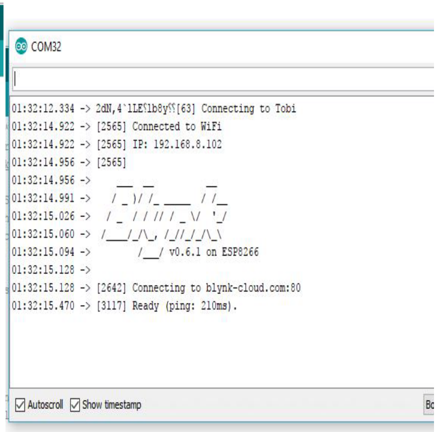


Figure 9 depicts the system's weather information-sourcing at a certain point in time for the system's location, in this case, Minna, Nigeria. The system will behave following the weather information obtained from openweather.org. In the case of the depiction in Figure 9, irrigation will be allowed because there is no likelihood of rain on this specific day. "It's going to rain later!" says the warning. Unless the weather forecast changes, the system will not irrigate on that particular day. This is not ideal for predicting the weather; instead, a locally-based weather station is recommended, but it is fairly costly to set up, whereas the source for broad weather data is the cheapest. The cloud connectivity of the system is depicted in Figure 10. According to the message displayed on the Arduino serial monitor, the esp8266 is connected to the android app powered by blynk. The module is connected to the application and ready to accept data when the system prints (ping: "number in ms"). If the serial monitor does not print anything, restart the system by hard-pressing the RST pin on the esp8266 node MCU. The bylnk is a platform that simplifies the process of connecting a system to the internet and gives it an IoT feel. As a result, the app may now be used to monitor sensor readings.

The application interface is used to display the soil moisture content at a given moment. The temperature and humidity of the soil at a certain point in time are depicted in Figure 11. The ON/OFF switch widget is used to control the system from afar. The

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farmer will be able to review soil data and, if necessary, alter the system without having to go to the field. The advantage of such an interface is its simplicity, or how easy it is to use, especially for non-experts. The Android application was built for anyone who works in the agricultural industry. The interface is also necessary to connect the sensor to the internet, allowing the farmer or user to examine field data without being physically present. There are various ways to make the user interface easier for the user; another benefit of this development is that the user's interaction with the interface is fluid and straightforward due to the way it is created. The advantage of this innovation over the previous system is that it simplifies complicated ideas for non-specialists, such as a regular farmer, to comprehend through easy user interface interaction, allowing the farmer to administer the system without any complexity. The temperature panel receives the live reading from the same DHT 11 sensors implanted at the plant's root region to monitor the root area's temperature at any given time, while the humidity panel receives the humidity reading from the system's DHT 11 sensors.The soil moisture panel monitors the soil moisture level at a given time, the Millis panel displays the system connection time, and the on/off panel remotely operates the irrigation system. This method has several advantages over the previous strategy, including reduced labor input, efficient water resource management, comprehensive control of farm activities, and effective and efficient administration of the irrigation procedure on the farm.

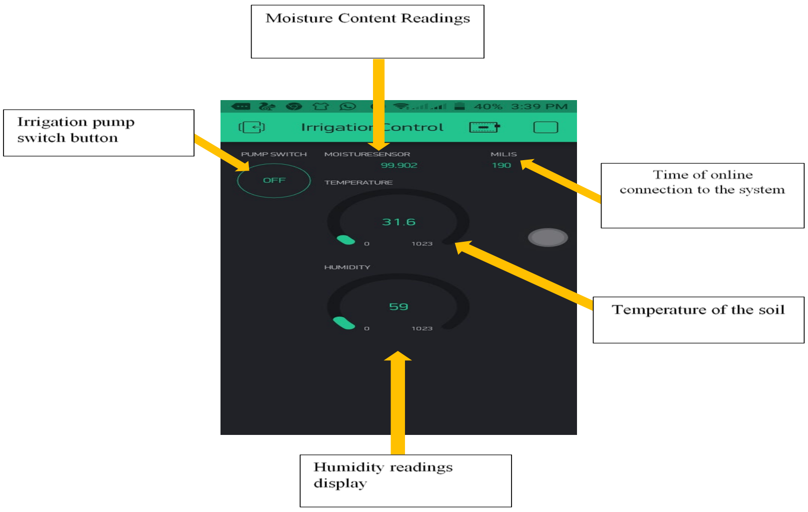

Fig. 11. Label Diagram of the Android App Interface

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Fig. 12. Android Interface Readings Taken at Different Interface

