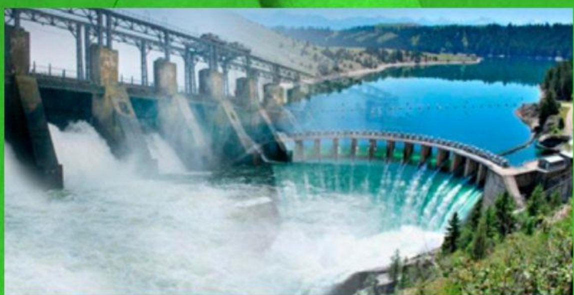
ISSN 2709-4529
Volume 4 ❂ Number 2,
December 2023

Journal of Digital Food, Energy & Water Systems [JD-FEWS]



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

Editorial Team

Table of Contents

Volume 4 Number 2 December 2023

ARTICLES

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

A Review of Environmental, Social and Governance Frameworks in Sustainable Disposal of Waste from Renewable Energy Resources

Elias Olasumbo OJETUNDE
Department of Accountancy University of Dundee, Scotland, Ojetunde Olasunbo & Co Chartered Accountants & Tax practitioners, Nigeria; eliasojetunde@gmail.com

Iheanacho Henry DENWIGWE
[3]Electrical Electronics and Computer Engineering University of Lagos, Nigeria; iheanachodenwigwe@gmail.com

Prince Anthony NWACHUKWU
[4]Department of Information Technology University of Denver, USA; pa_nwachukwu@outlook.com

John A. ADEBISI
Electrical and Computer Engineering, University of Namibia, Namibia; adebisi_tunji@yahoo.com

Received: 23 November 2023

Review: 10 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: The shift to renewable energy sources is essential for mitigating climate change, but it poses fresh challenges for environmentally responsible waste management. This article reviews and investigates the complex problems associated with the disposal of renewable energy components from an environmental, social, and governance (ESG) perspective. The article further highlights the need for thorough oversight and careful management of various components due to the environmental concerns associated with their disposal as they frequently contain hazardous elements. The social effects on communities impacted by disposal procedures are also explored, and the importance of fair distribution of benefits is emphasized. Transparency, accountability, and stakeholder involvement are bolstered by effective governance, which is a central theme of this discussion that draws on ESG concepts. Successful ESG-integrated disposal plans are demonstrated by industry case studies. Possible hindrances in sustainable disposal are also highlighted with firm suggestions on way-forward, which include technical innovation and global collaboration. The study underlines the irreplaceable role played by ESG in guiding responsible waste management toward a sustainable, green energy future.

***Keywords*:** *Renewable energy, Governance, Solar, Photovoltaics, Environmental Sustainability, Waste Management.*

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

1.0 Introduction

The state of the global energy scene is extremely important. The need to switch to ecologically friendly and sustainable energy sources is more important than ever as the threat of climate change grows[1]. Renewable energy technologies have become highly instrumental in the fight against climate change in this period of unparalleled environmental difficulties[2]. They provide a means of cutting greenhouse gas emissions and laying the groundwork for a sustainable future since they can be used to harness plentiful, clean energy sources like solar, wind, and hydropower. Renewable energy sources draw on the plentiful, replenishable resources found in nature, as opposed to conventional fossil fuels, which diminish finite resources and increase greenhouse gas emissions[3]. A fundamental change in how we think about the production and use of energy is brought about by renewable energy technology [4] [5]. Renewable energy technologies mark a fundamental change in how we think about producing and using energy. A wide range of renewable energy technologies exist, along with their various applications and the revolutionary effects they have on the world's energy landscapes[6], [7]. A more ecologically conscious and sustainable energy paradigm is being ushered in by a number of technologies, including geothermal power plants, hydroelectric dams, and photovoltaic solar panels. These technologies have the potential to transform the energy industry and spark a more resilient, sustainable, and prosperous future for the world through innovation and broad adoption[8][9]. In order to mitigate climate change, which is a crisis that jeopardizes the ecological balance of our planet and the welfare of present and future generations, renewable energy solutions are essential. When it comes to solving some of the most important global issues of our day, renewable energy solutions are extremely important[10]. Growing amounts of greenhouse gases are being released into the atmosphere of the Earth as a result of the burning of fossil fuels for transportation, industrial activities, and the production of electricity. This has caused the oceans to become more acidic and resulted in rising global temperatures. Negligence has an adverse effect on ecosystems, human livelihoods, and the availability of food [11].

Renewable energy sources provide a lifeline as a cleaner, more sustainable option to conventional energy derived from fossil fuels. Through the capture of energy from renewable sources like sunshine, wind, and flowing water, these technologies help to minimize carbon emissions, reduce air pollution, and lessen our reliance on finite fossil fuel supplies[12]. They offer a workable way to slow down global warming and modify the planet's climate trajectory[13]. Reducing dependence on imported fossil fuels and diversifying energy sources might help countries improve their energy security and ease geopolitical tensions around energy resources [14]. Investing in renewable energy technologies reduces costs and promotes innovation. This supports the development of increasingly cost-effective and efficient solutions and promotes healthy competition in the energy market [15]. The renewable energy industry has proven that it is capable of promoting economic expansion. Jobs are created as a result of investments in renewable energy projects in manufacturing, research and development, and facility construction and operation. Renewable energy sources are essentially limitless, in contrast to finite fossil fuel supplies. The sun, wind, water, and the heat from the earth all serve as a plentiful and never-ending source of energy. Renewable energy technologies can offer a scalable and economical option for areas lacking access to cheap and dependable power. Remote locations may be able to receive electricity thanks to off-grid systems, especially those run by solar and wind power[16]. In contrast to massive hydropower dams, the environmental impact of many renewable technologies is negligible. Installations of solar and wind power, for instance, require very little land and do not interfere with ecosystems or wildlife habitats. Small-scale wind turbines and rooftop solar panels are examples of distributed renewable energy technologies that can improve grid resilience by decentralizing electricity generation[17]. As a result, there is less susceptibility to interruptions brought on by severe weather or other situations. Numerous renewable technologies have rather minimal environmental effects, in contrast to massive hydroelectric projects. Examples of renewable energy sources that do

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

not disturb ecosystems or wildlife habitats are solar and wind farms, which have very low requirements for land use.[18]

The advantages of renewable energy technologies for the environment are however not without complexity. Although they greatly lower emissions while they are in operation, managing them after they reach the end of their useful life poses unique issues. To guarantee the sustainability of these technologies throughout their life cycles, the disposal of renewable energy components, such as solar panels, wind turbine blades, and energy storage devices, needs to be taken care of.

The necessity of addressing the environmental and social issues related to waste disposal from sources of renewable energy is the rationale behind this study, which focuses on incorporating ESG frameworks for all-encompassing and sustainable solutions. Some of the significant aspects of this study include.

- Integration of core principles of ESG: This research investigates how waste produced from renewable energy sources might be disposed of while considering ESG frameworks. For waste management procedures to be in line with more general sustainability objectives, integration is essential.
- Renewably Sourced Energy through Sustainable Waste Management: The waste that is produced in tandem with the global transition to renewable energy sources—such as solar panels and wind turbine blades—presents special difficulties. This study tackles the requirement for environmentally responsible waste management techniques that successfully reduce the negative effects of renewable energy technology on the environment.
- Assessment of Environmental Impact: This study explores how waste disposal practices related to renewable energy technology affect the environment. To limit harm and improve the long-term viability of renewable energy sources, measures for minimizing their effects on the environment must be developed.
- Implications to communities and the society: In ESG frameworks, the social and communal dimensions of sustainability are highlighted. This study evaluates the social effects of waste disposal techniques, taking community involvement, safety, and health into account. This more expansive viewpoint is essential for encouraging socially conscious behavior.
- Regulatory compliance and governance: The management of waste is significantly influenced by governance principles. The regulatory frameworks and governance structures controlling the disposal of waste from renewable energy sources may be examined in the study. Responsible waste management techniques require an understanding of these standards and adherence to them.
- Identifying best practices: The study pinpoints and assess best practices for ESG-compliant waste management utilizing renewable energy sources. These observations can be very helpful in guiding businesses, decision-makers, and practitioners toward the adoption of sustainable waste management practices.
- Corporate Ethics and Reputation: Compliance with ESG guidelines for waste disposal is not just mandated by law but also an essential aspect of corporate social responsibility for businesses operating in the renewable energy space. The outcomes of this study provide insights into how businesses can improve their ESG performance, which would benefit their stakeholder interactions and reputation.
- Policy Recommendations: The study could result in the creation of policy suggestions for governing bodies and oversight organizations. These suggestions can direct the creation of all-encompassing waste management regulations that support environmentally friendly practices in the renewable energy industry.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

Summarily, this study contributes valuably by expanding the scope of knowledge, offering useful perspectives, and directing players in the renewable energy industry toward more environmentally friendly and socially conscious methods of disposing of waste.

2.0 Environmental impact of end-of-life renewable energy technologies

The amount of waste produced by retired systems and components is increasing along with the rapid adoption of renewable energy technology. These materials pose particular environmental issues when disposed of, even though they are linked to decreased emissions during their operational phase. As an illustration, although solar panels are praised for producing clean energy, they also include rare earth metals and other potentially dangerous components that need to be disposed of properly. Similar difficulties may arise with recycling and environmentally friendly disposal of wind turbine blades, which are frequently made of composite materials. It is important to consider the effects incorrect disposal has on the ecosystem. Ineffective waste management can have a negative impact on nearby ecosystems, pollute the land and water, and disturb habitats. In addition, it raises moral questions about how equally the effects of the trash should be distributed, since vulnerable populations may suffer disproportionately from inappropriate waste disposal methods[19]– [23]. Thus, in order to minimize the ecological impact associated with the decommissioning of renewable energy technology, the section addresses the adoption of responsible disposal procedures, recycling programs, and adherence to regulatory criteria.

The idea of Environmental, Social, and Governance (ESG), arises as a guide to negotiate these environmental challenges and create a framework for responsible garbage disposal. As shown in Figure 1, ESG guidelines offer a comprehensive method for assessing the ethical and sustainable aspects of a company's operations, which includes waste management procedures[24], [25]. Beyond environmental factors, ESG also includes social factors and governance practices that affect an organization's operations and decision-making. ESG principles emphasize the significance of social consequences on communities, ecologically responsible waste management, and governance structures that give priority to long-term results in the context of renewable energy technology[26]. ESG provides a methodical way to evaluate and enhance waste management plans regarding elements of renewable energy. Figure 1 highlights the significance of responsibility, transparency, and stakeholder involvement, laying the foundation for an all-encompassing and responsible strategy for various renewable energy technologies' end-of-life phase [27].

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

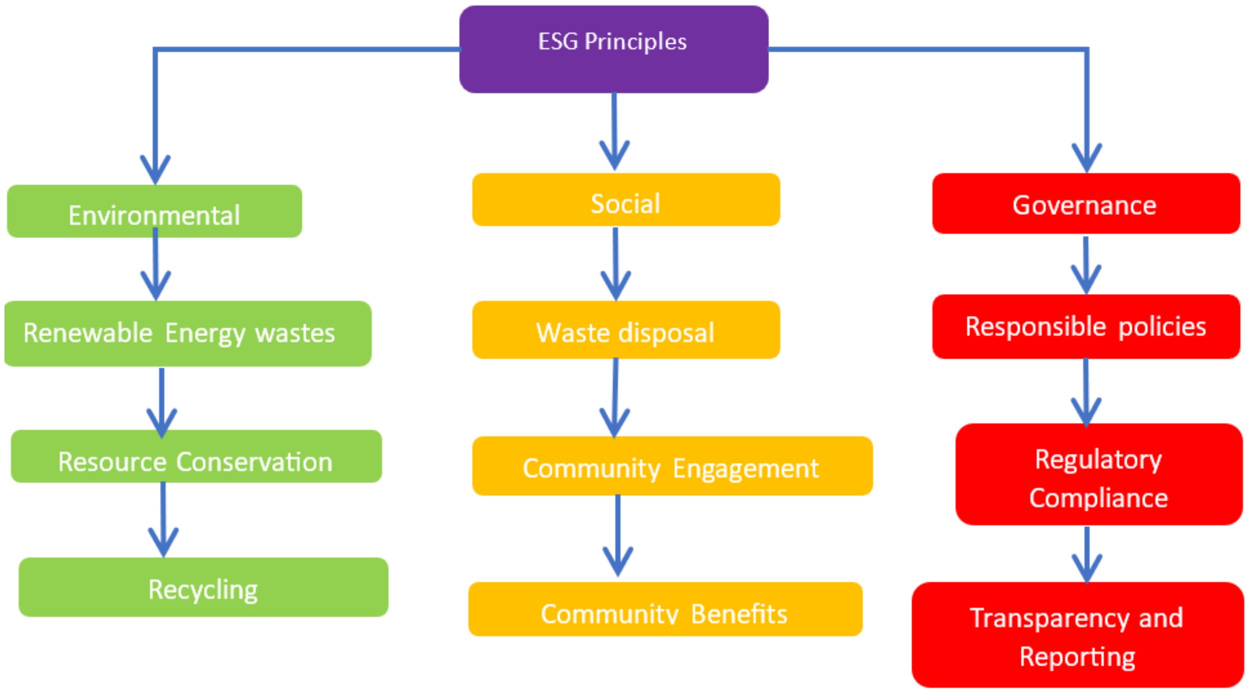


Figure 1. Relationship between ESG (Environmental, Social, and Governance) and renewable waste disposal

The nuances of ESG are explored in this study with respect to the environmentally responsible removal of components of renewable energy in the pages that follow. In addition to providing case studies and best practices, we examine the environmental, social, and governance aspects that influence responsible waste management. The essay explains how important ESG is to building a just and sustainable future for renewable energy technology, because the promise of a greener, cleaner world depends on how end-of-life waste is disposed of [28]–[30].

2.1 Environmental considerations in the disposal of renewable energy technologies

The use of renewable energy technologies is a promising development in the worldwide endeavor to combat climate change. Over the course of their useful lives, these technologies dramatically lower greenhouse gas emissions by utilizing energy from renewable resources like sunshine, wind, and water. The environmental issues surrounding the elimination of renewable energy technologies once their useful lives are done are, nevertheless, sometimes disregarded as the world adopts renewable energy at a faster rate. We will examine the environmental issues surrounding the elimination of these technologies in this discourse, stressing the significance of resource conservation, waste management, and responsible recycling [31]. Addressing climate change and securing an energy future that is sustainable depends on the expansion of the renewable energy sector. It is imperative to take into account the complete lifespan of these technologies, encompassing their disposal as well. In order to maintain renewable energy's sustainability from an environmental and financial standpoint, proactive approaches to waste disposal, recycling, and conserving resources are essential. An authentically green and sustainable energy transition depends on an ethical end-of-life management of renewable energy technology, which is also an environmental concern [32]. Various considerations are discussed as follows.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

A. Challenges in disposal

There is a limited lifespan for each component in all forms of renewable energy technology, including energy storage systems, wind turbines, and solar panels. Decommissioning or replacement of these parts are eventually required. To prevent adverse environmental impacts, proper management of this material's disposal is necessary. For instance, dangerous materials like cadmium and lead are included in solar panels, despite their reputation for producing clean energy. These substances pose hazards to human health and ecosystems if they are not handled properly and leak into the environment [33]. In a similar vein, recycling wind turbine blades—which are frequently made of composite materials—can be difficult. These products could wind up in landfills, adding to the volume of rubbish and possibly contaminating it. Systems for storing energy, which are essential for maintaining grid stability and integrating intermittent renewable energy sources, may include parts that pose a risk to the environment. This is potentially hazardous materials contained in the batteries.

B. Recycling as a Solution

Recycling offers a viable way to lessen the negative environmental effects of disposing of renewable energy equipment. It is now feasible to retrieve important components from these devices because to advancements in recycling procedures. Recycling solar panels, for example, can salvage valuable metals and lessen the need to extract raw materials, thereby reducing environmental impact and preserving resources. When it comes to wind turbine blades, scientists are looking for inventive ways to reuse these materials, from building with them to creating new materials with other uses. Even though these initiatives remain in their initial phases, they show a rising dedication to lowering waste and its negative effects on the environment [34].

C. Waste Management

Another essential element of ethical disposal is effective waste management. To avoid contaminating the environment, tight containment procedures, frequent monitoring, and the safe disposal of potentially hazardous material in landfills are crucial. The impact of trash from renewable energy sources is kept restricted and localized thanks to good waste management techniques[27].

D. Resource Conservation

Resource conservation is one of sustainability's core ideas. Effective recycling procedures and conscientious waste management techniques reduce environmental hazards while simultaneously preserving important resources. The renewable energy industry may lessen its impact on the environment and cut expenses related to obtaining raw materials by decreasing the requirement for raw material extraction. The circular economy's guiding principles are furthered by resource conservation throughout the disposal phase, which is consistent with larger sustainability aims[31].

Attaining an energy future that is sustainable and reducing climate change depend on the growth of the renewable energy sector. But it's crucial to take into account every stage of these technologies' lifecycle, including disposal. For renewable energy to continue to be economically and environmentally viable, proactive approaches to resource conservation, waste management, and recycling is essential. Additionally, an environmental issue, effective end-of-life handling of renewable energy technology is essential to a truly green and environmentally friendly energy shift[25].

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

2.2 Review of related works

Following the world's shift to renewable energy, issues regarding the environmental and social effects of disposing of waste from renewable energy technology have surfaced. To investigate how ESG concepts might be integrated into the sustainable disposal of waste from renewable energy resources, this literature review critically evaluates previous research and frameworks. This section therefore reviews existing studies on ESG frameworks to provide a better understanding on their impact on renewable energy wastes disposal. The swift growth of sustainable energy technologies, such as wind, solar, and hydropower, has drawn more attention to the end-of-life issues these technologies present. Studies by Yeom et al. [35] and Mozhiarasi [36] emphasize the possible repercussions on the environment and society of inappropriate waste disposal methods within the renewable energy industry. Applying ESG frameworks to corporate sustainability is a crucial topic for this study's discussion. Escrig-Olmedo et al. [37] maintains that robustness and long-term performance in business operations depend on the integration of ESG principles. The framework for comprehending how ESG can be modified to handle waste disposal issues unique to the renewable energy environment is thus established.