The Android app User interface is depicted in Figure 12 at various readings taken at various intervals. This is to show how the app uses the internet to communicate with the system. The app widgets update themselves to reflect the real-time sensor data as the system's sensor reading parameters change. Every second, this page is refreshed. As seen in Figure 12, the displayed value is updated every zone second, as previously indicated. The user can also manually turn on/off the system using this panel if necessary. This function has been implemented to provide the user with a sense of control over what is happening at the farm. Assume that the farmer or users desire to irrigate land using a unique irrigation method and timetable. In that situation, the manual on/off switch will, of course, come in handy. Figure 13 depicts the system's response time or the amount of time it takes for the system to respond when it is operated over the internet over the Glo 4G network. It displays the number of tries with a 4G network response time equivalent. This facilitates the operation of the system and the integration of smartness, promoting the usage of IoT in agriculture. The system provides other benefits in addition to the ones already discussed. The system offers the impression that the farmer or farm user has complete control over the technology. The signal analyzes the sensor readings and sends them to the Blynk app via Wi-Fi for remote monitoring and control through the 4G network, which is fast and reliable for this type of operation.

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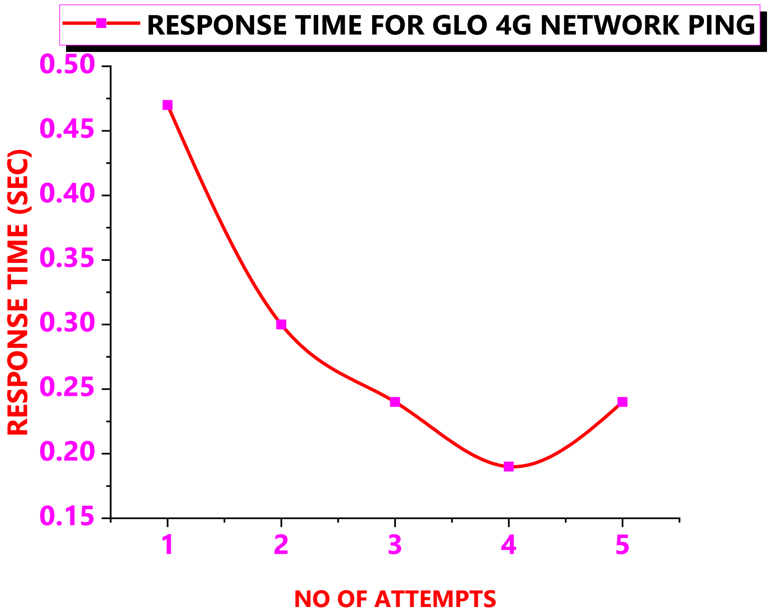

Fig. 13. The Response Time of the System using 4G Network

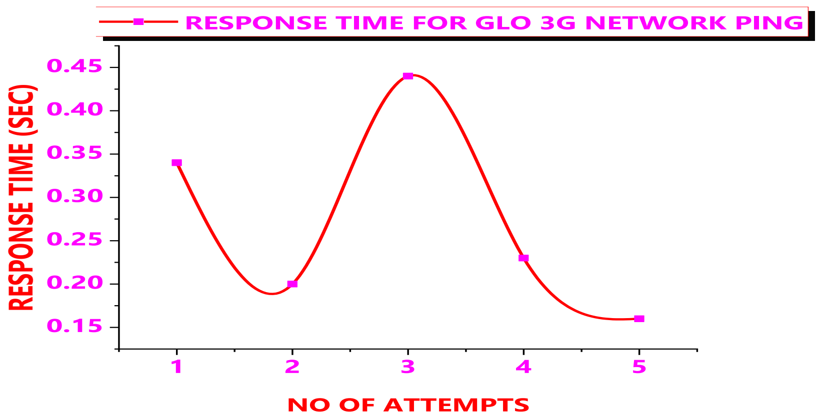

Fig. 14. Response Time of the System Using 3G Network

Figure 14 depicts the system's response time in five different attempts when using the 3G Glo service option. When studying and testing the system, the reaction time is critical. It determines the system's efficiency and effectiveness in responding to control

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and data flow changes. The 3G outcome is comparable to the 4G result. Both are, without a doubt, excellent services. These tests are performed to guarantee that the system is reliable under various service scenarios. Human error and a minor service lag are to blame for the variations in response time. The system is projected to produce the results of easy operation, reduced labor, minimal water waste, and efficient irrigation management based on the results of this test. Figure 15 depicts the application's response time when using a 2G network service. Five such attempts were performed, and the system's response time was measured accordingly. The quickest response time was 0.34 seconds, and the slowest was 0.75 seconds. This is the amount of time it takes the system to respond to each event that occurs in the application interface at any given time. When viewed through the eyes of a person, this may go unnoticed. Even though the reaction time on the 2G network is not up to 1 second, it is still fast when compared to the other network types employed. A response time of less than 1 second for all three network service types suggests that the system is efficient and effective. Figure 16 depicts the system's response time after five distinct trials using three different Glo network configurations. The reaction time on the 4G network was the fastest, while the response time on the 2G network was the slowest, implying that the 2G network has a longer delay. Despite this, the fastest response time is less than a second. As a result, the system is long-lasting in terms of speed. Irrigation becomes more precise, simple, and stress-free. This irrigation concept might be applied to large-scale farming in Nigeria, boosting the country's agricultural economy to the next level. The technology is expected to provide low-cost maintenance, ease of operation, reduced complexity, and efficient irrigation management in farming.