Comprehensive Environmental Impact Assessments (EIAs) are crucial for renewable energy projects, as demonstrated in studies, such as [38] and [39]. The ecological consequences of waste disposal practices are also addressed by the assessments, in addition to the evaluation of the environmental implications of energy production. The importance of social factors in disposal of waste is growing. Arena et al. [40] and Lee et al. [41] emphasize the necessity of evaluating the social ramifications of disposing of waste from renewable energy, including matters pertaining to stakeholder participation, safety, and community health. The significance of a socially conscious approach to waste management is emphasized by the two research articles. Important components of the sustainability equation are the legal frameworks and governance structures that control the disposal of garbage. Elele [42] and Oyedotun [43]explore the legislative gaps and governance issues that could prevent efficient waste management. Strong governance systems that are in line with ESG principles are essential, as these publications highlight. A major focus of the review of literature is the determination of optimal procedures for disposing waste. Innovative waste management techniques that support sustainability objectives are discussed by Sheoran [44] and Hoyer [45]. For companies looking to improve their disposal procedures, these studies provide useful standards. t's critical to comprehend how ESG principles are included into the whole renewable energy supply chain. The need for a comprehensive strategy that takes into account production, operating, and end-of-life concerns is emphasized in Whitelock [46]'s exploration of how ESG factors might be incorporated into the supply chain. An organization's reputation is impacted by its corporate responsibility for waste disposal. Wood [47] discusses the relationship between good business reputation and ethical waste management techniques are related in the renewable energy industry. These pieces demonstrate how brand image and ESG practices are related. Table 1 provides a review of relevant studies on ESG frameworks in the renewable energy sector.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

Table 1. Review of related works and its findings

Author	Year	Aim	Findings/Conclusion
Dhanya et al. [48]	2020	To achieve sustainable development of bioenergy through the efficient enforcement of zero waste discharge policies.	A sustainable bioenergy industry addresses the difficult issue of waste disposal of renewable energy resources in the face of climate change. It does this by improving fuel security, stepping up organic waste conversion techniques to bioenergy, particularly biogas and biohydrogen generation.
Amin et al. [49]	2023	To analyze the major sources of solid waste generation and potential waste management strategies, including thermal treatment (gasification, pyrolysis, and incineration) and biological landfills.	Individual country-specific solutions for municipal solid waste management are highly recommended for energy generation that have the least negative environmental impact possible.
Munir et al. [50]	2023	To increase understanding of the potential for food waste to produce hydrochar, a clean fuel that can replace traditional non-renewable energy sources in the steel industry.	Significant greenhouse gas emissions are produced during the energy-intensive process involved in steel production, which exacerbates climate change and environmental damage. The utilization of fuels obtained from food waste offers a viable substitute for conventional fossil fuels. In addition to solving the problem of trash disposal, turning food waste into useful energy resources lowers carbon emissions and the industry's dependency on finite energy sources, supporting the ideas of the circular economy and sustainable development.
S. Cho et al [51]	2023	To decrease the spread of microplastics by combating the widespread, unregulated usage and careless disposal of products made of plastic.	Waste from microplastics can be converted into electrical energy by utilizing the inherent triboelectric characteristic of microplastics.
Chagunda et al. [52]	2023	To assess the viability of waste-to-energy (WtE) initiatives that provide off-grid communities with access to electricity by measuring waste chain components and doing field research, in addition to producing primary data sets through quantitative study design.	The amount, classes, moisture content, calorific values, and technologies employed are among the variables that impact the energy recovery process from Municipal Solid Waste (MSW). These variables are critical in determining the sustainability of WtE projects in comparison to other waste treatment projects, as well as the choice of the appropriate waste treatment and technology for waste treatment. Also, the majority of waste classes are appropriate for WtE generation in terms of moisture content and calorific values.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

R. Bera et al. [53]	2023	Use the Safe and Sustainable 'Clean Food' (CF) model to demonstrate how renewable sources help the system resources regenerate and restore themselves to enhance the Circular Economy (CE) in Agriculture.	When the model was assessed in light of all the fundamentals of circular agriculture, it became clear that it had the potential to increase crop yield by up to 19.5% while lowering or doing away with non-renewable inputs like chemical pesticides and fertilizers, which reduced the likelihood of residues of pesticides in food (vegetables) by roughly 93%. Soil quality was increased by up to 27% through resource recycling through the bioconversion of MSW and landfill trash into safe compost. Most notably, the CF Model delivered the essence of CE in agriculture by improving everyone's access to safe and nutritious food while decoupling economic development from the linear patterns of finite and non-renewable extraction, use, and disposal of resources. This was demonstrated by the GHG elimination of 6.4 to 11.7 kg CO_2-eq / kg food production, 64% increase in productivity of energy, 16.7% increase in employment, and roughly 19.7% increase in gross income.
Burra et al. [54]	2023	To demonstrate the need for the synergistic integration of gypsum waste from the construction and demolition (C&D) industry as a sustainable disposal technique in order to efficiently recover resources and control energy	Enhanced syngas yield and homogeneity, as well as improved operating conditions from the gypsum interaction with MSW, were demonstrated in the results, this may aid in the advancement of gypsum waste incorporation.
Naviglio et al. [55]	2022	To show how wastes from oranges to produce value-added nutritional products in order to reduce the amount of waste to be disposed in the agro-industrial sector	The study shows how hydroalcoholic extraction of orange peels from industrial processing waste, yields an extract rich in essential oils that can be used in the food industry to make liqueurs and/or fragrances, as well as in the cosmetic and pharmaceutical industries.The residue obtained is an important commodity rich in dietary fiber with applications in the pharmaceutical and nutraceutical industries. Additionally, the same chemical has agricultural applications as fertilizer. Given this, waste from the processing of citrus fruits can be viewed as a renewable and sustainable energy source.
H.Hosseinzadeh-Bandbafha [56]		To demonstrate how the assessment of the environmental sustainability of Waste Cooking Oil (WCO) biodiesel production in comparison to diesel and first-generation biodiesel can be	Even though LCA's environmental assessment of biodiesel production is well-established, there are still a number of issues and limitations. In the similar studies, system limits are generally well-defined. Nevertheless, waste management has been

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

		conducted using a highly effective tool called life cycle assessment (LCA).	disregarded in several studies; for instance, the analysis typically excludes the disposal of soap and other solid residues. Furthermore, as this waste stream could be a raw material for various other applications, the "zero-burden assumption" used to WCO (as biodiesel feedstock) in the published literature might not be a fair assumption. For the existing and in-development technologies utilized in WCO biodiesel production, inadequate data at the inventory level, particularly information pertaining to the creation of innovative catalysts (including enzymes) and materials used for product purification, is also a problem. As a result, the goal of future research should be to reduce the uncertainties that have been raised during this effort. Moreover, by utilizing cutting-edge methods like hydrodynamic cavitation reactors, incorporating additional renewable energy sources, and utilizing green catalysts during the WCO biodiesel production and combustion stages, efforts should be made to evaluate the environmental effects of WCO biodiesel production systems.
Ranjetha et al. [57]	2022	To demonstrate the utilization of locally accessible industrial and agricultural waste and by-products, such as steel slag aggregate (SSA), manufactured sand (M-sand), palm oil clinker (POC), and fuel ash (POFA), for the creation and building of environmentally sustainable low-cost homes.	The adoption of green technologies and the incorporation of waste by-products into concrete were shown to have many benefits. Revisions to concrete mixes utilizing waste product substitutes would help reduce environmental issues, the negative consequences of incorrect waste disposal, the dependency on non-renewable materials, and encourage the use of sustainable construction.

2.3 Social Aspects of End-of-Life Waste Disposal for Renewable Energy Technologies

Future clean energy as well as environmental sustainability are promised by the development of renewable energy technology. However, as these technologies get closer to the end of their useful lives, important social issues of waste management and disposal come up. In addition to environmental issues, there are ramifications for laborers, communities, and larger social structures [58]. First are community impacts, there is always a community impact when garbage disposal or recycling facilities are located. These sites' existence frequently elicits conflicting emotions. On the one hand, they may present chances for employment and local income. However, they may also pose a risk to one's health and safety. For instance, the process of recycling solar panels, while essential, may involve the release of hazardous materials. If not properly managed, these materials could pose risks to local water supplies or air quality. Furthermore, the transportation of waste to these sites can increase traffic, noise, and potentially lead to accidents. Additionally, these dumping sites are frequently located near underprivileged or marginalized groups, which may lack the means or political clout to oppose them. This brings up issues related to environmental justice: Are certain areas

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

unfairly burdened more than others by the expansion of renewable energy?[59], [60]. Another critical social factor are the labour considerations; adequate precautions must be provided for workers in the waste management industry, particularly for those handling potentially harmful products from renewable technology. This includes labor rights issues like fair compensation, suitable hours of work, and the ability to organize, in addition to physical safeguards like the proper equipment and training. Waste management can give rise to unofficial or even unlawful labor practices in various areas. It is crucial to make sure that the renewable energy sector neither causes nor exacerbates these problems. The workers who enable the industry's pursuit of sustainability should not bear the cost of that effort[61]. In addition to aforementioned is Equitable Benefits and Community Engagement. The end-of-life disposing of renewable energy sources presents potential as well as obstacles, particularly in the area of community benefits. Well-managed disposal facilities can develop into local employment hotspots, bringing money and jobs to otherwise economically struggling areas. Ensuring equitable distribution of these benefits and giving communities a say in the development and management of projects are crucial. Public hearings, community benefit agreements, and other means of participation can help achieve this. For example, the money collected from the disposal of waste might be reinvested in regional initiatives like infrastructure, healthcare, or education. Additionally, outreach and education initiatives can be launched to make sure that the community's citizens are aware of the activities occurring nearby, the possible hazards, and the precautions being taken to lessen those risks[59].

2.4 Governance and Policy Implications

Effective policies and efficient governance are essential for managing the waste produced by renewable energy technologies at the end of their useful lives. This section examines the issue's governance and regulatory framework, emphasizes the significance of Environmental, Social, and Governance (ESG) concepts, evaluates the present policies, and makes recommendations for future developments[61]. In terms of governance and policy implications the following factors comes to play. Governance and regulations using resilient framework is required for the management and disposal of waste from renewable energy sources. To guarantee environmental preservation, public health, and safety, waste management procedures must be supervised by regulatory organizations and government agencies. Environmental impact studies, trash classification, permitting procedures, and zoning laws are all part of this governance and regulation. In the same vein, the handling and destruction of waste generated from renewable energy sources require a robust governance system. Government agencies and regulatory bodies need to oversee waste management practices in order to ensure public health, safety, and environmental preservation. This governance includes zoning rules, waste classification, environmental impact evaluations, and permitting processes. Another component is thorough permitting procedures, which is essential for evaluating the environmental effects of garbage disposal locations. Thorough environmental impact assessments need to be carried out in order to determine potential benefits and dangers. A complete understanding of the effects that trash disposal has on nearby ecosystems and populations should be the basis for granting permits. The role of governmental policies is further stressed to classification of wastes. The toxicity and ecological impact of waste produced by renewable energy methods might differ. To ascertain the needs for treatment, transportation, and disposal, appropriate waste classification is crucial. By separating hazardous trash from non-hazardous waste, this classification helps to ensure that the right disposal techniques are applied.

The implication of government policies is driven by principles and its development procedures. Policies concerning the disposal of waste from renewable energy sources are heavily influenced by Environmental, Social, and Governance (ESG) principles. Accountability, transparency, and ethical issues in decision-making processes are highlighted by ESG principles. The guidelines promote openness in waste management procedures. Clear reporting of trash

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

generation, disposal techniques, and environmental effect assessments should be mandated by policy. Stakeholders are able to evaluate the social and environmental effects of waste management related to renewable energy because of this transparency. Viewing policies from accountability perspectives, waste management policies should clearly define who is responsible for what. It is the responsibility of stakeholders — government organizations, waste management businesses, and providers of renewable energy—to ensure that waste disposal practices comply with ESG guidelines. Legal repercussions for non-compliance, fines, and penalties are examples of accountability methods as well as Ethical Considerations. ESG principles place a strong emphasis on moral issues including equity, justice, and community involvement. Policies ought to support moral waste management techniques that put the health of the impacted communities and employees first. The equal distribution of the advantages of waste management is thus a matter of ethics.

Assessing how well-aligned current waste management policies are with ESG principles and how well they can reduce their negative effects on the environment and society can help determine how effective they are. Possible areas for policy improvement include but not limited to Community Involvement*:* Policies ought to require community involvement and participation in garbage disposal decision-making processes. By interacting with the community, you can make sure that their issues are taken care of and that the advantages are shared fairly. In other words, companies that produce renewable energy may be offered financial incentives by policy frameworks to invest in environmentally friendly waste management techniques. This may promote the creation of cutting-edge recycling and repurposing technology**.** Monitoring and Reporting by tightening up the standards for monitoring and reporting can lead to a more thorough comprehension of how waste disposal affects society and the environment. Regular reporting and assessments should be required by policy to guarantee adherence to ESG guidelines. Albeit, policies can support the development of technology for recycling and trash reduction but a more environmentally friendly approach to trash management may result from fostering innovation. The management of end-of-life waste from energy generated from renewable sources depends critically on efficient governance and well-structured legislation, assessment and improvement. ESG principles emphasize accountability, transparency, and ethical issues and offer a framework for developing policies. Waste disposal can comply with ESG principles by evaluating existing policies and implementing the required changes, guaranteeing social justice, environmental preservation, and a transition to sustainable energy.

3.0 Vital Role of ESG Principles

Disposing the end-of-life waste for renewable energy technology, companies and governments can use ESG principles as a compass to steer them toward socially and ecologically acceptable practices. These guidelines place a strong emphasis on the value of accountability, openness, and stakeholder involvement—all essential components of guaranteeing a sustainable future. ESG guidelines offer a framework for morally and responsibly disposing of garbage as the globe works to create a greener and more environmentally friendly energy landscape. Governments as well as organizations can achieve governance excellence when handling waste from renewable energy sources, promote social fairness, and lessen their impact on the environment by following these principles. Key steps to build the capacity to recycle renewable energy waste as part of circular decarbonization is presented in Figure 2. This framework follows a circular decarbonization principles. The procedures illustrated in figure 2 seek to create a systematic way to recycle waste from renewable energy sources. The environmental impact of renewable energy technology can be reduced while maintaining compliance with environmental, social, and governance (ESG) criteria. This requires prioritizing effective waste management and recycling practices. Overall, it is impossible to overestimate the importance of ESG in environmentally friendly disposal. It is the impetus behind waste management techniques that are socially and environmentally responsible, paving the way for a more sustainable and greener future. In addition to adopting

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

renewable energy technologies, let's embrace ESG principles to fulfill our social and environmental obligations and leave a sustainable energy legacy for future generations. In this section, we discuss how effective ESG principles can effectively enhance the reputation of organizations when they consider environmental impact, effective governance and social responsibility in the conduct of their operations.

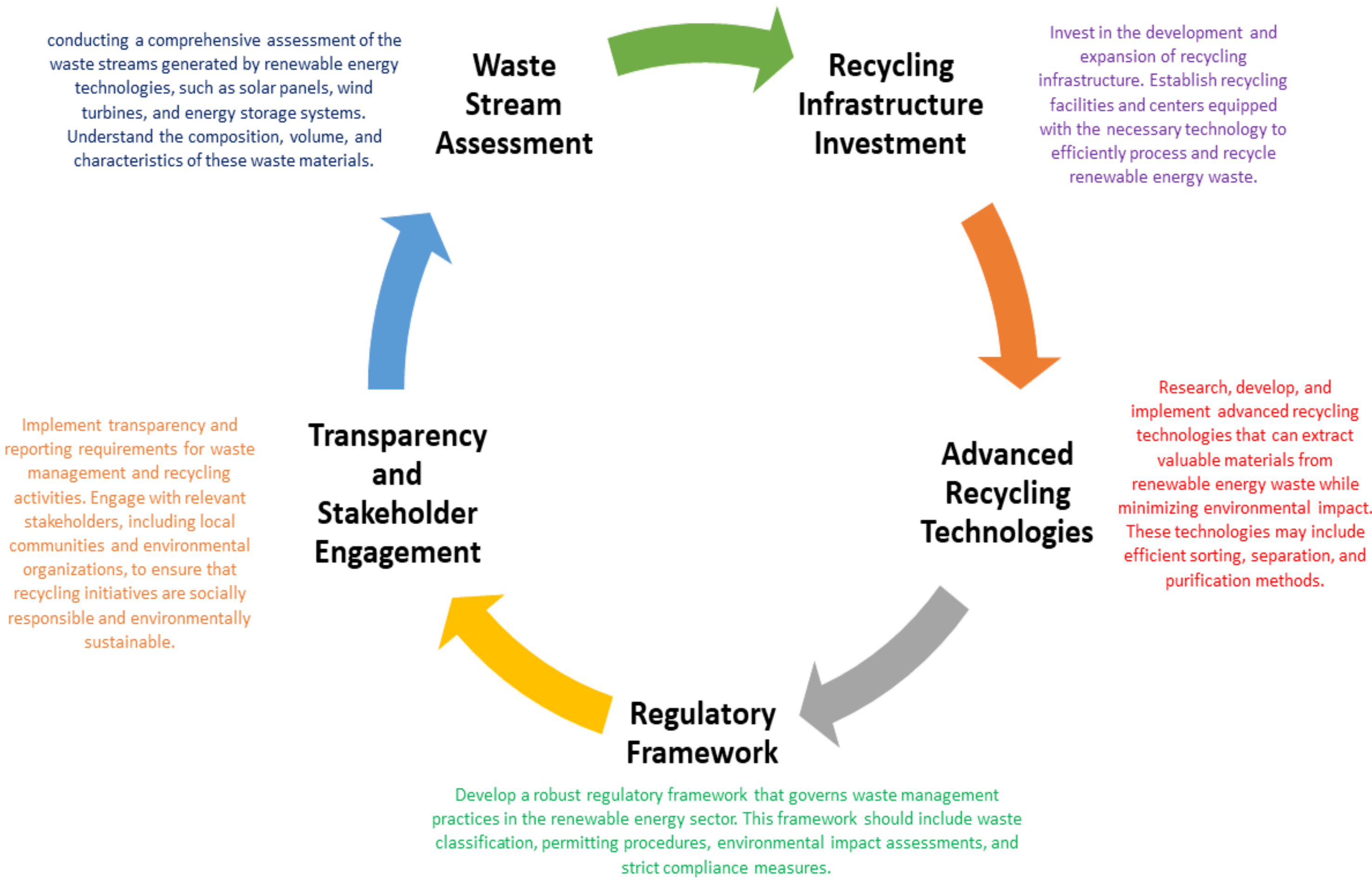


Figure 2. Steps to of circular decarbonized recycling of renewable energy waste.

3.1 Case studies, best practices and lessons learnt

Investigating case studies of effective end-of-life waste disposal strategies in the renewable energy industry provides important information about how ESG elements are integrated. This section highlights firms and locations that have demonstrated effective waste management in line with ESG principles, offering insights and repeatable methods. The first case study considered for the purpose of this review is First Solar's Recycling Program. First Solar is a leading manufacturer of thin-film solar panels. A thorough recycling operation for thin-film photovoltaic, or Photovoltaic (PV), panels has been put in place by First Solar. Cadmium telluride is a dangerous substance present in these panels. Fortunately, First Solar has recycled up to 90% of the materials used in these panels, efficiently managing their end-

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

of-life disposal [62]. As a result, the environmental effect of garbage disposal is greatly reduced. Among their program's salient elements are Collection centers which functions to guarantee the secure gathering and conveyance of used panels to recycling facilities. First Solar set up collection centers using Advanced Recycling Technologies (ART) to recover valuable resources with the least amount of negative environmental impact. The enterprise uses sophisticated recycling methods in a transparent manner - keeping with the ESG values of accountability. First Solar reports on its recycling activities using a public approach. Another case study considered for this review is the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive. With the WEEE Directive, the European Union has adopted a comprehensive strategy for handling end-of-life waste from renewable energy systems. Strict guidelines are set forth in this directive for the gathering, recycling, and ecologically responsible disposal of electronic trash, which includes parts of solar panels and wind turbines. Important facets of this directive consist of; extended producer responsibility **-** producers bear the financial and administrative burden of arranging for the disposal, recycling, and treatment of waste equipment. This is consistent with the accountability principles of ESG. The also use minimum recycling targets to lessen the impact on the environment and conserve resources, the directive establishes precise criteria for the reuse and recovery of elements from electronic waste. Information and Awareness forms a critical component for the promotion of community involvement, the EU supports public education and awareness campaigns that educate consumers about the need of properly disposing of electronic waste.

These case studies provide numerous valuable insights and scalable methodologies with Lessons learned and replicable practices from various perspectives. By making an investment in cutting-edge recycling technology to reduce environmental impact and recover valuable materials, businesses, this can help manage end-of-life trash effectively. Furthermore, enforcing greater producer responsibility, as outlined in the EU's WEEE Directive, businesses can be held accountable for the full life cycle of their products, in line with the accountability principles of ESG. Although, transparency and reporting forms part of accountability; yet ESG standards must be upheld to when waste management initiatives are reported. This will encourage transparency of businesses and make available public information about waste management plans. Another important reference from the case studies is to be socially conscious when interacting with local communities and raising awareness of the value of efficient garbage disposal; this must be done with absolute support of laws and regulations, like the WEEE Directive, are frequently necessary for effective waste management. Legislators ought to think about passing laws that support ethical trash management.

It is worthy to note that; these case studies demonstrate the possibility of implementing ESG concepts into end-of-life waste disposal procedures that are successful in the renewable energy industry. Businesses and localities may imitate these best practices and help to create a more environmentally friendly and responsible energy future by investing in cutting-edge recycling technologies, enforcing greater producer accountability, and encouraging transparency and community participation.

4.0 Sustainable disposal of wastes from renewable energy resources

Organizations and governments can optimize waste disposal methods for renewable energy technology with the use of Environmental, Social, and Governance (ESG) frameworks. This section explores the diverse impact of ESG on waste management, with a focus on accountability, transparency, and stakeholder involvement. It also emphasizes the role that investors and shareholders play in promoting the adoption of ESG principles. Governmental agencies and other enterprise can use ESG frameworks as a set of guiding principles to ensure that their waste disposal methods are in line with ethical and sustainable standards. The integrated strategy that takes governance, social, and environmental aspects into account when disposing of waste from renewable energy sources in a sustainable manner is therefore

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

covered in this section. With this strategy, the renewable energy industry is guaranteed to adopt ethical and sustainable waste management techniques that meet global sustainability goals.

Three main points are highlighted by these frameworks as depicted in figure 3:

A. Environmental Considerations: ESG guidelines emphasize how important it is to reduce waste disposal's negative environmental effects. This entails resource conservation, appropriate waste treatment, and recycling. Organizations are encouraged by ESG to implement life cycle assessments and take into account the full environmental impact of waste disposal from birth to death.

B. Social Responsibility: By addressing the labor and community components of garbage disposal, ESG encourages social responsibility. This entails guaranteeing these communities receive fair benefits and taking into account the welfare of the communities impacted by waste disposal methods. It also includes labor-related issues including worker safety and ethical labor practices.

C. Corporate Governance: In order to hold businesses responsible for the disposal of their waste procedures, corporate governance is essential to waste management. ESG frameworks promote accountability, openness, and moral decision-making in waste management procedures.

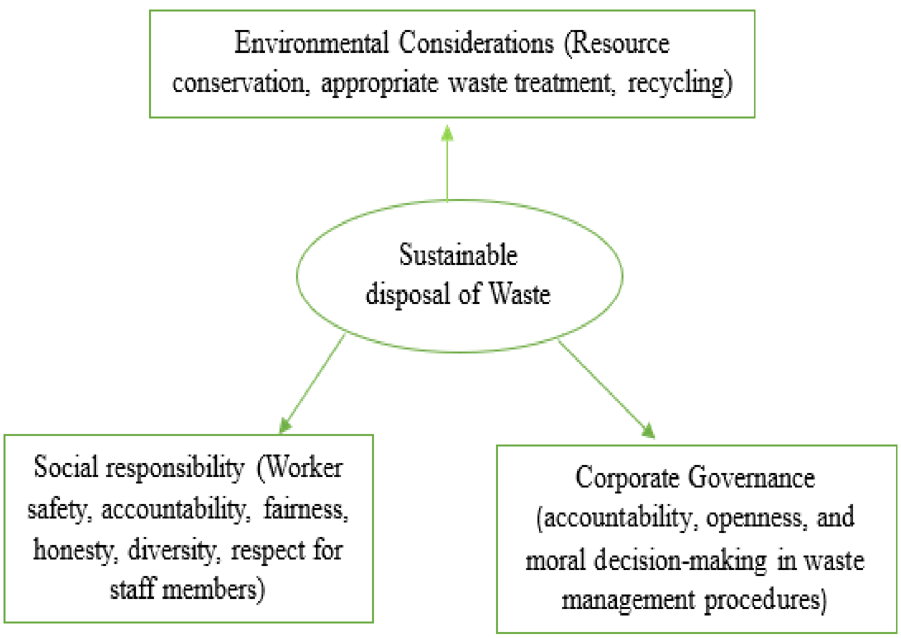


Figure 3. Framework for sustainable disposal of Renewable energy waste

4.1 Stakeholders Engagement

Stakeholders' participation, accountability, and transparency are essential elements of implementing ESG in garbage disposal. This will further foster transparency. Governments and enterprises are encouraged by ESG principles to be open and honest regarding their waste management initiatives. Reports on trash production, disposal techniques, and environmental effect analyses are all included in this transparency. Transparent reporting holds companies responsible

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

for their actions and enables stakeholders to evaluate the social and environmental effects of trash disposal. Besides, one of the critical cornerstones of ESG is accountability. Governments and organizations are responsible for making sure waste management follows ESG guidelines. This responsibility could be in the form of observing regulations, paying fines or penalties, or facing legal repercussions for noncompliance. Stakeholder's engagement is recommended by ESG principles because it entails actively including relevant parties and impacted communities in waste disposal decision-making processes. Businesses are greatly influenced by shareholders and investors to implement ESG waste management principles. Some of the ways shareholders and investors influence businesses are to increasingly take into account environmental, social, and governance (ESG) aspects. Investors might decide to favor some businesses that exhibit ethical waste management techniques in line with ESG guidelines. Therefore, businesses that put an emphasis on ESG in waste management can draw in more investors. Although, through activism and resolution voting on ESG matters, shareholders can have an impact on firms. Some of the resolutions from stakeholders' forums may advocate for more sustainable practices, equal benefits for impacted communities, and increased transparency in waste management through effective financial performance. Long-term profitability may be enhanced by businesses that give ESG principles first priority when managing trash. Investors and stockholders may also find sustainable waste management strategies appealing because they can lower costs, lessen environmental responsibilities, and improve a company's reputation. Significantly, ESG frameworks function as heuristics that optimize waste management plans for renewable energy technology. They place a strong emphasis on governance, social, and environmental issues, with stakeholder involvement, accountability, and transparency being essential to the implementation of ESG. Moreover, the consequence of harmonizing waste disposal methods with sustainability and accountability is highlighted by the impact of investors and shareholders in promoting the use of ESG principles in waste management.

4.2 Challenges and Future Directions

No doubt, sustainable disposal of renewable energy components are faced with some challenges, and it is important for this review to specify some future directions. Although the transition to a system based on renewable energy offers hope for a better future for the earth, there are obstacles along the way, particularly with regard to sustainable disposal. Highlights of areas prepared for research, policy development, and innovation while discussing the challenges encountered in the sustainable disposal of renewable energy components. It also makes recommendations for future paths. Some of the constraints affecting sustainable disposal of renewable energy components include technological limitations**.** Despite advancements in recycling technologies, certain elements found in renewable energy elements cannot be recycled effectively. Retrieving and reusing certain rare materials, such as those used in wind turbines and solar panels, is still difficult.

Considering some economic factors, sustainable disposal techniques may not necessarily be the most profitable. Businesses may be discouraged from investing in environmentally friendly disposal due to the expenses of recycling and repurposing materials due to regulatory variability**.** In other words, distinct national and regional regulatory frameworks pertaining to garbage disposal result in disparities in standards and practices. The situation is made more difficult by the lack of a single worldwide standard and logistical challenges**.** Number of components that requires disposal are fast increasing along with the use of renewable energy sources therefore, managing higher throughput without sacrificing environmental sustainability possess a very huge challenge.

Overall major complication is the lack of knowledge among stakeholders and consumers about the significance of sustainable disposal and the means by which it can be accomplished effectively.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

5.0 Summary and Conclusion

This article has carried out a very comprehensive review of environmental, social, and governance (ESG) aspects of disposing of end-of-life waste for renewable energy systems. It further examined the importance of this subject as a global fight against climate change from the renewable energy sources perspective. Although the renewable energy technologies promise a more sustainable and clean future, disposing their components after use poses a number of issues that need to be resolved urgently. There are dangers posed to the environment and public health when disposing of components used in renewable energy, as they frequently contain toxic elements. For instance, electronic components are frequently found in renewable energy systems, like wind turbines and solar panels. To keep dangerous elements out of the environment, these electronics must be disposed of and recycled properly. Numerous renewable energy systems depend on specific elements might also require a lot of resources to extract, including rare earth metals. Reducing the negative environmental effects of production and disposal of these materials therefore requires the establishment of efficient recycling and recovery procedures which has been reviewed in this article. Certain parts of renewable energy technologies, such solar panels, could include dangerous substances like cadmium and lead. Utilizing safe recycling and disposal techniques is therefore necessary to avoid tainting the environment.

The magnitude of decommissioning initiatives is anticipated to rise in tandem with the ongoing expansion of renewable energy infrastructure. This calls for careful planning and the application of disposal techniques. The recycling and disposal of renewable energy technology require well-defined legislative frameworks. Managing end-of-life waste requires effective governance and regulatory activities. It can be concluded that ESG guidelines can help governments and organizations optimize their waste disposal plans while maintaining stakeholder participation, accountability, and openness. These rules ought to encourage sustainable behaviors while addressing safety and environmental issues. The development of more effective and long-lasting recycling methods for renewable energy technology requires research and development work. It is also essential for industrial players, legislators, researchers, and environmentalists to collaborate in addressing disposal issues and provide feasible solutions. Overall, comprehensive lifecycle evaluations can be directed towards the creation of more sustainable methods and technologies by identifying possible adverse effects on the environment at every phase, including disposal.

5.1 Recommendations and Future work

The following recommendations are therefore drawn from this review. Firstly, that investing in research and development for disposal technologies should be taken more seriously by public and private organizations with top priority. This will develop environmentally friendly methods of disposing of and recycling components of renewable energy. It will further encourage finding more effective ways to extract uncommon minerals or biodegradable component solutions. Understanding the full life cycle of technologies that produce renewable energy should be the main goal of future research with reference to innovations that reduce waste at every stage of an item's lifespan, from production to decommissioning, can come from a holistic perspective. On the other hand, international organizations ought to endeavor to provide unified guidelines for the environmentally friendly disposal of components used in renewable energy sources. This can promote uniformity and establish a standard for other nations.

Making lucrative incentives available for Sustainable Disposal**,** effective collaborations among stakeholders at local, regional, and global level is very important. This will also foster public awareness campaigns among others. It is evident that the need for environmentally friendly disposal solutions grows as the world's energy use becomes increasingly widespread. Through recognition of obstacles and proactive pursuit of future paths, interested parties may guarantee that the revolution in renewable energy is genuinely sustainable in every meaning of the term.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

References

[1] R. Kardooni, S. B. Yusoff, and F. B. Kari, “Renewable energy technology acceptance in Peninsular Malaysia,” *Energy Policy*, vol. 88, 2016, doi: 10.1016/j.enpol.2015.10.005.

[2] A. Qazi *et al.*, “Towards Sustainable Energy: A Systematic Review of Renewable Energy Sources, Technologies, and Public Opinions,” *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2906402.

[3] I. Siksnelyte-Butkiene, E. K. Zavadskas, and D. Streimikiene, “Multi-criteria decision-making (MCDM) for the assessment of renewable energy technologies in a household: A review,” *Energies*, vol. 13, no. 5. 2020. doi: 10.3390/en13051164.

[4] J. Adebisi, P. Ibili, M. Emezirinwune, and K. Abdulsalam, “Comparative Study of Hybrid Solar Photovoltaic - Diesel Power Supply System,” *African Journal of Inter/Multidisciplinary Studies*, vol. 5, no. 1, 2023, doi: 10.51415/ajims.v5i1.1217.

[5] J. A. Adebisi, I. H. Denwigwe, and O. M. Babatunde, “Hydrogen storage for micro-grid application: a framework for ranking fuel cell technologies based on technical parameters,” *International Journal of Electrical and Computer Engineering*, vol. 13, no. 2, 2023, doi: 10.11591/ijece.v13i2.pp1221-1230.

[6] A. M. Levenda, I. Behrsin, and F. Disano, “Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies,” *Energy Research and Social Science*, vol. 71. 2021. doi: 10.1016/j.erss.2020.101837.

[7] B. Babatunde O, O. Ayoninuoluwa, A. Ayodele, and O. Rowland, “IMPACT OF GLOBALISATION ON THE INDUSTRIAL GROWTH IN NIGERIA (1981-2014): IMPLICATION TO PSYCHOLOGIST AND ECONOMIST,” *European Journal of Business, Economics and Accountancy*, vol. 5, no. 5, 2017, [Online]. Available: www.idpublications.org

[8] P. G. J. Persoon, R. N. A. Bekkers, and F. Alkemade, “The knowledge mobility of Renewable Energy Technology,” *Energy Policy*, vol. 161, 2022, doi: 10.1016/j.enpol.2021.112670.

[9] I. H. Denwigwe, J. D. Akinde-Peters, O. M. Babatunde, O. Samson Adedoja, I. A. Taiwo, and T. B. Adedoja, “An Android-based mobile platform for understanding Residential PV system sizing,” *African Journal of Science, Technology, Innovation and Development*, 2021, doi: 10.1080/20421338.2021.1959280.

[10] D. Li, G. Heimeriks, and F. Alkemade, “Knowledge flows in global renewable energy innovation systems: the role of technological and geographical distance,” *Technol Anal Strateg Manag*, vol. 34, no. 4, 2022, doi: 10.1080/09537325.2021.1903416.

[11] D. Richards and H. Yabar, “Potential of Renewable Energy in Jamaica’s Power Sector: Feasibility Analysis of Biogas Production for Electricity Generation,” *Sustainability (Switzerland)*, vol. 14, no. 11, 2022, doi: 10.3390/su14116457.

[12] C. Carbone, D. Ferrario, A. Lanzini, S. Stendardo, and A. Agostini, “Evaluating the Carbon Footprint of Cement Plants Integrated With the Calcium Looping CO2 Capture Process,” *Frontiers in Sustainability*, vol. 3, 2022, doi: 10.3389/frsus.2022.809231.

[13] X. Fu, X. Wu, C. Zhang, S. Fan, and N. Liu, “Planning of distributed renewable energy systems under uncertainty based on statistical machine learning,” *Protection and Control of Modern Power Systems*, vol. 7, no. 1, 2022, doi: 10.1186/s41601-022-00262-x.

[14] J. Vourdoubas, “Review of Sustainable Energies Use in Greenhouses in Greece,” *Journal of Agricultural Studies*, vol. 5, no. 4, 2018, doi: 10.5296/jas.v6i2.12973.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

[15] B. Jyothi, B. Pabbuleti, and B. Thirumala Rao, "Significance of Renewable Energy Sources for Future Technologies Built on Geographical Conditions and Period of Seasons," *ECS Trans*, vol. 107, no. 1, 2022, doi: 10.1149/10701.1537ecst.

[16] J. M. L. Cózar, "Energía Solar Termica," *Manuales de Energías Renovables*, vol. 4, 2006.

[17] Ernst and Young LLP, "Technical Study of Electric Vehicles and Charging Infrastructure," *Bureau of Energy Efficiency (BEE)*, no. March 2019.

[18] I. Alsaidan, A. Alanazi, W. Gao, H. Wu, and A. Khodaei, "State-of-The-Art in microgrid-integrated distributed energy storage sizing," *Energies (Basel)*, vol. 10, no. 9, 2017, doi: 10.3390/en10091421.

[19] F. Asdrubali, G. Baldinelli, F. D'Alessandro, and F. Scrucca, "Life cycle assessment of electricity production from renewable energies: Review and results harmonization," *Renewable and Sustainable Energy Reviews*, vol. 42. 2015. doi: 10.1016/j.rser.2014.10.082.

[20] V. Mukoro, A. Gallego-Schmid, and M. Sharmina, "Life cycle assessment of renewable energy in Africa," *Sustainable Production and Consumption*, vol. 28. 2021. doi: 10.1016/j.spc.2021.08.006.

[21] M. Milousi, M. Souliotis, G. Arampatzis, and S. Papaefthimiou, "Evaluating the environmental performance of solar energy systems through a combined life cycle assessment and cost analysis," *Sustainability (Switzerland)*, vol. 11, no. 9, 2019, doi: 10.3390/su11092539.

[22] Z. Yang, H. Huang, and F. Lin, "Sustainable Electric Vehicle Batteries for a Sustainable World: Perspectives on Battery Cathodes, Environment, Supply Chain, Manufacturing, Life Cycle, and Policy," *Adv Energy Mater*, vol. 12, no. 26, 2022, doi: 10.1002/aenm.202200383.

[23] "Life Cycle Assessment of Hydrogen Fuel Cells: Environmental Impact and Sustainability," *Journal of Energy Technologies and Policy*, 2023, doi: 10.7176/jetp/13-1-07.

[24] S. Abanades *et al.*, "A conceptual review of sustainable electrical power generation from biogas," *Energy Science and Engineering*, vol. 10, no. 2. 2022. doi: 10.1002/ese3.1030.

[25] G. Mello, M. Ferreira Dias, and M. Robaina, "Evaluation of the environmental impacts related to the wind farms end-of-life," *Energy Reports*, vol. 8, 2022, doi: 10.1016/j.egyr.2022.01.024.

[26] M. Massoud, G. Vega, A. Subburaj, and J. Partheepan, "Review on recycling energy resources and sustainability," *Heliyon*, vol. 9, no. 4. 2023. doi: 10.1016/j.heliyon.2023.e15107.

[27] M. Azam *et al.*, "Status, characterization, and potential utilization of municipal solid waste as renewable energy source: Lahore case study in Pakistan," *Environ Int*, vol. 134, 2020, doi: 10.1016/j.envint.2019.105291.

[28] S. Hendiani and G. Walther, "Sustainability performance evaluation of renewable energy systems using a new multi-expert multi-criteria interval type-2 fuzzy distance to ideal solution approach," *Appl Energy*, vol. 347, 2023, doi: 10.1016/j.apenergy.2023.121436.

[29] G. Zsembinszki *et al.*, "Life cycle assessment (Lca) of an innovative compact hybrid electrical-thermal storage system for residential buildings in mediterranean climate," *Sustainability (Switzerland)*, vol. 13, no. 9, 2021, doi: 10.3390/su13095322.

[30] B. Kılıçarslan, I. Bozyel, D. Gökcen, and C. Bayram, "Sustainable Macromolecular Materials in Flexible Electronics," *Macromolecular Materials and Engineering*, vol. 307, no. 6. 2022. doi: 10.1002/mame.202100978.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

[31] G. Sandin, G. M. Peters, and M. Svanström, "Life cycle assessment of construction materials: The influence of assumptions in end-of-life modelling," *International Journal of Life Cycle Assessment*, vol. 19, no. 4, 2014, doi: 10.1007/s11367-013-0686-x.

[32] A. Salnikova, Y. Chepurko, N. Starkova, and H. N. Hoàng, "External effects of renewable energy projects: Life cycle analysis-based approach," *International Journal of Energy Economics and Policy*, vol. 9, no. 4, 2019, doi: 10.32479/ijeep.7959.

[33] J. Neiva de Figueiredo and S. F. Mayerle, "A systemic approach for dimensioning and designing anaerobic bio-digestion/energy generation biomass supply networks," *Renew Energy*, vol. 71, 2014, doi: 10.1016/j.renene.2014.06.031.

[34] D. L. Klass, "A critical assessment of renewable energy usage in the USA," *Energy Policy*, vol. 31, no. 4, 2003, doi: 10.1016/S0301-4215(02)00069-1.

[35] I. T. Yeom, V. G. Sharmila, R. Y. Kannah, P. S. Sivashanmugam, and J. R. Banu, "Municipal waste management," in *Municipal and Industrial Waste: Sources, Management Practices and Future Challenges*, 2018. doi: 10.1201/9781003171126-27.

[36] V. Mozhiarasi and T. S. Natarajan, "Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value-added products," *Biomass Conversion and Biorefinery*. 2022. doi: 10.1007/s13399-022-02352-0.

[37] E. Escrig-Olmedo, M. ángeles Fernández-Izquierdo, I. Ferrero-Ferrero, J. M. Rivera-Lirio, and M. J. Muñoz-Torres, "Rating the raters: Evaluating how ESG rating agencies integrate sustainability principles," *Sustainability (Switzerland)*, vol. 11, no. 3, 2019, doi: 10.3390/su11030915.

[38] P. M. Omenge, G. W. Eshiamwata, S. M. Makindi, and G. O. Obwoyere, "Public participation in environmental impact assessment and its substantive contribution to environmental risk management: Insights from EIA practitioners and other stakeholders in Kenya's renewable energy sub-sector," *WIT Transactions on Ecology and the Environment*, vol. 237, 2019, doi: 10.2495/ESUS190121.

[39] A. Shaktawat and S. Vadhera, "Sustainability Assessment of Renewable Energy Technologies in Context to India Using Multicriteria Analysis with and without Incorporating Risk Analysis," *Journal of Environmental Assessment Policy and Management*, vol. 23, no. 3 3 4, 2021, doi: 10.1142/S146433322250020X.

[40] U. Arena, F. Ardolino, and F. Di Gregorio, "Technological, environmental and social aspects of a recycling process of post-consumer absorbent hygiene products," *J Clean Prod*, vol. 127, 2016, doi: 10.1016/j.jclepro.2016.03.164.

[41] B. Ata, D. Lee, and M. H. Tongarlak, "Optimizing organic waste to energy operations," *Manufacturing and Service Operations Management*, vol. 14, no. 2, 2012, doi: 10.1287/msom.1110.0359.