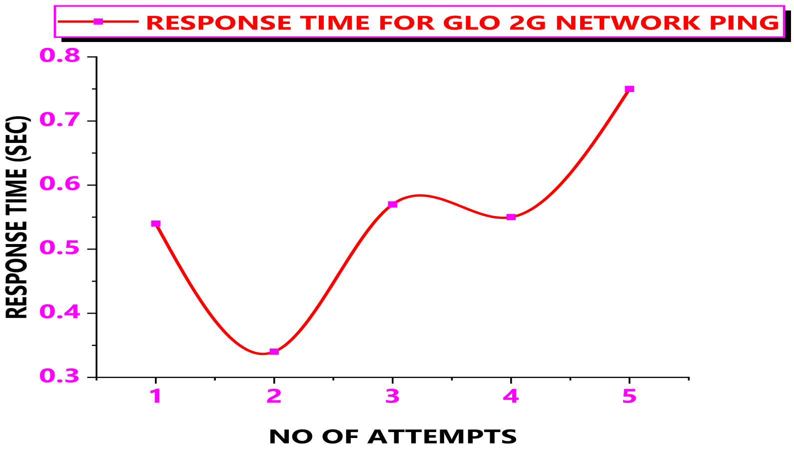

Fig. 15. The Response Time of the System using 2G Network

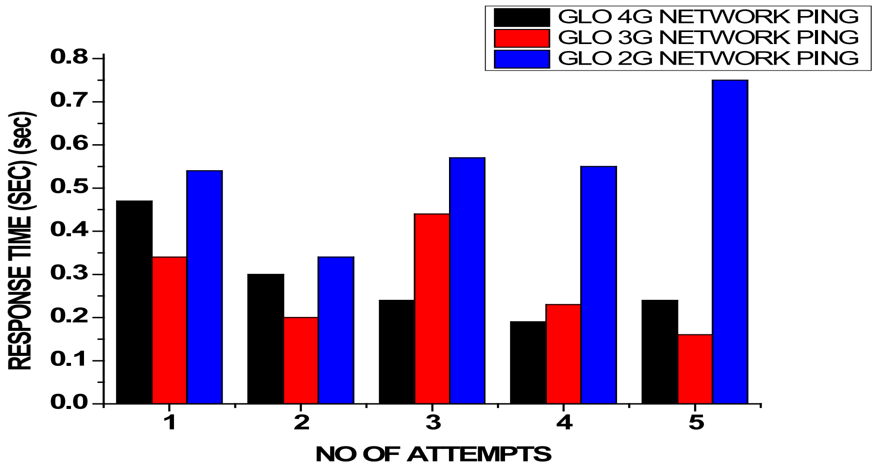

Fig. 16. The Response Time of the System using 2G, 3G and 4G Network

Different readings on the three soil types were taken in an inquiry to evaluate the system's performance. Figure 17 shows ten readings for sandy, ten for loamy, and ten for clayey soils, in that order. It should be noted that the clayey soil takes longer to reach saturation than the other soil types. It takes longer to saturate the soil due to its qualities, which allow it to absorb more water due to the proximity of the soil particle pack.It is also worth noting that, due to the absorbing rate of sandy soil, the sandy soil saturation period is short in comparison to others. A range of soil types, including sandy, loamy, and clayey, were used to evaluate the automated approach. The fastest average response time was 0.8 seconds, which was less than one second. As a result, the system is effective in terms of response time. According to the saturation calculation, sandy soil has a lower water retention capacity than loamy and clayey soil. The soil moisture content is maintained at 60% to obtain the water applied to the soil in cubic millimeters. The test is carried out using a manual irrigation approach, but the results reveal that the improved method is more efficient.