[42] E. C. Elele and I. N. Subanda, "Residents Social Behavior in The Implementation of Denpasar City Waste Management Policy," *Jurnal Ilmiah Ilmu Administrasi Publik*, vol. 10, no. 1, 2020, doi: 10.26858/jiap.v10i1.10990.

[43] T. D. T. OYEDOTUN and S. MOONSAMMY, "Linking national policies to beneficiaries: Geospatial and statistical focus to waste and sanitation planning," *Environmental Challenges*, vol. 4, 2021, doi: 10.1016/j.envc.2021.100142.

[44] M. Sheoran and D. Das Gupta, "International best practices for e-waste take back and policy interventions for India," *Facilities*. 2023. doi: 10.1108/F-03-2023-0027.

[45] E. M. Hoyer *et al.*, "Preliminary safety analyses in the high-level radioactive waste site selection procedure in Germany," *Advances in Geosciences*, vol. 56, 2021, doi: 10.5194/adgeo-56-67-2021.

JDFEWS 4 (2): 1-22, 2023
ISSN 2709-4529

[46] V. G. Whitelock, “Multidimensional environmental social governance sustainability framework: Integration, using a purchasing, operations, and supply chain management context,” *Sustainable Development*, vol. 27, no. 5, 2019, doi: 10.1002/sd.1951.

[47] D. A. Wood, “Sustainability challenges for the upstream sectors of the natural gas industry,” in *Sustainable Natural Gas Reservoir and Production Engineering: Volume 1*, vol. 1, 2021. doi: 10.1016/B978-0-12-824495-1.00007-3.

[48] B. S. Dhanya, A. Mishra, A. K. Chandel, and M. L. Verma, “Development of sustainable approaches for converting the organic waste to bioenergy,” *Science of the Total Environment*, vol. 723, 2020, doi: 10.1016/j.scitotenv.2020.138109.

[49] N. Amin *et al.*, “Municipal solid waste treatment for bioenergy and resource production: Potential technologies, techno-economic-environmental aspects and implications of membrane-based recovery,” *Chemosphere*, vol. 323, 2023, doi: 10.1016/j.chemosphere.2023.138196.

[50] M. T. Munir, N. Ul Saqib, B. Li, and M. Naqvi, “Food waste hydrochar: An alternate clean fuel for steel industry,” *Fuel*, vol. 346, 2023, doi: 10.1016/j.fuel.2023.128395.

[51] S. Cho *et al.*, “Sustainable utilization of aging-deteriorated microplastics as triboelectric nanogenerator,” *Chemical Engineering Journal*, vol. 470, 2023, doi: 10.1016/j.cej.2023.144283.

[52] M. F. Chagunda, T. M. Ruhiiga, and L. G. Palamuleni, “Evaluation of energy generation potential from municipal solid waste in the North-West province, South Africa,” *International Journal of Renewable Energy Development*, vol. 12, no. 5, 2023, doi: 10.14710/ijred.2023.52248.

[53] R. Bera *et al.*, “‘CLEAN FOOD’: A MODEL FOR SAFE AND SUSTAINABLE AGRICULTURE TOWARDS ACCOMPLISHMENT OF CIRCULAR ECONOMY,” *Journal of Solid Waste Technology and Management*, vol. 49, no. 2, 2023, doi: 10.5276/jswtm/iswmaw/492/2023.115.

[54] K. R. G. Burra, I. F. Hernández, M. J. Castaldi, S. Goff, and A. K. Gupta, “Effect of Gypsum Waste Inclusion on Gasification of Municipal Solid Waste,” *Journal of Energy Resources Technology, Transactions of the ASME*, vol. 145, no. 2, 2023, doi: 10.1115/1.4054825.

[55] D. Naviglio *et al.*, “Waste Recovery and Circular Economy: A Resource from Orange Peels Deriving from Production of Orange Juice,” *Macromol Symp*, vol. 404, no. 1, 2022, doi: 10.1002/masy.202100287.

[56] H. Hosseinzadeh-Bandbafha *et al.*, “Environmental life cycle assessment of biodiesel production from waste cooking oil: A systematic review,” *Renewable and Sustainable Energy Reviews*, vol. 161, 2022, doi: 10.1016/j.rser.2022.112411.

[57] K. Ranjetha, U. J. Alengaram, A. M. Alnahhal, S. Karthick, W. J. W. Zurina, and K. J. Rao, “Towards sustainable construction through the application of low carbon footprint products,” in *Materials Today: Proceedings*, 2022. doi: 10.1016/j.matpr.2021.10.275.

[58] J. Smith, A. Apsley, L. Avery, E. Baggs, B. . . . Balana, and K. Yongabi, “The potential of small-scale biogas digesters to alleviate poverty and improve long term sustainability of ecosystem services in Sub-Saharan Africa,” *1st World Sustain. Forum*, vol. 5, no. 10, 2013.

[59] W. Moeller *et al.*, “Creating An Engineering For Developing Communities Emphasis In Environmental Engineering,” 2020. doi: 10.18260/1-2--15545.

[60] J. ADEBISI, O. Amusan, P. Olawoore, and others, “Technical comparison of hybrid renewable energy systems for Information Technology services,” *Journal of Digital Food, Energy \& Water Systems*, vol. 3, no. 2, 2022.

[61] S. Srivastava, "An Overview on Recycling of Photovoltaic Modules at the End of Life (EoL)," *INTERANTIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT*, vol. 06, no. 05, 2022, doi: 10.55041/ijsrem16386.

[62] M. A. Green, "Learning experience for thin-film solar modules: First Solar, Inc. case study," *Progress in Photovoltaics: Research and Applications*, vol. 19, no. 4. 2011. doi: 10.1002/pip.1057.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

Enhancing Load Prediction Accuracy using Optimized Support Vector Regression Models

Abdulsemiu OLAWUYI

University of Osun, Osun State, Nigeria; Abdulsemiu.olawuyi@pgc.uniosun.edu.ng

Titus AJEWOLE

University of Osun, Osun State, Nigeria; titus.ajewole@uniosun.edu.ng

Muyideen LAWAL

University of Osun, Osun State, Nigeria; muyideen.lawal@uniosun.edu.ng

Tolulope AWOFOLAJU

University of Osun, Osun State, Nigeria; tolulope.awofolaju@uniosun.edu.ng

Received: 25 November 2023

Review: 11 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: This paper investigates the effect of Support Vector Regression hyperparameters optimization on electrical load prediction. Accurate and robust load prediction helps policy makers in the energy sector to make inform decision and reduce losses. To achieve this, Bayesian optimization technique was employed for the hyperparameters optimization which are then used for the load prediction. The hyperparameters are the regularization parameters and the epsilon. In addition, the effects of sliding window during the load prediction were also evaluated. The sliding window values were varied from 1 to 5. The results showed that the sliding window of 1 had the optimized hyperparameters with the best performing evaluation metrics of 0.01912 and 0.09493 for MSE and MAE respectively.

Keywords: *Support vector regression, hyperparameters, Bayesian optimization, load prediction, sliding window*

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

1. Introduction

Increase in population and industrialization have necessitate high consumption of electrical power [1], [2]. Consequently, attention has been devoted to the management and control of power system across the globe [3], [4]. Electrical load prediction plays crucial role in power system operation and planning [5]. Accurate and robust load forecasting is, therefore, needed [6]. Human and financial resources have been devoted to control and manage electric power efficiently [7]. There is, therefore, need to employed all necessary tools available to achieve stable, effective and affordable power system that is devoid of losses The forecasting of power generated from the generation and the power needed form the consumers end is at the heart of an Energy Panning Model [8]. Load forecasting is the way of anticipating future electric power based on previous data and the weather conditions [9]. There are several load forecasting horizons employed by the power system companies for different applications in the industries [10]. These applications include planning [11], control [12], future load scheduling [13], staff hiring [14] and equipment expansion [15]. Short term load prediction is the forecasting of future from minutes to a week [16]. STLF is useful in power system control [17]. Medium term load prediction is from a week to a year [18].. Long term load prediction has the longest time horizon which is usual more than a year [19]. Medium term prediction is employed in the area of setting up of fuel supply and sustainment operation and Long term prediction improves system operations delivery and planning [20]. Long term prediction is also employed for power system expansion [5].Therefore, accurate load prediction is absolutely essential on the efficient administration of power system planning, control and management. An inaccurate load forecast could lead to waste of scarce resources. Grid collapse is inevitable in absence of robust load prediction.

Several approaches have been employed for load predictions. Statistical methods and machine learning methods have been employed by researchers for the implementation of load forecasting. Statistical methods employed in load prediction include Time series analysis; like Moving average (MA), Autoregressive model (AR), Autoregressive integrated moving average (ARIMA), Autoregressive moving average model (ARMA), Exponential smoothing is also part of the method. [21] presented a study that aims to develop and evaluate an ARIMA for forecasting radiation of the sun in South Korea's capital, Seoul. The dataset used was more than 37 year and was collected from the Korean Meteorological Administration. To test the accuracy of the model, it was compared with Monte Carlo simulations using RMSEs, Coefficient of Determination (R^2), Phillip-Perron Test and Jarque-Bera Test as evaluation metrics. However, the study does not consider other factors such as cloud cover, humidity and temperature which could affect the correctness of solar predictions. Additionally, more data points from different locations would be needed to further validate the results obtained in the study for a wider range of applications.

[22] employed ARIMA-based modelling to study factors that affect traffic congestion and provides a guide on how to build an effective model for predicting abnormal status. However, the study does not address the underlying causes of traffic congestion such as population growth or inadequate infrastructure. [23] presented an analysis and forecasted results for short-term electrical load forecasting, employing three predictive models: ARMA, ARIMA and Autoregressive Integrated Moving Average Model with Exogenous variable. The performance of the models was evaluated using MAPE. Although, the paper did not discuss the limitations of using time series approach for short term load prediction.

Artificial intelligence techniques have employed by researchers for load predictions. Examples of AI techniques used are expert systems [24], artificial neural network [25], Fuzzy logic systems [26], evolutionary algorithms [27] and deep learning [28], [29]. [30] presented a extensive study of very-short term (hour-ahead) and short-term (day ahead)

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

load prediction in an urban building by applying neural networks (NN). The performance of the NN was evaluated in view of two backpropagation learning principle, the Levenberg-Marquardt and Bayesian technique. It also investigates how network model parameters, such as number of neurons, hidden layers, and input layers, affect the model's ability to precisely predict loads. To exhibit its efficiency, it was tested on exact dataset from a campus in downtown Montreal that constitutes many types of buildings with diverse functionalities. However, the effects of different work design parameters on load forecasting accuracy could be further explored. Also, it would be beneficial to investigate alternative machine learning models such as Support Vector Regression (SVRs) or ensembles in order to compare their performance against ANNs for short-term load prediction tasks. [31] proposed a model employing fuzzy logic to forecast short-term energy demand with respect to weather parameters. They employed triangular membership functions with support upon collected data along with production rules formed through basic language understanding in order to make forecasts about future load demand. Finally, they suggest further studies could focus on tuning their proposed model more accurately while reducing time and computational effort required for such tasks. [32] presented a machine learning with evolutionary models based short term load prediction model for power systems, which uses Wavelet Transform and Artificial Fish Swarm Optimization to improve the predictive process. However, the authors suggested that future studies could focus on improving predictive outcomes of this method by using deep learning and hyper-parameter optimization techniques. [33] investigated the potential of using deep learning approaches for residential load forecasting under high volatility and uncertainty. A new Pooling-based Deep Recurrent Neural Network (PDRNN) was proposed to solve overfitting challenges caused by naïve deep networks, accepting more layers before occurrence of overfitting while still capturing geographical information common between interconnected customers. Although further research could be done to explore how data privacy and security can be addressed when using deep learning techniques for residential load forecasting. Additionally, investigating if the findings of the study are applicable to other types of households.

The aim of this study is to optimize the hyperparameters of the Support Vector (SVR) for improved load prediction. The specific objectives of the studies are to develop the SVR models with Python using Google Collab platform and to also evaluate and compare the SVR models using sliding window techniques.

2. Review of Literature

Ref [34] proposes a hybrid model called SVR-LSTM for short-term load forecasting in a microgrid (MG) in Africa. The model combines Support Vector Regression (SVR) and Long Short-Term Memory (LSTM) algorithms. The SVR-LSTM model is compared with conventional SVR and LSTM models, and it shows better results with a correlation coefficient of 0.9901, compared to 0.9770 and 0.9809 for SVR and LSTM respectively. [35] developed a machine learning algorithm for electric load forecasting that incorporates an asymmetric loss function to account for the different costs associated with over-prediction and under-prediction errors. The framework is tested using electric load data from New South Wales in Australia and is shown to result in a significant reduction in daily economic costs compared to basic support vector regression. The cost reduction ranges from 42.19% to 57.39% depending on the actual cost ratio of the two types of errors. [36] propose a hybrid support vector regression (HSVR) for medium and long-term load forecasting in the smart grid. It focuses on the coupling and interdependent relationship between hyperparameters and model parameters in the optimization process.

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

3. Materials and Methods

3.1 Description of the dataset

Monthly dataset for the six-business hub in Ogun State were used in this study. The six hubs were used in order to captured the entire load consumption of Ogun State. The initial dataset was in Mega-Watt-hour (MWh), its summation was divided by twenty-four to convert it to MW. The duration of the entire dataset is 5 years, from 2018 to 2022. The actual total consumption in MW, which is the target during the prediction, was evaluated. The sample of the 2018 dataset was presented in Table 1. The data was obtained from Ibadan Electricity Distribution Company (IBEDC). Ogun State is a state in the southwestern zone in Nigeria, it is the second largest economy in the region. The state was created on 3rd February 1976. Ogun State borders Osun and Oyo states in the northern zone, to the north is Lagos state, Ondo state and Republic of Benin in the eastern and western zone respectively. Ogun state capital is Abeokuta, the most densely populated area in the state. Other notable areas in the state are Sagamu, Ota, Ijebu-Ode and Sango.

Table 1: Energy consumption distribution

Months	Ijebu	Ijeun	Olumo	Ota	Sagamu	Sango	Actual Total Consumption in MW
January	7,187	7,383	7,961	15,072	17,814	11,222	2,777
February	5,374	7,142	8,572	14,130	18,565	11,106	2,704
March	6,882	7,530	8,300	16,321	21,947	11,206	3,008
April	7,258	7,383	8,383	15,296	21,312	10,931	2,940
May	6,763	5,696	6,554	14,466	21,410	10,301	2,716
June	4,105	4,960	5,618	14,360	19,401	10,158	2,442
July	6,046	4,301	5,449	15,674	22,679	11,266	2,726
August	6,621	4,756	6,455	16,494	23,729	12,403	2,936
September	5,322	4,606	6,133	15,071	16,615	9,965	2,405
October	4,930	4,870	6,305	16,559	18,383	11,145	2,591
November	3,915	6,058	6,900	15,376	19,097	12,837	2,674
December	5,412	6,245	7,533	16,447	21,538	11,373	2,856

3.2 Models Implementation

Python code was employed for the development of the Support Vector Regression model. Python libraries like Pandas, Numpy, Matplotlib, Scikit-learn and skopt were imported. To optimize the hyperparameters of the SVR, Bayesian optimization techniques was employed. Sliding window techniques was used to develop the SVR models. The sliding window values were varied from 1 to 5 in order to observe the effects of the variation on the performances of the models. The dataset was divided into 70% for training and 30% for testing.

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

3.3 Support Vector Regression

Support vector regression (SVR) is a supervised machine learning model to handle regression problems [37]. SVR is a machine learning regression algorithm. Regression model is suitable to analyze the link between input and output variables. SVR develops an optimization question to learn a regression function that maps input and output variables [38].

The mathematical development of a linear support vector regression can be put as follows. Suppose Using the training data $\{(x_1, y_1), \ldots, (x_n, y_n)\}$, where x_n and y_n are input and target output respectively. The linear function f can be put as [38]:

$$y = f(x) = w \cdot x + b = w^T x + b \qquad (1)$$

where $w \cdot x$ stands for the dot the product of input data x with the weight vector w. Equation (1) can also be re-written as:

$$\min \frac{1}{2}\|w\|^2$$

$$subject\ \ to \begin{cases} y_n - w^T x_n - b \le \varepsilon \\ w^T x_n + b - y_n \le \varepsilon \end{cases} \qquad (2)$$

The original optimization problem in Equation (2) is now be represented as a multiobjective optimization problem with supplementary parameters ξ and ξ^*

$$\min \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{l}\left(\xi_n + \xi_n^*\right),$$

$$subject\ to \begin{cases} y_i - w^T x_n - b \le \varepsilon + \xi_n \\ w^T x_n + b - y_n \le \varepsilon + \xi_n^* \\ \xi_n, \xi_n^* \ \ \ge \ \ 0 \end{cases} \qquad (3)$$

where $C > 0$ is a regularization parameter that determines the trade-off between the flatness of function f and the prediction errors. A large C value gives more weight to minimizing the prediction errors, while a small C value gives more weight to minimizing the flatness.

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

Two SVR hyperparameters, the regularization parameters (C) and epsilon (ε), were optimized. The mean test score and the rank test score of the optimize hyperparameters were obtained. The best ranked hyperparameter was subsequently used for the training and testing.

3.4 Model Performance Evaluation

To evaluate the Support Vector Regression models, mean square error (MSE) and mean absolute error (MAE) were employed. Equation 4 and 5 represent the MSE and MAE respectively. The more the evaluation results are closer to zero, the better the performance of the model. The metrics were used to interpret and determine the accuracy of the model.

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|y - \hat{y}\right| \qquad (4)$$

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(y - \hat{y}\right)^2 \qquad (5)$$

4. Results and Discussion

4.1 Hyperparameters Optimization

Table 2 shows the results of the hyperparameters optimization when the sliding window, w is one (w=1). The hyperparameters were graded according to their rank test score with respect to the mean test score. The lower the mean test score, the higher the rank test score. The best ranked hyperparameters' values for regularization parameter, C and epsilon, ε are 333.131121 and 0.01 respectively with a mean test score of -0.039581. Table 2 represents when the sliding window is two (w=2). The best hyperparameters for C and ε are 380.189396 and 0.01 respectively, with a mean test score of -0.044034. The optimization results when the sliding window is three (w=3) is shown in Table 3. The value of the hyperparameters C and ε is 1.513561 and 0.01 respectively. Iteration indices 2 and 10 have the same rank test score of 1.

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

Table 2: Optimization results when sliding window, w, is one (w=1)

Iteration index	Hyperparameters		Mean Test Score	Rank Test Score
	C	Epsilon		
10	333.131121	0.01	-0.039581	1
13	125.892541	0.01	-0.039581	2
11	380.189396	0.01	-0.039616	3
2	1.513561	0.01	-0.040062	4
0	1.513561	0.07	-0.045347	5
7	1.148154	0.05	-0.046432	6
6	660.693448	0.08	-0.047407	7
5	109.647819	0.1	-0.053295	8
12	6.918310	0.1	-0.053298	9
9	0.165959	0.04	-0.057868	10

Table 2: Optimization results when sliding window, w, is two (w=2)

Iteration index	Hyperparameters		Mean Test Score	Rank Test Score
	C	Epsilon		
11	380.189396	0.01	-0.044034	1
12	660.693448	0.01	-0.044117	2
10	331.131121	0.01	-0.044328	3
14	109.647820	0.01	-0.045258	4
2	1.513561	0.01	-0.045411	5
13	1.148154	0.01	-0.045602	6
7	1.148154	0.05	-0.050325	7
6	660.693448	0.08	-0.051769	8
0	1.513561	0.07	-0.053758	9
5	109.647820	0.1	-0.060272	10

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

Table 3: Optimization results when sliding window, w, is three (w=3)

Iteration index	Hyperparameters		Mean Test Score	Rank Test Score
	C	Epsilon		
2	1.513561	0.01	-0.045954	1
10	1.513561	0.01	-0.045954	1
12	1.513561	0.03	-0.052053	3
7	1.148154	0.05	-0.058582	4
11	1.513561	0.05	-0.059019	5
13	1.513561	0.06	-0.060360	6
0	1.513561	0.07	-0.062599	7
6	660.693448	0.08	-0.065770	8
9	0.165959	0.04	-0.067642	9
5	109.647820	0.1	-0.074636	10

Table 4 shows the optimization results when sliding window is 4. The regularization parameter, C and Epsilon, ε are 1.513561 and 0.01 respectively. The minimum mean test score is -0.057324 with iteration index of 2. Table 5 represents the result when the sliding window is 5. Iteration index of 5 has the most optimized hyperparameters of 109.657820 and 0.01 for C and ε respectively.

Table 4: Optimization results when sliding window, w, is four (w=4)

Iteration index	Hyperparameters		Mean Test Score	Rank Test Score
	C	Epsilon		
2	1.513561	0.01	-0.057324	1
11	1.513561	0.01	-0.057324	2
10	331.131121	0.01	-0.065398	3
7	1.148154	0.05	-0.070806	4
9	0.165959	0.04	-0.076877	5
5	109.647820	0.1	-0.078764	6
0	1.513561	0.07	-0.081203	7
4	0.023988	0.02	-0.083706	8
1	0.036308	0.1	-0.084794	9
14	0.006918	0.01	-0.085940	10

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

Table 5: Optimization results when sliding window, w, is five (w=5)

Iteration index	Hyperparameters		Mean Test Score	Rank Test Score
	C	Epsilon		
5	109.647820	0.1	-0.051088	1
6	660.693448	0.08	-0.061645	2
10	109.647820	0.06	-0.066291	3
12	6.918310	0.1	-0.068731	4
2	1.513561	0.01	-0.076404	5
7	1.148154	0.05	-0.078657	6
0	1.513561	0.07	-0.084140	7
9	0.165959	0.04	-0.085037	8
4	0.023988	0.02	-0.086637	9
1	0.036308	0.1	-0.090386	10

4.2 Performance evaluation of the Optimized Hyperparameters

The most optimized hyperparameters were subsequently selected and were employed for the prediction. Figures 1-5 show the actual versus predicted values of the load. The data points are 16, 15, 14, 13, and 12 are for sliding window 1, 2, 3, 4 and 5 respectively. Figure 1 shows the actual data with the predicted when the sliding window is one. The maximum predicted value 2549.80 MW in the sixth month while the actual value is 2625.56 MW in the fifth month. The minimum actual and predicted was at twelfth and eleventh month respectively. The predicted and actual value was 1911.39 MW and 1725.18 MW respectively. Figure 2 shows the actual and predicted for the sliding window of two, the maximum value of predicted and actual was 2552.51 MW at fifth month and 2625.56 MW at fourth month respectively. On the other hand, the minimum predicted, and actual value was at 1857.00 MW at eleventh month and 1725.18 MW at tenth month respectively. Figure 3 shows the actual and predicted when the sliding window is three. The maximum and minimum value of predicted energy consumed was 2551.29 MW for fourth month and 1884.14 MW for tenth month respectively. Figure 4 depicts the actual and predicted when the sliding window is four. The maximum and minimum value of predicted energy consumed was 2550.09 MW for third month and 1943.88 MW for sixth month respectively. Figure 5 shows the actual and predicted when the sliding window is five. The maximum and minimum value of predicted energy consumed was 2545.60 MW for first month and 1931.80 MW for fifth month respectively.

Table 6 depicts the performance evaluation of the support vector regression models. Mean Square Error (MSE) and Mean Absolute Error (MAE) were employed for evaluation. The Model with sliding window of 1 had the best performance of MSE and MAE of 0.01912 and 0.09493 respectively. The model at sliding window of 3 had the least performance with 0.02209 and 0.10404 for MSE and MAE respectively. The sliding window technique is a viable approach that had proved to increase the performance of load prediction.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

Table 6: Performance evaluation with the Sliding window

Sliding Window (w)	MSE	MAE
1	0.01912	0.09493
2	0.02116	0.10366
3	0.02209	0.10404
4	0.02048	0.10206
5	0.01999	0.09974

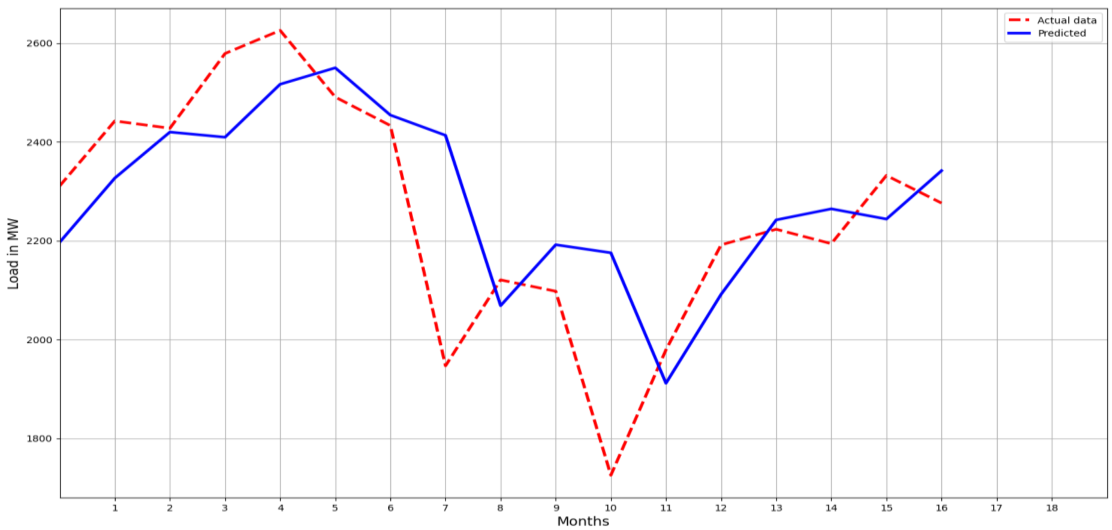


Figure 1: Actual and predicted values for w=1

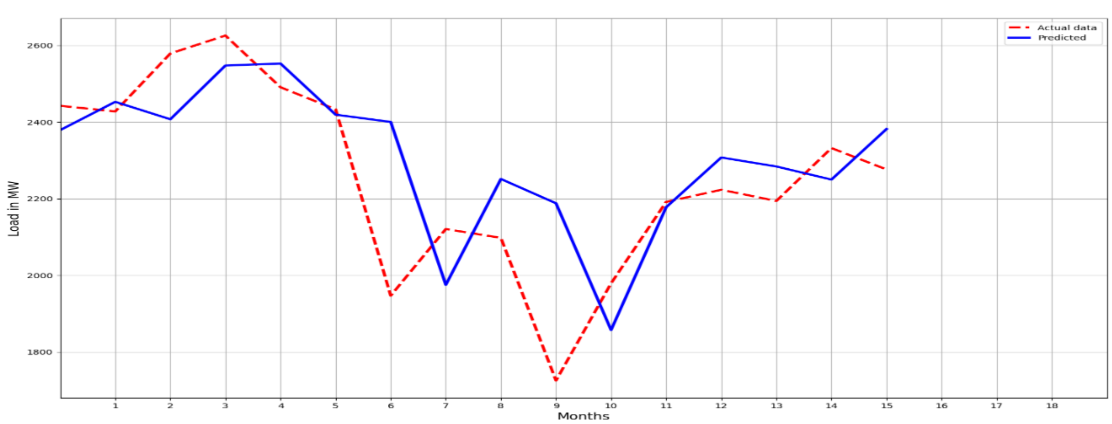


Figure 2: Actual and predicted values for w=2

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

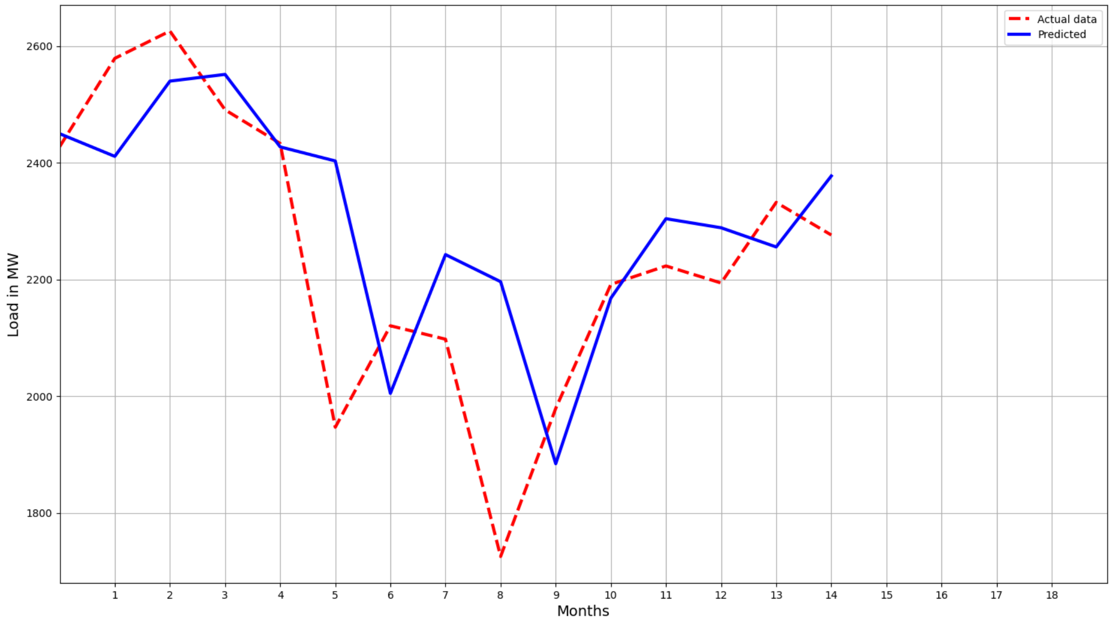


Figure 3: Actual and predicted values for w=3

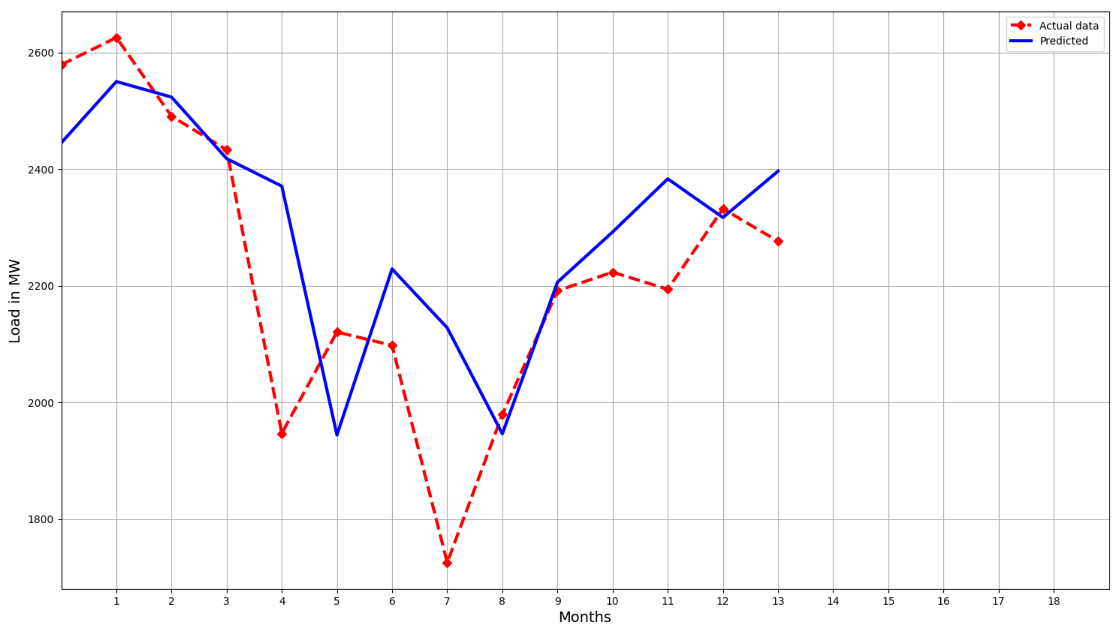


Figure 4: Actual and predicted values for w=4

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

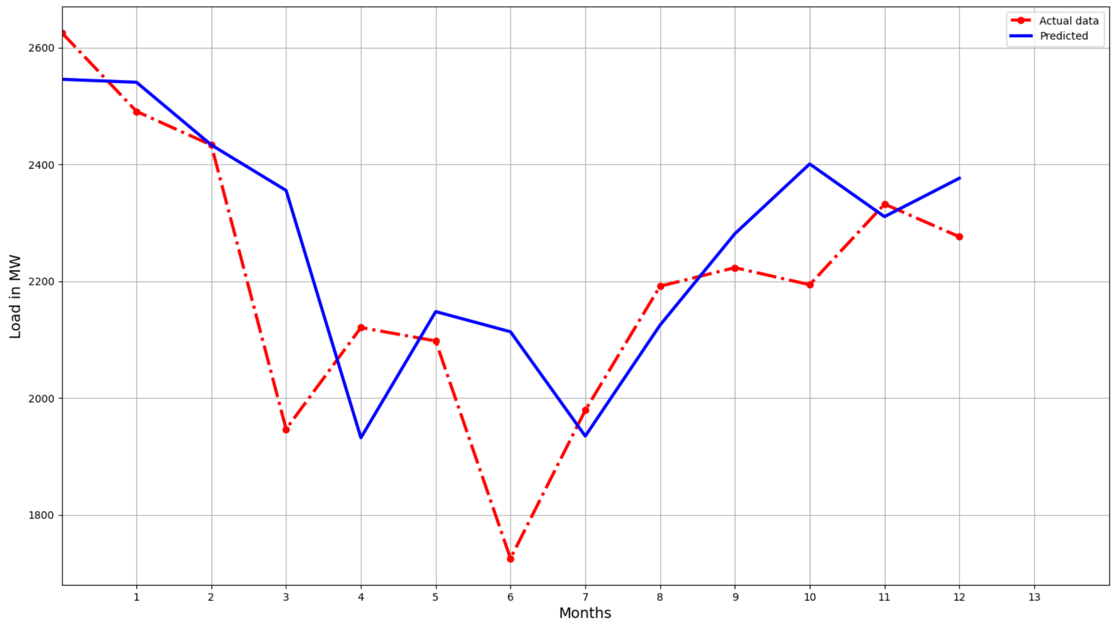


Figure 5: Actual and predicted values for w=5

5.0 Conclusion

The study investigated the performance of Support Vector Regression (SVR) models using sliding window (w) technique. The electrical load dataset of six business hubs in Ogun State, Nigeria was employed for the development of the models. The results showed that, the values of the sliding window have effect on the load prediction. For efficient and effective load forecasting, the hyperparameters of the SVR were also optimized using Bayesian technique. The best performing model was obtained when the sliding window was one, that is, w=1. Summarily, this work discovered that, a sliding window technique could be employed to enhance load prediction. This could be used to reduces electrical load losses and revenue generation increment. Since this research study developed a linear SVR, in future, Radial basis function of SVR could also be investigated. In addition, optimization of the neural network hyperparameters could also be investigated in future studies.

Future studies could employ other machine learning algorithm like optimized neural network and ensemble methods. The sliding window techniques can also be used with different dataset. Furthermore, weather parameters could also be added in future research.

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

References

[1] A. Azam, M. Rafiq, M. Shafique, H. Zhang, M. Ateeq, and J. Yuan, “Analyzing the relationship between economic growth and electricity consumption from renewable and non-renewable sources: Fresh evidence from newly industrialized countries,” *Sustain. Energy Technol. Assess.*, vol. 44, p. 100991, 2021.

[2] M. Sikder *et al.*, “The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO2 emissions in developing countries: evidence from the panel ARDL approach,” *Sci. Total Environ.*, vol. 837, p. 155795, 2022.

[3] T. Ahmad *et al.*, “Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities,” *J. Clean. Prod.*, vol. 289, p. 125834, 2021.

[4] R. V. Yohanandhan, R. M. Elavarasan, P. Manoharan, and L. Mihet-Popa, “Cyber-physical power system (CPPS): A review on modeling, simulation, and analysis with cyber security applications,” *IEEE Access*, vol. 8, pp. 151019–151064, 2020.

[5] T. O. Ajewole, A. A. Olawuyi, M. K. Agboola, and O. Onarinde, “A comparative study on the performances of power systems load forecasting algorithms,” *Turk J Electr Power Energy Syst*, vol. 1, no. 2, pp. 99–107, 2021.

[6] X. Tang, Y. Dai, T. Wang, and Y. Chen, “Short-term power load forecasting based on multi-layer bidirectional recurrent neural network,” *IET Gener. Transm. Distrib.*, vol. 13, no. 17, pp. 3847–3854, 2019.

[7] A. Salam and A. El Hibaoui, “Comparison of Machine Learning Algorithms for the Power Consumption Prediction:-Case Study of Tetouan city–,” in *2018 6th International Renewable and Sustainable Energy Conference (IRSEC)*, IEEE, 2018, pp. 1–5.

[8] K. B. Debnath and M. Mourshed, “Forecasting methods in energy planning models,” *Renew. Sustain. Energy Rev.*, vol. 88, pp. 297–325, 2018.

[9] G. Hafeez, K. S. Alimgeer, and I. Khan, “Electric load forecasting based on deep learning and optimized by heuristic algorithm in smart grid,” *Appl. Energy*, vol. 269, p. 114915, 2020.

[10] B. Dietrich, J. Walther, M. Weigold, and E. Abele, “Machine learning based very short term load forecasting of machine tools,” *Appl. Energy*, vol. 276, p. 115440, 2020.

[11] U. Cali *et al.*, “Applications of artificial intelligence in the energy domain,” *Digit. Power Mark. Syst. Using Energy Inform.*, pp. 139–168, 2021.

[12] H. G. Bergsteinsson, J. K. Møller, P. Nystrup, Ó. P. Pálsson, D. Guericke, and H. Madsen, “Heat load forecasting using adaptive temporal hierarchies,” *Appl. Energy*, vol. 292, p. 116872, 2021.

[13] P. Ma, S. Cui, M. Chen, S. Zhou, and K. Wang, “Review of family-level short-term load forecasting and its application in household energy management system,” *Energies*, vol. 16, no. 15, p. 5809, 2023.

[14] M. A. Majeed *et al.*, “Artificial Neural Network Modelling for Short Term Load Forecasting,” in *2021 International Conference on Technology and Policy in Energy and Electric Power (ICT-PEP)*, IEEE, 2021, pp. 302–306.

[15] Y. Lei *et al.*, “multi-objective stochastic expansion planning based on multi-dimensional correlation scenario generation method for regional integrated energy system integrated renewable energy,” *Appl. Energy*, vol. 276, p. 115395, 2020.

[16] S. Rai and M. De, “Analysis of classical and machine learning based short-term and mid-term load forecasting for smart grid,” *Int. J. Sustain. Energy*, vol. 40, no. 9, pp. 821–839, 2021.

[17] Y. Yang, E. U. Haq, and Y. Jia, “A novel deep learning approach for short and medium-term electrical load forecasting based on pooling LSTM-CNN model,” in *2020 IEEE/IAS Industrial and Commercial Power System Asia (I&CPS Asia)*, IEEE, 2020, pp. 26–34.

[18] H. Eskandari, M. Imani, and M. P. Moghaddam, “Convolutional and recurrent neural network based model for short-term load forecasting,” *Electr. Power Syst. Res.*, vol. 195, p. 107173, 2021.

[19] S. H. Rafi, S. R. Deeba, and E. Hossain, “A short-term load forecasting method using integrated CNN and LSTM network,” *IEEE Access*, vol. 9, pp. 32436–32448, 2021.

[20] O. Olabode, O. A. Amole, T. Ajewole, and I. Okakwu, “Medium-term load forecasting in A nigerian electricity distribution region using regression analysis techniques,” *2020 Int. Conf. Math. Comput. Eng. Comput. Sci. ICMCECS*, vol. null, pp. 1–5, 2020, doi: 10.1109/ICMCECS47690.2020.240907.

[21] M. H. Alsharif, M. K. Younes, and J. Kim, “Time series ARIMA model for prediction of daily and monthly average global solar radiation: The case study of Seoul, South Korea,” *Symmetry*, vol. 11, no. 2, p. 240, 2019.