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Table 1. Soil Moisture content, water applied to Loamy soil, sandy soil, and clayey soil, Saturation time, and Response Time (sec)

S/N	Moisture Content %	Water Applied mm^3	Saturation time (sec)	Response Time (sec)
Sandy soil				
1	3	500	8.00	0.67
2	6	474	5.50	0.70
3	9	448	4.72	0.80
4	12	422	4.42	0.75
5	15	396	4.34	0.69
6	18	370	4.12	0.78
7	21	344	3.00	0.70
8	24	318	3.22	0.72
9	27	292	3.45	0.76
10	30	266	2.52	0.82
Loamy soil				
1	8	450	6.00	0.99
2	16	391	4.70	0.76
3	24	318	4.02	0.80
4	32	253	3.00	0.84
5	36	252	3.20	0.76
6	39	250	3.42	0.80
7	40	175	3.56	0.78
8	48	110	1.70	0.81
9	56	45	1.00	0.78
10	57	32	0.9	0.78
Clay soil				
1	16	383	7.6	0.74
2	32	253	6.5	0.82
3	36	250	6.3	0.72
4	39	248	6.1	0.78
5	42	178	6.0	0.79
6	45	102	5.5	0.77
7	48	110	5.0	0.75
8	51	100	4.8	0.76
9	54	80	4.7	0.75

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10	57	40	4.5	0.81

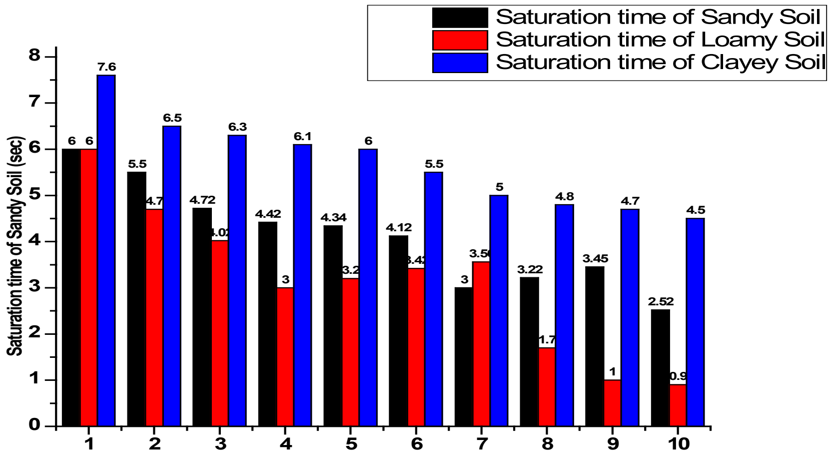

Fig. 17. Graph showing the comparison between various types of soil.

Average response time for loamy Soil = $\frac{0.67+0.70+0.80}{3}$ = 0.72sec; average saturation time for loamy soil = $\frac{8.00+5.50+4.72}{3}$ = 6.073sec; while average response time for sandy soil = $\frac{0.99+0.76+0.80}{3}$ = 0.85sec; average saturation time for sandy soil = $\frac{6.00+4.70+4.02}{3}$ = 4.906sec; and average response time for Clay soil = $\frac{0.74+0.82+0.75}{3}$ = 0.77sec; average saturation time for Clay soil = $\frac{7.6+6.5+5.0}{3}$ = 6.366 sec.

The many integrated units carry out their tasks following the set goals. Water is discharged to the soil according to the need at the time. Because the voltage recorded in a dry condition surpassed 3 volts, corresponding to a 3 percent soil moisture level, the soil is watered until the voltage detected in a moist state is 1 volt, corresponding to a soil moisture level of less than 60%. This is used to determine the amount of watering required. The graph displays the distinctions and comparisons between the various soil types. There is a certain sort of plantation that should or can be cultivated on each soil. Therefore, the soil for a particular plantation is chosen based on the specifications or requirements of the plant that would grow best on it. As illustrated in Figure 12, the value presented is refreshed every one second, as indicated previously. The user can also utilize this panel to manually turn on/off the system if necessary. This project's irrigation approach can be applied to large-scale farming, bringing Nigeria's agricultural sector to the next level. The technology is expected to provide low-cost maintenance, ease of operation, reduced complexity, and efficient irrigation management in farming.

5 Conclusion

One of the backbones of agricultural technology has been the automated irrigation system. Many techniques of providing water to fields were developed over time. IoTs have been used to increase agricultural yields, improve quality, and lower expenses in agriculture. This research proposed an Arduino-based smart irrigation system using a wireless sensor network to overcome the problem of overwatering, underwatering, and efficient time utilization in farming. This system is implemented and evaluated using Arduino IDE, Proteus Simulation Tools, and the Blynk Platform. The effect of the four-mobile network: MTN, GLO, Airtel, and 9mobile on response time for Gidan- Kwano area was evaluated. Testing carried out on the system resulted in a response time of 0.75 seconds for the Glo 2G network and 0.45 seconds for the Glo 4G network. Less than 1sec in the worst-case scenario. Compared with the already existing irrigation systems, this system design emerged to be simple to use by the farmer, smart, efficient in terms of portability, and affordable compared with other systems. Also, the appropriate soil moisture content is maintained, whether it rains or not. This reduces excesses and ensures healthy plant growth, increasing agricultural productivity, and cultivating crops are made possible throughout the year. The system will also help power and drive agricultural innovation through the use of IoT.

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