JDFEWS 4 (2): 23-36, 2023
ISSN 2709-4529

[22] T. Alghamdi, K. Elgazzar, M. Bayoumi, T. Sharaf, and S. Shah, "Forecasting traffic congestion using ARIMA modeling," in *2019 15th international wireless communications & mobile computing conference (IWCMC)*, IEEE, 2019, pp. 1227–1232.

[23] G. S. Sheshadri, "Electrical load forecasting using time series analysis," in *2020 IEEE Bangalore Humanitarian Technology Conference (B-HTC)*, IEEE, 2020, pp. 1–6.

[24] L. Zhang *et al.*, "A review of machine learning in building load prediction," *Appl. Energy*, vol. 285, p. 116452, 2021.

[25] T. O. Ajewole, A. A. Olawuyi, M. K. Agboola, and O. Onarinde, "A Comparative Study on the Performances of Power Systems Load Forecasting Algorithms," 2021.

[26] Z. P. Ncane and A. K. Saha, "Forecasting solar power generation using fuzzy logic and artificial neural network," in *2019 Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa (SAUPEC/RobMech/PRASA)*, IEEE, 2019, pp. 518–523.

[27] A. Slowik and H. Kwasnicka, "Evolutionary algorithms and their applications to engineering problems," *Neural Comput. Appl.*, vol. 32, no. 16, pp. 12363–12379, 2020.

[28] B. Farsi, M. Amayri, N. Bouguila, and U. Eicker, "On short-term load forecasting using machine learning techniques and a novel parallel deep LSTM-CNN approach," *IEEE Access*, vol. 9, pp. 31191–31212, 2021.

[29] M. Khodayar, G. Liu, J. Wang, and M. E. Khodayar, "Deep learning in power systems research: A review," *CSEE J. Power Energy Syst.*, vol. 7, no. 2, pp. 209–220, 2020.

[30] H. Dagdougui, F. Bagheri, H. Le, and L. Dessaint, "Neural network model for short-term and very-short-term load forecasting in district buildings," *Energy Build.*, vol. 203, p. 109408, 2019.

[31] P. Mukhopadhyay, G. Mitra, S. Banerjee, and G. Mukherjee, "Electricity load forecasting using fuzzy logic: Short term load forecasting factoring weather parameter," in *2017 7th International Conference on Power Systems (ICPS)*, IEEE, 2017, pp. 812–819.

[32] I. M. Mehedi *et al.*, "Intelligent machine learning with evolutionary algorithm based short term load forecasting in power systems," *IEEE Access*, vol. 9, pp. 100113–100124, 2021.

[33] H. Shi, M. Xu, and R. Li, "Deep learning for household load forecasting—A novel pooling deep RNN," *IEEE Trans. Smart Grid*, vol. 9, no. 5, pp. 5271–5280, 2017.

[34] A. Moradzadeh, S. Zakeri, M. Shoaran, B. Mohammadi-Ivatloo, and F. Mohammadi, "Short-term load forecasting of microgrid via hybrid support vector regression and long short-term memory algorithms," *Sustainability*, vol. 12, no. 17, p. 7076, 2020.

[35] J. Wu, Y.-G. Wang, Y.-C. Tian, K. Burrage, and T. Cao, "Support vector regression with asymmetric loss for optimal electric load forecasting," *Energy*, vol. 223, p. 119969, 2021.

[36] Z. Wang, X. Zhou, J. Tian, and T. Huang, "Hierarchical parameter optimization-based support vector regression for power load forecasting," *Sustain. Cities Soc.*, vol. 71, p. 102937, 2021.

[37] H. Drucker, C. J. Burges, L. Kaufman, A. Smola, and V. Vapnik, "Support vector regression machines," *Adv. Neural Inf. Process. Syst.*, vol. 9, 1996, Accessed: Nov. 19, 2023. [Online]. Available: https://proceedings.neurips.cc/paper/1238-support-vector-regression-machines

[38] F. Zhang and L. J. O'Donnell, "Support vector regression," in *Machine learning*, Elsevier, 2020, pp. 123–140.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Multivariate analysis of water quality of 'omi-omo' stream Ikole Ekiti, Nigeria.

Oluwaseun Ayodele ILESANMI
Agricultural and bioresources Engineering Department Federal University Oye Ekiti, Nigeria;
oluwaseun.ilesanmi@fuoye.edu.ng

Abraham Olusola OLOYE
Agricultural and bioresources Engineering Department Federal University Oye Ekiti, Nigeria

Peter Odunayo OLUWAFEMI
Agricultural and bioresources Engineering Department Federal University Oye Ekiti, Nigeria

Okwunna Maryjane UMEGO
Agricultural and bioresources Engineering Department Federal University Oye Ekiti, Nigeria

Eric Olorunwa OMOFUNMI
Agricultural and bioresources Engineering Department Federal University Oye Ekiti, Nigeria

Received: 23 November 2023

Review: 10 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract - The multivariate Principal Component Analysis (PCA) was used to assess the variations in the water quality of the "Omi Omo" Stream. This allowed for the identification of temporal and spatial variations in the water quality caused by contamination by analysing the similarities and differences between the sampling points. For three months, four sampling locations along the streamline provided data on the quality of the water. Temperature and other physicochemical parameters were used to analyse the samples. Turbidity, alkalinity, Electrical Conductivity (EC), Total hardness TH, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biological oxygen demand (BOD), heavy metals (Cadmium - Cd, Copper - Cu, Lead - Pb, Iron - Fe, Manganese - Mn), sulphate, phosphate, nitrate, and chloride were also determined. For the months under study, PCA helped identify and extract the factors causing variations in water quality. The important factors influencing the variation in water quality for the three months of study were turbidity, TDS, alkalinity, electrical conductivity, nitrate, calcium, and chloride. The comparison of the stream's physicochemical parameters with the World Health Organization (W.H.O) standards shows an acceptable correlation except for the turbidity and the EC which for some periods were higher than the acceptable level of the W.H.O standard. The study's findings will assist pertinent authorities in determining how to improve the declining water quality caused by pollution from various human activities.

Keywords: *Contamination, Multivariate, Physicochemical, Principal Component Analysis, W.H.O., Water management, Water quality*

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

1.0 Introduction

Water is now one of the main environmental issues and is impacted by both natural and man-made disturbing factors, such as land recovery, overflows, and wastewater, with great competition for access to it increasing [1]. Surface waters are helpless against contamination because of common techniques, namely, disintegration, precipitation, weathering of crustal materials and anthropogenic exercises such as industrial, horticultural, and urban activities [2]. Due to its significance for human prosperity, surface water quality management has received increased attention in recent years. When surface water becomes polluted, it usually brings about an imbalance in the ecosystem, this, in turn, affects the beneficial interactions that are essential between living organisms and the environment [3].

Pollution causes the natural harmony in the world to be disturbed. Water quality management programmes increasingly include the identification of the factors controlling the behavioural properties of aquatic systems in addition to the assessment of the aquatic systems' quality. But in order to have accurate data about water quality, ongoing and frequent monitoring programmes are needed because hydro chemical and biological characteristics vary over time and space [4].

The Omi-Omo Stream needs to have its capacity to carry pollutants evaluated because the riparian population, particularly those who use the water for domestic and agricultural uses, depends on it. In nature, the human need for water is important and it's required in both premium quality and quantity [5].

In water quality monitoring, the concern is centred on keeping impurities within safe limits. [6] described the pollution of water as the biofouling of the aquatic environment in a way that prevents water from being used for its intended purpose. Thus, while water may contain certain pollutants, it may not be described as polluted provided it meets the intended use for which it was designated. The source of the pollution may be dispersed randomly throughout the water body or concentrated at one location. When the former is the case, it is described as a point source. When the latter is the case, it is called a non-point source [7].

Proper management usually goes hand in hand with getting quality from our natural resources and the same goes for our water resources [8]. Only within a legal framework is it possible to manage water quality, and for a while, many nations had antiquated, rudimentary water laws that limited the efficacy of water quality management [9]. Although there have been observations of water quality for over a century, the understanding that hydrologic processes have an impact on water quality has made the need for systematic management of water quality imperative. Due to this, there is now a need for a more thorough comprehension of the procedure and its application within an organised programme for managing water quality [10; 11]. For any water quality management programme to be successful, all stakeholders must be involved in the identification of discharges to receiving waters [12; 13; 14]. Similar to this, [9] claimed that better decisions about water quality management result from the integration of indigenous knowledge with scientific knowledge. Having access to current, high-quality, and trustworthy data is crucial for effectively managing the quality of the water [15; 16]. Climate change is increasing the frequency and intensity of extreme weather events that may have an impact on the safety of

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

drinking water [17]. However, the cost and duration of on-site water quality assessments frequently act as a barrier to data availability [18; 19].

A well-thought-out and implemented water quality management programme yields results that support prompt, important management decisions that are grounded in comprehensive, reliable data [19]. Every component of the programme offers vital and relevant solutions to issues pertaining to water [18]. River discharges have been widely used as a covariate in the evaluation of water quality and in the development of water quality standards for rivers that are considered for wastewater disposal, provided that the discharge conditions are low. Nonetheless, different rivers have different constituent concentrations, stream discharges, and parameter interactions [14]. This is explained by the fact that a number of variables, such as drought or the dry season, affect the water in streams and rivers and cause variations in the quality of the water [20]. This variance is evident in the way that different loading volumes have different effects on rivers or other water bodies that receive wastewater. There might be none or very little effect at a given discharge, but the same loading volume can have a greatly degrading effect at low discharges [21]. The needs and goals of the assessment determine which parameters should be used for the water quality assessment [22]. For this investigation, among other parameters, the ones below were examined.

Temperature, pH, Alkalinity, Turbidity, Total Alkalinity, Ammonia, Phosphorus, Dissolved Oxygen, Biological Oxygen Demand, Total Suspended Solids, Total Dissolved Solids, and few Heavy metals.

The above parameters were also considered by [23] in the water quality assessment of a river in Nigeria. Characteristics of temporal variation are crucial and according to [24], the degree of the pollutant's temporal and spatial variation determines the risk associated with it.

2. Methods

2.1 Area of study

Omi-Omo Stream in 6˚15N7˚10E was the focal water body for the study. This stream has its source from the stream flows from Fesola River which is located at oke orin, Ikole local government area, and Omi Iru in Ikole, the streams then converge at Omi Omo Street and flows through Omi Omo stream. The riparian population uses the stream for domestic, ponding and irrigation purposes.

2.2 Collection of water samples

For three months (July to September 2021), water samples were taken once a month from four sampling locations. Grab samples were taken at various locations by carefully dipping sample containers that had already been cleaned into the water and the temperature was recorded immediately at the various sampling points.

2.2.1 Sampling Points: The points at which water samples were collected were labelled A to D.

Point A: Stream source.

Point B: The point of major contamination

Point C: 2m downstream from the point of major contamination.

Point D: 100m downstream from the major contamination point.

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

The samples collected were taken to the laboratory for analysis on the same day. Below are the method and means applied in detecting the levels of parameters considered for this research; the research applied standard laboratory procedures as described by the American Public Health Association's Standards methods for examination of water and wastewater [25].

Table 1: Techniques for calculating physicochemical parameters.

Parameter	Method of determination
pH	HANNA Hi208 pH meter.
Temperature (°C)	Thermometer
EC (us/cm)	DDS-307 Conductivity meter.
Alkalinity (mg/l)	Titration method
TH (mg/l)	EDTA Titration method
TDS (ppm)	HM TDS-3 TDS Meter
DO	Winkler's method
BOD	Winkler's method
TSS	Filtration method
Lead (ppm)	Spectronic 20 machine
Chloride (mg/l)	Argentometric method
Sulphate (mg/l)	Turbidimetric method
Phosphate (mg/l)	Spectronic meter
Nitrate (mg/l)	UV spectrophotometric method
Turbidity (NTU)	Labtech AVI-654 Turbidity meter.
Ca	EDTA Titration method
Cd, Mn, Fe, Cu	Buck Scientific 210VGP atomic absorption spectrophotometer (AAS).

Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Hardness (TH), Cadmium (Cd) (ppm), Manganese (Mn) (ppm), Iron (Fe) (ppm), Calcium (Ca) (ppm), Copper (Cu) (ppm)

2.3 Statistical Analysis

Factor Analysis (FA) which is similar to Principal Component analysis, an extremely potent method was used. With the least amount of information loss and maximum preservation of the variability found in the dataset, this method lowers the dimensionality of a dataset made up of numerous interconnected variables (Equation 1).

$$F_i = a_1 x_1 j + a_2 x_2 j + \cdots + a_m x_m j \quad (1)\ [26]$$

Given that F_i is the factor; a is the loading; x is the measured value of variable; i is the factor number; j is the sample number; and m is the total number of variables.

2.4 Principal Component Analysis (PCA)

The PCA method was used to conduct the analysis and determine the most important parameters in the assessment of water quality. In order to determine significant water quality parameters, PCA was used in this study to analyse 19 variables from four separate sampling locations during the water quality monitoring months of July, August, and September 2021. A factor's significance can be gauged by its eigenvalues, and the most significant factors are those with the highest eigenvalues. Significant eigenvalues are those that are 1.0 or higher [27]. Principal

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

components are thus classified as "Strong," "Moderate," and "Weak," with absolute loading values of >0.75, 0.75-0.50, and 0.50-0.30, respectively [28].

3 Results and Discussions

3.1 The relationship between the variables (Correlation)

Finding the parameter correlation matrix is the first stage in the factor analysis process. It is employed to take into consideration the extent to which individual pairs of water quality variables share variability with one another. We were able to obtain the correlation matrix, which allows us to see the relationship between the parameters (Table 2 – 4).

Studies that examine the correlation between various variables are a very useful tool for advancing research and discovering new areas of knowledge. The range of uncertainty related to decision-making is decreased by the study of correlation. Most of the anions and cations have inverse relationships with pH. There is a highly significant ($p<0.01$) positive correlation between EC and TDS and SO4-, two water quality parameters. Additionally, there is a noteworthy positive correlation ($p<0.05$) with TH. This suggested that the hydrochemical properties of these parameters are comparable in the studied region. Due to their low concentrations, DO do not considerably increase conductivity. At a highly significant level, alkalinity and TH have a positive correlation ($p<0.05$). TH exhibits a highly significant ($p<0.05$) positive correlation with TDS, Ca, and sulphate, as well as a highly significant ($p<0.01$) positive correlation with sulphate. TDS has a significant positive correlation ($p<0.5$) with calcium and a significant positive correlation ($p<0.01$) with sulphate. At a highly significant level, DO and BOD have a positive correlation ($p<0.01$). At a highly significant level, manganese and lead had a negative correlation ($p<0.01$). At a highly significant level, calcium exhibits a positive correlation with both sulphate and chloride ($p<0.05$). Phosphate and iron had a highly significant negative correlation ($p<0.01$). Lead and Nitrate have a highly significant positive correlation ($p<0.01$).

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Table 2: Correlation coefficients for Nineteen Physicochemical parameters for the of July

	pH	Temp.	EC	Alk.	TH	TDS	DO	BOD	TSS	Mn	Ca	Fe	Cu	Pb	Cl^-	SO_4^-	PO_4^-	NO_3	Turb
pH	1.000																		
Temp	-.407	1.000																	
EC	-.593	.360	1.000																
Alk.	-.218	.149	.912	1.000															
TH	-.495	.169	**.979***	**.951***	1.000														
TDS	-.596	.337	**1.000****	.912	**.983***	1.000													
DO	-.465	.777	-.124	-.448	-.321	-.140	1.000												
BOD	-.333	.663	-.320	-.615	-.503	-.335	**.980***	1.000											
TSS	-.170	-.827	.047	.062	.200	.074	-.609	-.579	1.000										
Mn	.714	.156	-.758	-.611	-.806	-.774	.287	.418	-.647	1.000									
Ca	-.509	.032	.944	.915	**.987***	**.952***	-.397	-.567	.352	-.878	1.000								
Fe	-.589	.400	-.255	-.628	-.400	-.259	.866	.885	-.145	.060	-.396	1.000							
Cu	-.002	-.895	-.281	-.255	-.134	-.256	-.511	-.419	.944	-.383	.025	-.016	1.000						
Pb	-.842	.132	.857	.643	.848	.866	-.053	-.216	.414	**-.958***	.882	.071	.132	1.000					
Cl^-	-.452	-.138	.874	.873	.948	.886	-.515	-.664	.498	-.906	**.985***	-.442	.186	.861	1.000				
SO_4^-	-.591	.276	**.996****	.916	**.991****	**.998****	-.190	-.381	.136	-.807	**.969***	-.281	-.195	.881	.914	1.000			
PO_4^-	.550	-.195	.341	.695	.451	.340	-.743	-.787	-.047	-.010	.414	**-.977***	-.195	-.064	.424	.349	1.000		
NO_3	-.836	.250	.912	.701	.886	.918	-.003	-.181	.289	-.916	.897	.050	-.006	**.990****	.855	.925	-.013	1.000	
Turb	-.831	.638	.893	.641	.790	.887	.324	.131	-.139	-.659	.738	.192	-.407	.844	.629	.866	-.072	.905	1.000

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Table 3: Correlation coefficients for Nineteen Physicochemical parameters for the of August

	pH	Temp	EC	Alk.	TH	TDS	DO	BOD	TSS	Mn	Ca	Fe	Cu	Pb	Cl^-	SO_4^-	PO_4^-	NO_3	Turb
pH	1.000																		
Temp	.367	1.000																	
EC	-.701	-.045	1.000																
Alk.	-.735	.067	**.985***	1.000															
TH	-.410	-.853	-.231	-.265	1.000														
TDS	-.712	-.029	**1.000****	**.990***	-.232	1.000													
DO	-.293	-.915	.278	.131	.571	.255	1.000												
BOD	.241	-.483	.198	.030	-.019	.167	.764	1.000											
TSS	-.464	.621	.351	.507	-.325	.379	-.702	-.821	1.000										
Mn	.738	.846	-.193	-.163	-.908	-.194	-.644	.002	.116	1.000									
Ca	-.310	-.681	-.415	-.411	**.960***	-.410	.327	-.248	-.193	-.803	1.000								
Fe	-.503	.088	**.969***	.942	-.431	**.965***	.219	.309	.280	.030	-.616	1.000							
Cu	-.585	.528	.492	.634	-.287	.519	-.580	-.742	.986*	.022	-.197	.408	1.000						
Pb	-.803	-.787	.257	.242	.869	.260	.585	-.075	-.009	**-.994****	.771	.026	.088	1.000					
Cl^-	.315	.054	.404	.287	-.563	.380	.345	.828	-.438	.448	-.748	.592	-.377	-.477	1.000				
SO_4^-	.178	-.444	-.802	-.797	.759	-.800	.094	-.236	-.344	-.429	.875	-.915	-.419	.371	-.682	1.000			
PO_4^-	.203	-.636	-.731	-.777	.807	-.737	.358	.058	-.591	-.489	.850	-.824	-.637	.410	-.466	**.955***	1.000		
NO_3	-.317	-.685	.573	.427	.221	.549	.914	.844	-.553	-.416	-.058	.570	-.409	.379	.627	-.316	-.042	1.000	
Turb	-.686	-.918	.231	.172	.888	.226	.771	.177	-.258	-.984*	.743	.031	-.151	.965*	-.291	.375	.487	.562	1.000

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Table 4: Correlation coefficients for Nineteen Physicochemical parameters for the of September

	pH	Temp	EC	Alk.	TH	TDS	DO	BOD	TSS	Mn	Ca	Fe	Cu	Pb	Cl^-	SO_4^-	PO_4^-	NO_3	Turb
pH	1.000																		
Temp	.858	1.000																	
EC	.711	.322	1.000																
Alk.	-.093	-.579	.382	1.000															
TH	-.771	-.709	-.226	.023	1.000														
TDS	.658	.184	.942	.625	-.347	1.000													
DO	**-.956***	-.848	-.524	.079	.924	-.545	1.000												
BOD	-.265	.222	-.851	-.732	-.137	-.878	.085	1.000											
TSS	.433	-.074	.683	.856	-.412	.888	-.438	-.766	1.000										
Mn	.920	.916	.387	-.258	-.924	.379	**-.981***	.096	.262	1.000									
Ca	-.664	-.670	-.055	.092	**.985***	-.188	.854	-.292	-.300	-.878	1.000								
Fe	-.075	.049	-.591	.008	-.576	-.352	-.223	.612	.023	.281	-.696	1.000							
Cu	.514	.018	.717	.804	-.477	.909	-.517	-.749	**.996****	.346	-.361	.024	1.000						
Pb	.591	.796	.354	-.728	-.143	.058	-.429	.095	-.376	.506	-.084	-.484	-.302	1.000					
Cl^-	.847	.454	.914	.428	-.580	**.955***	-.769	-.702	.816	.638	-.432	-.216	.861	.225	1.000				
SO_4^-	.368	.106	.132	.546	-.772	.423	-.570	-.109	.723	.492	-.768	.696	.732	-.496	.496	1.000			
PO_4^-	-.080	-.312	.582	.274	.659	.424	.357	-.753	.154	-.457	.779	**-.951***	.129	.195	.216	-.569	1.000		
NO_3	.791	.392	.765	.523	-.717	.895	-.798	-.591	.888	.668	-.599	.065	.927	.008	**.956***	.730	-.022	1.000	
Turb	-.772	-.494	-.498	-.365	.909	-.670	.877	.264	-.754	-.796	.843	-.402	-.800	.043	-.806	-.873	.386	-.930	1.000

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

3.2 Present Water Quality

Table 5 and Figure 1 display the findings of the heavy metals and physicochemical parameters of the samples that were taken at various times.

Table 5: Physicochemical parameters and heavy metals of samples collected at different points.

PARAMETERS	Point of sampling			
	A	B	C	D
Ph	6.86	7.04	6.95	6.66
Temperature (°C)	21.63	21.57	21.73	21.23
Electrical conductivity (µs/cm)	230.00	342.67	208.67	287.67
Alkalinity (mg/l)	103.33	94.00	83.00	108.00
Total Hardness (mg/l)	54.96	66.91	71.84	89.23
Total dissolved solid (ppm)	194.67	218.00	180.33	242.67
Dissolved oxygen	7.40	7.02	7.48	7.62
Basic oxygen demand	2.17	1.92	2.21	2.05
Total suspended solid	58.64	60.61	52.29	58.26
Cadmium (ppm)	0.01	0.01	0.01	0.01
Manganese (ppm)	9.74	9.62	9.66	8.46
Calcium (ppm)	22.90	27.41	27.08	32.02
Iron (ppm)	2.88	1.69	2.06	2.11
Copper (ppm)	0.06	0.07	0.03	0.05
Lead (ppm)	0.01	BDL	BDL	0.02
Chloride (mg/l)	28.40	35.51	19.41	21.67
Sulphate (mg/l)	14.63	14.89	15.17	18.02
Phosphate (mg/l)	1.00	1.19	1.17	1.16
Nitrate (mg/l)	2.87	2.65	2.39	3.32
Turbidity (NTU)	1.48	1.40	1.70	1.99

BDL – Below detected limit.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

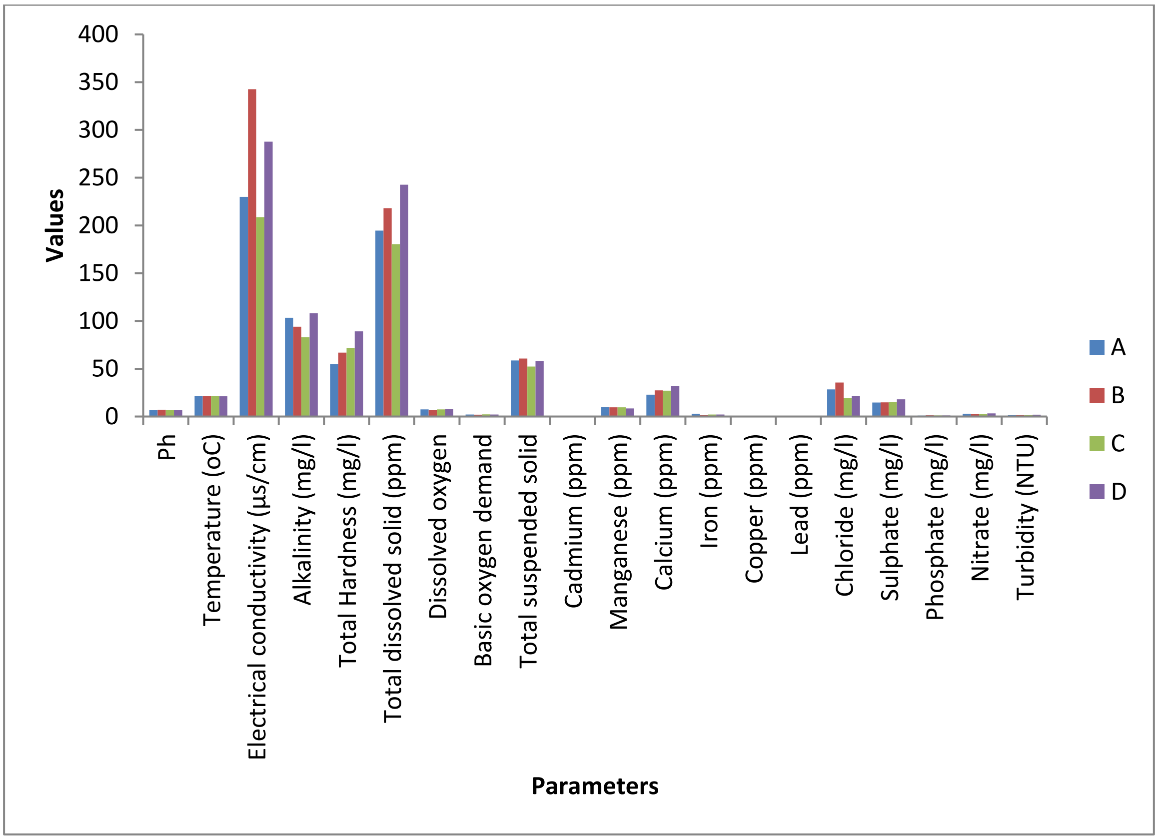


Fig 1. Heavy metals and physicochemical parameters water sample at points A, B, C and D

The PCA is summarised in Tables 6, 7, and 8, along with the loadings, eigenvalues of each PC, total variance explained, cumulative variance, and strong loading values that are indicated.

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Table 6: PCA of water quality parameters of the Stream in July

Variables	Component		
	1	2	3
Nitrate	**.987**	-.146	-.073
Sulphate	**.974**	.201	.100
TDS	**.969**	.184	.163
EC	**.965**	.182	.189
Pb	**.962**	-.176	-.209
Total Hardness	**.947**	.318	.035
Ca	**.945**	.303	-.123
Turbidity	**.905**	-.251	.342
Chloride	**.896**	.342	-.283
Mn	**-.886**	.055	.460
Alkalinity	**.806**	**.570**	.157
pH	**-.747**	**.664**	.035
Fe	-.091	**-.993**	.073
Phosphate	.142	**.981**	.135
BOD	-.270	**-.831**	.487
DO	-.083	**-.823**	**.562**
Cu	-.087	-.049	**-.995**
TSS	.229	.053	**-.972**
Temperature	.266	-.361	**.894**
Eigen values	10.366	4.752	3.882
% Variance Explained	54.556	25.011	20.433
% Cumulative Variance	54.556	79.567	100

Principal Component Analysis was used as the extraction method, and Varimax with Kaiser Normalisation was used as the rotation method. Bold figures denote absolute values >0.5 of parameters with strong loading values.

Three PCs, or 100% of the variance, were revealed by the PCA of the July data (Table 6). The first PC, which was best represented by nitrate, sulphate, TDS, EC, lead (Pb), calcium (Ca), turbidity, total hardness, chloride (Cl), manganese, alkalinity, and pH, explained 54.556% of the total variance. Iron, alkalinity, pH, phosphate, BOD, and DO account for 25.011% of the variance in PC 2. PC 3 significantly increased the load on DO, copper, TSS, and temperature and explained 20.433% of the total variance (Figure 2).

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

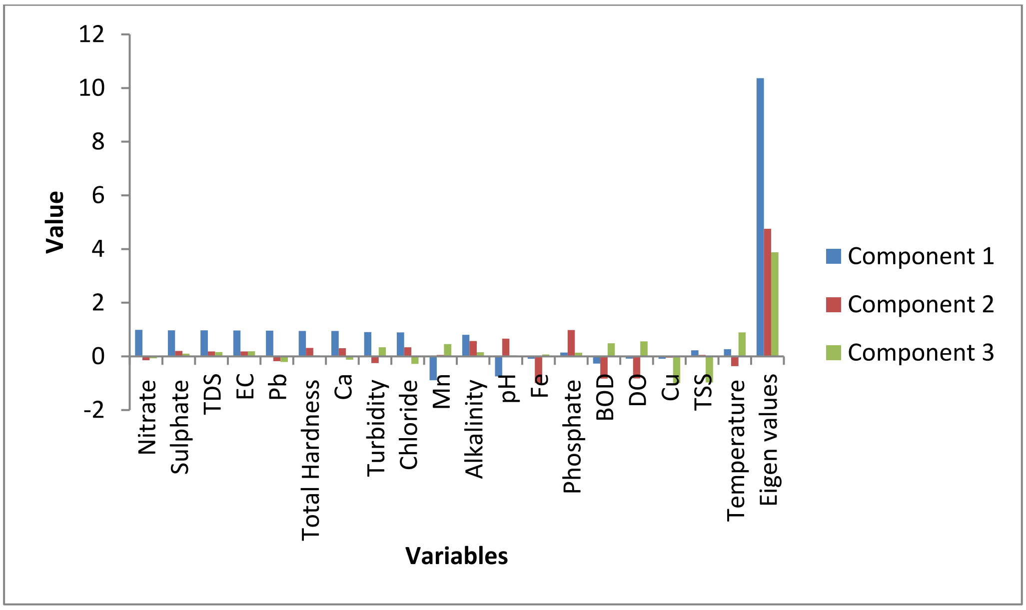


Figure 2: Component Analysis of water quality variables in July

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Table 7: PCA of water quality parameters of the Stream in August

Variables	Component		
	1	2	3
TDS	**.992**	.121	.036
EC	**.991**	.119	.067
Alkalinity	**.990**	.097	-.104
Fe	**.980**	-.108	.169
Sulphate	**-.864**	.496	-.089
Phosphate	**-.816**	**.540**	.204
Mn	-.072	**-.996**	-.045
Pb	.143	**.989**	-.040
Turbidity	.101	**.970**	.220
Total Hardness	-.351	**.933**	.083
Ca	**-.512**	**.849**	-.131
Temperature	.092	**-.831**	**-.549**
pH	**-.643**	**-.707**	.295
BOD	.139	-.056	**.989**
TSS	.429	-.107	**-.897**
Cu	**.556**	-.025	**-.831**
Nitrate	.482	.346	**.805**
DO	.155	**.600**	**.785**
Chloride	.418	**-.513**	**.749**
Eigenvalues	7.104	7.041	4.856
% Variance Explained	37.387	37.056	25.556
% Cumulative Variance	37.387	74.444	100

Principal Component Analysis was used as the extraction method, and Varimax with Kaiser Normalisation was used as the rotation method. Bold figures denote absolute values >0.5 of parameters with strong loading values.

Three components that accounted for 100% of the variance overall were extracted from the PCA of the August data (Table 7). PC 1 loaded heavily on sulphate, TDS, EC, and Alkalinity, iron, sulphate, phosphate, pH, copper, and calcium, and it explained 37.387% of the variance. Phosphate, manganese, lead, calcium, temperature, DO, pH, turbidity, total hardness, and lead accounted for 37.056% of the variance in PC 2. PC 3 provided the best explanation for 25.556% of the variation and included BOD, TSS, Copper, Nitrate, DO, and Chloride (Figure 3)

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

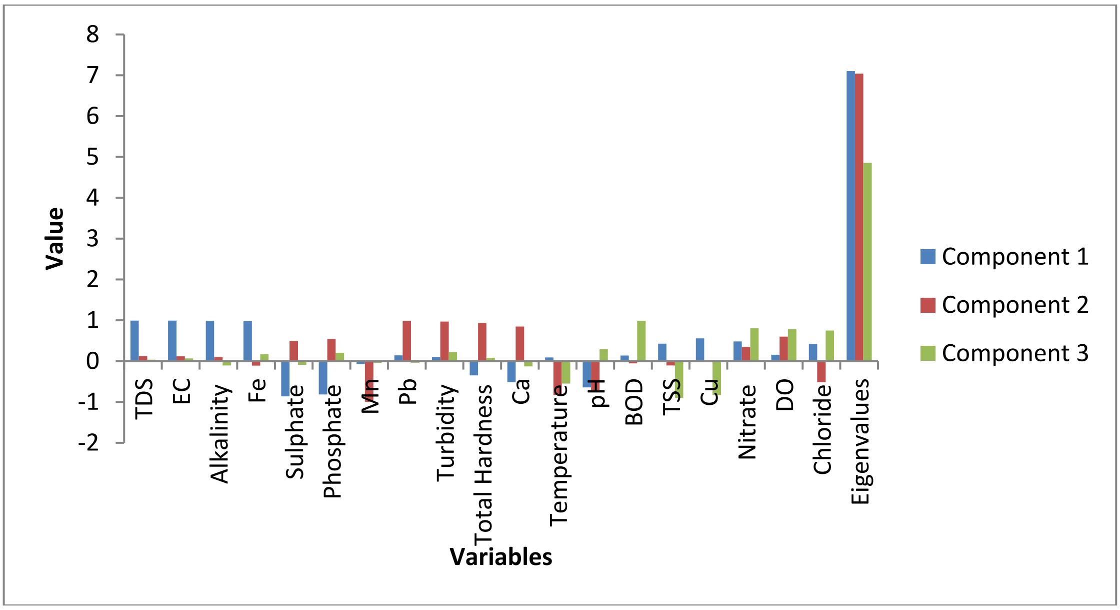


Figure 3: Component Analysis of water quality variables in August

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

Table 8: PCA of water quality parameters of the Stream in September

Variables	Component		
	1	2	3
TSS	**.984**	-.007	-.179
Cu	**.979**	.085	-.186
TDS	**.939**	.288	.188
BOD	**-.867**	.097	-.489
Nitrate	**.863**	.447	-.234
Alkalinity	**.847**	**-.521**	-.107
Chloride	**.842**	**.537**	.048
EC	**.779**	.440	.446
Turbidity	**-.670**	**-.500**	**.549**
Temperature	-.087	**.991**	-.104
Mn	.204	**.903**	-.379
pH	.437	**.898**	-.055
DO	-.388	**-.854**	.346
Pb	-.288	**.828**	.481
Fe	-.157	-.067	**-.985**
Phosphate	.324	-.190	**.927**
Sulphate	**.589**	.074	**-.805**
Ca	-.169	**-.610**	**.775**
Total Hardness	-.300	**-.670**	**.679**
Eigenvalues	7.855	6.187	4.958
% Variance Explained	41.343	32.565	26.092
% Cumulative Variance	41.343	73.908	100

Principal Component Analysis was used as the extraction method, and Varimax with Kaiser Normalisation was used as the rotation method. Bold figures denote absolute values >0.5 of parameters with strong loading values.

Three components that accounted for 100% of the variance overall were identified in the PCA of the September data (Table 8 and Figure 4). PC 1 loaded heavily on nitrate, TSS, copper, EC, chloride, alkalinity, and turbidity and explained 41.343% of the variance. Manganese, lead, calcium, turbidity, total hardness, temperature, DO, and pH accounted for 32.565% of the variance in PC 2. The variables that best accounted for PC 3's explanation of 26.092% of the variance were iron, phosphate, sulphate, calcium, and total hardness.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

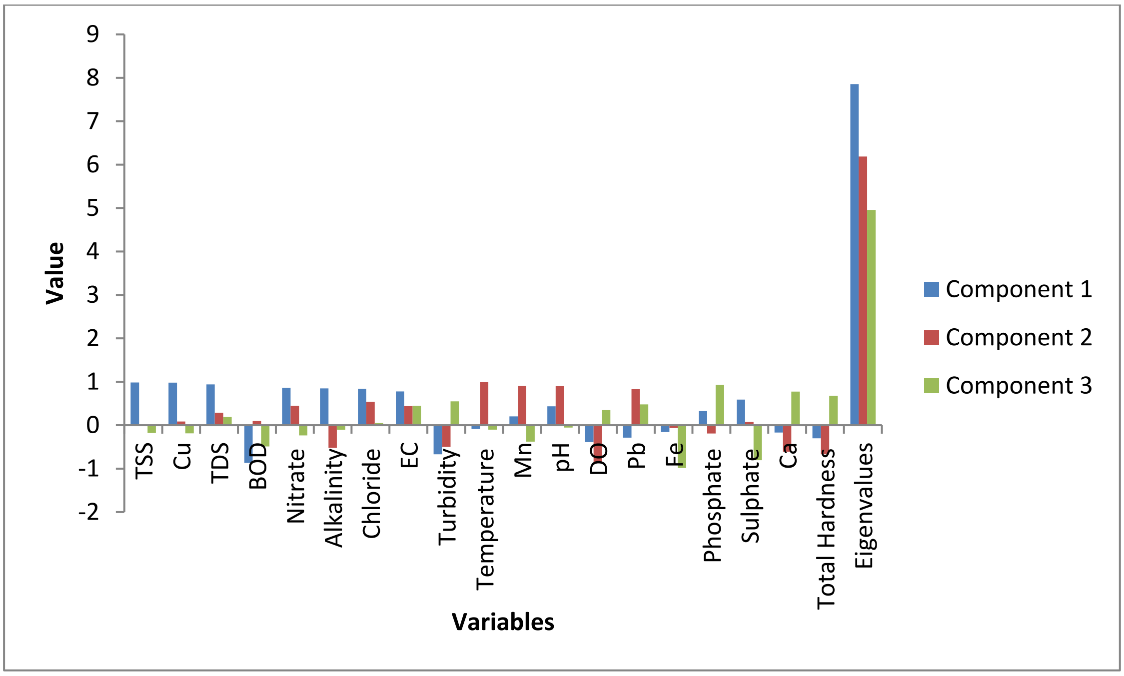


Figure 4: Component Analysis of water quality variables in September

The comparison of the stream quality with the W.H.O standard shows that the pH is within the acceptable range (Figure 5). The electrical conductivity increased above the W.H.O standard value. This relatively higher value could be attributed to the discharge of dirt and suspended inorganic matter and automobile effluent from the carwash close to the streamline because of the location of the stream. The high value of TDS may be an indication of increased runoff water from excess rainfall. Increased dissolved solids in irrigation water have an impact on crop yield, growth, and soil efficiency and the amount of copper content is within the W.H.O. standard range. There also is no deviation from the W.H.O. standard in the dissolved oxygen (DO). Because of the stream's comparatively low total hardness level, soft water is present. Total hardness brought on by calcium and magnesium was typically indicated by the build-up of soap scum and the requirement for excessive soap use in order to clean.

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

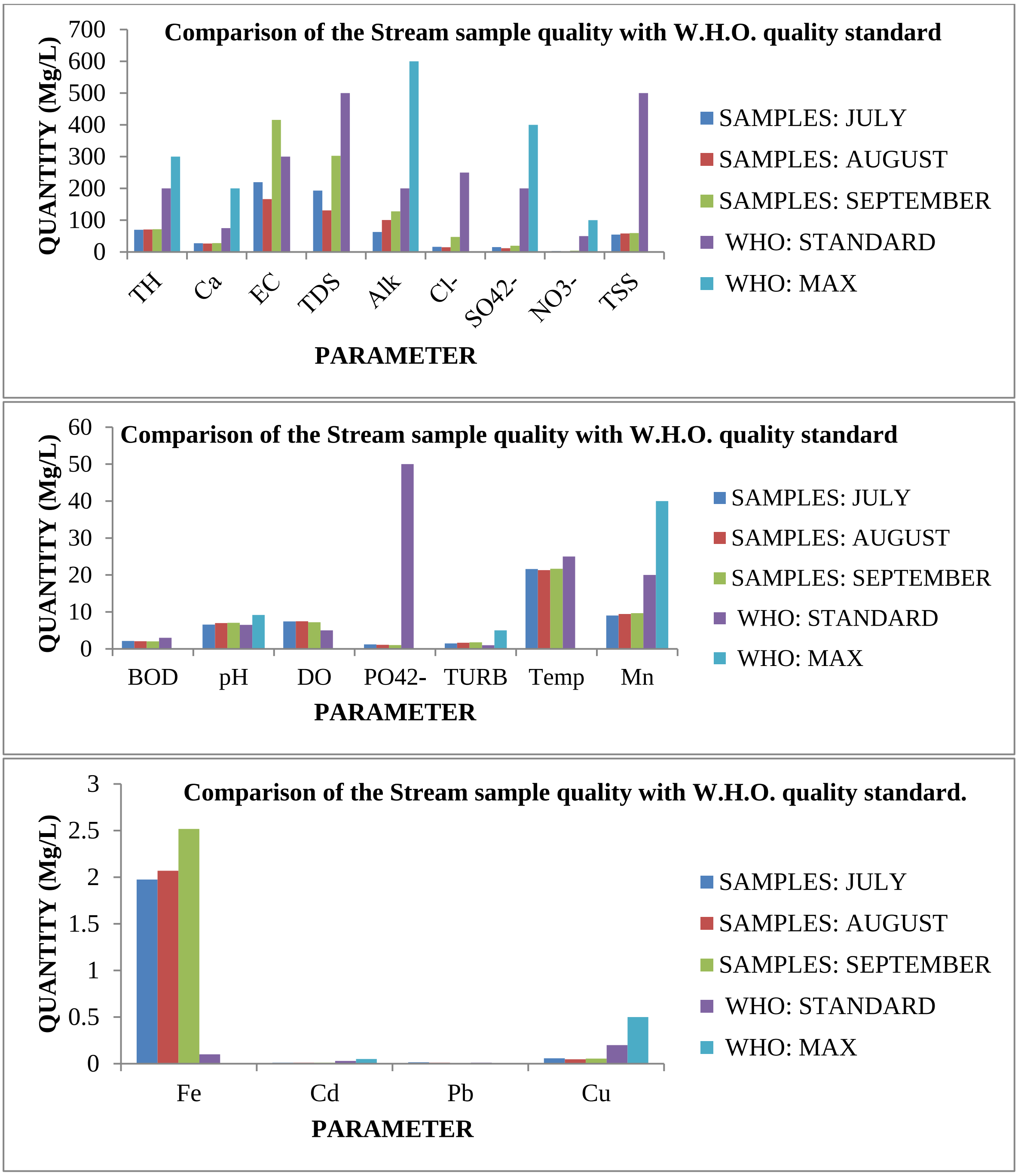


Figure 5: Comparison of detection levels with WHO Standard

4. CONCLUSION

The PCA results demonstrated the factors influencing variations in water quality, the most and significantly significant factors that were found to have an impact on the study's water qualities, and the correlation between the parameters affecting water quality. Finding the variables that regularly or consistently cause the water quality to fluctuate was also helpful. Furthermore, it might serve as a guide for choosing preventive actions for the

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

appropriate management of surface water. With the exception of turbidity and EC, which were higher than the W.H.O. standard's acceptable level, the comparison of the stream's physicochemical parameters with the standards demonstrates an acceptable correlation. As a result, the study's findings will support the pertinent authorities in developing policies that will help them effectively manage the water quality, which has declined as a result of pollution from numerous human activities. This research did not work on the microbial parameters of this river, therefore future research can explore working on analysing the microbiological parameters of "Omi Omo" Stream and more water quality parameters and heavy metals like Chemical oxygen demand, nickel and zinc.

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

5. REFERENCES

[1] E. O. Omofunmi, O. A. Ilesanmi & T. Orisabinone, T. Performance evaluation of hydraulic parameters of a developed drip irrigation system. Malysian Journal of Civil Engineering, 31,2: (2019) 9-16

[2] R. Kouadra, A. Demdoum, N. Chabour. et al. The use of hydrogeochemical analyses and multivariate statistics for the characterization of thermal springs in the Constantine area, Northeastern Algeria. Acta Geochim 38 (2019), 292–306. https://doi.org/10.1007/s11631-018-0298-z

[3] M. Gavrilescu. Water, Soil, and Plants Interactions in a Threatened Environment. Water, 13(19) (2020), 2746. https://doi.org/10.3390/w13192746

[4] A. Nayak, G. Matta & D. P. Uniyal. Hydrochemical characterization of groundwater quality using chemometric analysis and water quality indices in the foothills of Himalayas. Environ Dev Sustain 25 (2023), 14229–14260 . https://doi.org/10.1007/s10668-022-02661-4

[5] N. Akhtar, M. I. Syakir Ishak, S. A. Bhawani & K. Umar. Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review. Water, 13(19) (2020), 2660. https://doi.org/10.3390/w13192660

[6] S. Sharma and A. Bhattacharya. Drinking water contamination and treatment techniques. Appl Water Sci 7 (2017), 1043–1067. https://doi.org/10.1007/s13201-016-0455-7

[7] X. Liu, D. Li, H. Zhang, S. Cai, X. Li & T. Ao. Research on nonpoint sources pollution assessment method in data sparse regions: A case study of Xichong River Basin, China. Adv. Meteorol. 519671, 10 (2015).

[8] B. K. Mishra, P. Kumar, C. Saraswat, S. Chakraborty & A. Gautam. Water Security in a Changing Environment: Concept, Challenges and Solutions. Water, 13(4) (2020), 490. https://doi.org/10.3390/w13040490

[9] E. D. Ongley. Water Quality Management: Design, Financing and Sustainability Considerations -11. Invited Presentation at the World Bank's Water Week Conference: Towards for Managing Water Quality Management, April 3-4 (2000), Washington, D.C. USA.

[10] A. Teklitz, C. Nietch, M. S. Riasi & L. Yeghiazarian. Reliability theory for microbial water quality and sustainability assessment. Journal of Hydrology, 596, 125711 (2021). https://doi.org/10.1016/j.jhydrol.2020.125711

[11] T. Jiang, P. Kumar, H. Chien & O. Saito. Socio-Hydrological Approach for Water Resource Management and Human Well-Being in Pinglin District, Taiwan. Water, 15(18) (2022), 3302. https://doi.org/10.3390/w15183302

[12] E. O. Omofunmi, A. F. Adisa, O. A. Alegbeleye & O. A. Ilesanmi. Assessment of catfish effluents management in Lagos state, Nigeria. J Eng Technol, 2(2), (2017)33-36.

[13] D. V. Chapman & T. Sullivan. The role of water quality monitoring in the sustainable use of ambient waters. One Earth, 5(2) (2022), 132-137. https://doi.org/10.1016/j.oneear.2022.01.008

[14] A. Katherin. Stakeholder Engagement around Water Governance: 30 Years of Decision Making in the Bogotá River Basin. Urban Science, 7(3) (2023), 81. https://doi.org/10.3390/urbansci7030081

[15] I. A. Adeleke, N. I. Nwulu & O. A. Ogbolumani. A hybrid machine learning and embedded IoT-based water quality monitoring system. Internet of Things, 22, 100774 (2023). https://doi.org/10.1016/j.iot.2023.100774

[16] U. Ewuzie, N. O. Aku & S. U. Nwankpa. An appraisal of data collection, analysis, and reporting adopted for water quality assessment: A case of Nigeria water quality research. Heliyon, 7(9) (2021), e07950. https://doi.org/10.1016/j.heliyon.2021.e07950

[17] Harold van den Berg, B. Rickert, S. Ibrahim, K. Bekure, H. Gichile, S. Girma, A. Azezew, T. Z. Belayneh, S. Tadesse, Z. Teferi, F. Abera, S. Girma, T. Legesse, D. Truneh, G. Lynch, I. Janse & Ana Maria de Roda Husman. Linking Water Quality Monitoring and Climate-Resilient Water Safety Planning in Two Urban Drinking Water Utilities in Ethiopia. Journal of Water and Health 17.6 (2019) 989-1001. http://doi: 10.2166/wh.2019.059

[18] R. Peletz, J. Kisiangani, M. Bonham, P. Ronoh, C. Delaire, E. Kumpel, S. Marks & R. Khush. Why do water quality monitoring programs succeed or fail? A qualitative comparative analysis of regulated testing systems in sub-Saharan Africa. International Journal of Hygiene and Environmental Health, 221(6) (2018), 907-920. https://doi.org/10.1016/j.ijheh.2018.05.010

[19] E. Kumpel, C. MacLeod, K. Stuart, R. Khush & R. Peletz. From data to decisions: Understanding information flows within regulatory water quality monitoring programs. Npj Clean Water, 3(1) (2020), 1-11. https://doi.org/10.1038/s41545-020-00084-0

[20] M. D. Peña-Guerrero, A. Nauditt, C. Muñoz-Robles, L. Ribbe and F. Meza. Drought impacts on water quality and potential implications for agricultural production in the Maipo River Basin, Central Chile, Hydrological Sciences Journal, 65:6 (2020), 1005-1021, DOI: 10.1080/02626667.2020.1711911

[21] S. Mitra, A. J. Chakraborty, A. M. Tareq, T. B. Emran, F. Nainu, A. Khusro, A. M. Idris, M. U. Khandaker, H. Osman, F. A. Alhumaydhi, & J. Simal-Gandara. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University - Science, 34(3) (2022), 101865. https://doi.org/10.1016/j.jksus.2022.101865

[22] M. G. Uddin, S. Nash & A. I. Olbert. A review of water quality index models and their use for assessing surface water quality. Ecological Indicators, 122, 107218 (2021). https://doi.org/10.1016/j.ecolind.2020.107218

[23] I. P. Oboh & C. S. Agbala. Water Quality Assessment of the Siluko River, Southern Nigeria, African Journal of Aquatic Science, 42:3, (2017) 279-286, http://doi: 10.2989/16085914.2017.1371579

JDFEWS 4 (2): 37-56, 2023
ISSN 2709-4529

[24] C. Meng, X. Song, K. Tian, B. Ye & T. Si. Spatiotemporal Variation Characteristics of Water Pollution and the Cause of Pollution Formation in a Heavily Polluted River in the Upper Hai River. Journal of Chemistry, Vol. (2020) pp. 1–15. doi:10.1155/2020/6617227.
[25] APHA. Standards methods for examination of water and wastewater. 23rd ed. New York. American Public Health Association (APHA) American Water Works Association (AWWA) Water Environment Federation (WEF) (2017). ISBN 978-0875532875 pp. 1796.
[26] A. Kale, N. Bandela, J. Kulkarni & K. Raut. Factor analysis and spatial distribution of water quality parameters of Aurangabad District, India. Groundwater for Sustainable Development, 10, 100345 (2020). https://doi.org/10.1016/j.gsd.2020.100345
[27] N. Shrestha. Factor Analysis as a Tool for Survey Analysis. American Journal of Applied Mathematics and Statistics, vol. 9, no. 1 (2021) 4-11. doi: 10.12691/ajams-9-1-2.
[28] F. J. Ogbozige. Water Quality Monitoring: Identifying Critical Parameters. FUPRE Journal, 7(2) (2023) 29-36.

Author Biography

Dr. ILESANMI, O. A. is a Lecturer in the Department of Agricultural and Bioresources Engineering, Federal University, Oye Ekiti. His research focus is on Water Resources, the Environment and Climate Change.

OLOYE, Abraham O. is a **Lecturer** in the Department of Agricultural and Bioresources Engineering. A Registered Engineer,

OLUWAFEMI Peter Odunayo is a graduate of Agricultural and bioresources engineering and about pursuing a graduate degree

UMEGO Okwunna Maryjane obtained a B.Sc in Agricultural and Bioresources Engineering from Enugu State University of Science and Technology in 2012 with First Class Honours. She joined the Department of Agricultural and Bioresources Engineering, Federal University, Oye-Ekiti in September 2104 and currently undertaking her PhD study via commonwealth Scholarship. Her research interest is on water and environmental engineering. She is a COREN Registered Engineer.

Prof. OMOFUNMI, Eric Olorunwa is a professor of soil and water engineering and the current head, Department of Agricultural and Bioresources Engineering, Federal University, Oye Ekiti.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Adapted Irrigation Pump Load in Solar PV and Wind Energy Systems through Stepped Variable Frequency Drives

Samson Sing'oei SOSHYO
Technical University of Mombasa, Mombasa, Kenya, samsonsoshyo@gmail.com

Sameer Kamrudin **BACHANI**
Technical University of Mombasa, Mombasa, Kenya

Michael Juma **SAULO**
Technical University of Mombasa, Mombasa, Kenya

Lawrence Manyonge **MUKHONGO**
Technical University of Mombasa, Mombasa, Kenya

Received: 11 December 2023

Review: 18 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract—Wind and solar photovoltaic (solar-PV) power are highly variable and intermittent as exhibited by corresponding generation profiles. In the utilization of power directly for water pumping, the availability and reliability of water automatically followed the Renewable Energy Sources (RES) characteristics. On the other hand, Deferrable Irrigation Load (DIL), followed a specific irrigation water need profile. The DIL profile is determined by crop cycles and corresponding water needs. It was also affected by aspects of weather, mainly precipitation, temperature, and wind. This research considered the application of discrete switches and Variable Frequency Drives (VFDs) as a combined solution. Combined discrete and continuous switching through VFDs, to adapt pump load to DIL and RES profiles proved successful. Discrete switches engaged the exact number of pumps required to match an expected irrigation load. VFD further ensured continuous match of irrigation pump load to the anticipated DIL curve, through adjustment of pump speed points. Running of the system to adapt the pump power to the RES curve yielded better curve-fit results. The energy adapting technique was implemented to improve elasticity, hence the efficiency of the system. The results showed that the adapted system to the DIL curve-fit was 95.4% compared with a discrete-only system (91.35%). This represented a slight improvement of approximately 4.5%. The results demonstrated the smoother operation of the pump system and increased energy utilization efficiency. A further improvement on the control strategy for VFD coupled with the re-design of irrigation pipe networks was required to improve efficiency beyond 95.4%.

Keywords*—*Renewable Energy, Wind, Solar PV, Irrigation Pump, Variable Frequency Drive

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

1 Introduction

Kenya faces a food shortage problem, just like many other countries in the developing world. In all these countries, there is a need to address the food security problem (National Irrigation Board, 2018). Kenya has put in place strategies to shift focus from rain-fed agriculture to irrigation agriculture. Kenya has earmarked several irrigation projects and corresponding sites some of which are: Galana-Kulalu, Lotikipi, Perkerra, Rahole, and Wei Wei for this purpose [1]. The project's main purpose is to address the food security problem although significant commercial interest still exists, especially if cash crops can be grown there. However, there is a huge problem in the projects caused by the high pump costs, which increases the cost of food production, consequently leading to the lackluster performance of the projects. In the global struggle to ensure that, the Sustainable Development Goals (SDGs) [2] overarches national development, affordable and clean energy as well as zero hunger are key. In this pursuit, Kenya invested heavily in the financing of irrigation agriculture. For instance, in 2018, the Galana-Kulalu Food Project secured a loan whereby Bank Leumi of Israel signed KES 6.35 billion to finance the contract. Kenya also spent a significant amount of funding on other irrigation projects (Lotikipi, Perkerra, Rahole, and Wei Wei). The major cost of production in all these projects is the diesel used in the pumps or electric generators. Where there is a grid connection, the high electricity bills are also a discouragement [2]. However, in most irrigation sites there are significant renewable energy sources mainly solar PV [3] and wind. This presents the opportunity to tap these resources to address the high pump costs, thereby increasing irrigation energy efficiency thus reducing the cost of food produced. Other benefits include the reduction of environmental pollution through minimizing of carbon emissions, smoke, or noise mainly attributed to diesel pump engines or electric generators [4].

1.1 Problem Statement

One of the major challenges of irrigation projects was high input costs, due to diesel used by the diesel pumps and electric generators. However, there existed a solution in renewable energy source harnessing, particularly on hybrid wind and solar-PV energy. These alternative sources were variable and intermittent, and so were irrigation water needs and corresponding energy needs. It was, therefore, worth developing systems, which adapted pumps to (1) resultant Deferrable Irrigation Load (DIL), or to (2) Renewable Energy Resources (RES) themselves. A system combining discrete and continuous pump operation using Variable Frequency Drives (VFDs) was required as a possible pump adapting solution for effective and efficient utilization of energy in irrigation systems. It was necessary to run the adapted models on predetermined economic optimized energy system structures. Accurate modelling of the operation of energy systems to determine effectiveness and efficiency of such a system in terms of surpluses or deficits of energy generated vis-a-vis energy utilized.

1.2 Objectives of Study

Main Objective was to simulate and analyze irrigation energy utilization for adapted irrigation pump load, in economic optimized hybrid wind-solar energy system, using stepped variable frequency technique.

Specific Objectives were: (1) To simulate pumps adapted to deferrable irrigation load using stepped variable frequency technique; (2) To simulate pumps adapted to renewable energy resource using stepped variable frequency technique; and (3) to analyze percentage of curve fitting in crop-specific and site-specific scenarios in the applied stepped variable frequency technique.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

2 Literature Review

There were several solutions proposed to solve modern-day Energy-Water-Food (EWF) nexus-type problems [4]. This is whereby by solving energy problems in water provision, the food problems reduced significantly [5]. The Kenya government hired Green Arava an Israeli company to offer development and management services to a 10,000-acre test firm at Galana-Kulalu [6]. The crop under irrigation was maize. The agricultural officers [6] pursued the possibility of including other crops namely: beans, sugarcane, cotton, vegetables, or fruits. The pumps engaged could be as high as 15 units could or as low as one during a typical harvesting season. The price of diesel is usually high for example in Kenya at present is approximately $2, especially in the far-flung areas where the irrigation sites are located. Where direct diesel pumps are used, there is still a big issue concerning repairs and maintenance of the units [6]. The situation is a little better when diesel electric generators are used to power electric pumps [7]. Electric pumps whether submersible or surface-mounted are induction machines by nature.

2.1 Variable Frequency Drives

Variable Frequency Drives (VFDs) dominated electrical machine utilization for decades. There was significant use of power electronics to modulate frequency supply to vary the speed of the induction machine. There was utilization of VFDs in irrigation systems for driving the Induction Motor Pump [8]. In smart irrigation systems [9] electric drives vary in frequency consequently the water discharge required in farms. [10]developed variable-speed water pumping for photovoltaic systems. The system was for low-scale irrigation. [11] Still worked on photovoltaic systems for small farms. Optimal control of water used in irrigation farms was done by [11] using variable speed drives. There was efficiency and cost savings of the system as compared with the ON/OFF systems (discrete systems). There was deployment of Artificial intelligence (AI) technique to run a variable speed water pumping system by [11]. The Ant System Iteration Best (ASib) proved to yield 10% economic pump savings. The ASib was better than the Genetic Algorithm (GA) in this problem [12]. A problem of pumping systems design and performance was studied by [13]who compared reservoir and pump conditions and established that elevation and pump distances had a significant impact on efficiency. Center pivot irrigation systems were studied by [14] who found that a reduction of energy consumption by 12.2% was possible with the use of variable speed drives. The economic advantages of VFDs were studied by [15] who discovered that the use of VFDs reduced the investment costs by 15%. Detailed Study of pump affinity laws in [10] showed the relationship between rotor speed and discharge as well as power. This was a research on the MATLAB/Simulink platform. Renewable Energy in Irrigation

The use of renewable energy in irrigation was studied by [16] who studied hybrid wind-solar systems on small-scale farms (<2.0 Ha) and added farm uses where excess winds were experienced. [17] Also developed a hybrid wind-solar system for a dragon fruit field measuring 3000m^2 thus reducing the dependence on fossil fuels. [17] Studied the beneficial economics of a small-scale banana farm in Uganda. [18] Automated modern farming system and found out that it was favorably economical. Wind pump conditions were competently studied by [19], [20], [21], and [22] and all were in agreement that wind pumping for irrigation agriculture were more suited that solar PV systems. It was possible to bring large areas under irrigation with wind-powered pump systems.

2.1 Research Gap

There was an emerging gap in irrigation load modeling and characterization with VFD technology applied. In all the literature studied, rarely did the researchers develop annual models considering the nature of irrigation. They had dwelt less on irrigation load characterization and profiling. Further, still there was less emphasis given to the potential harnessing of RES at corresponding sites. The researchers concentrated much on one irrigation site and dwelt on a few crops. Few irrigations need curves ware determined by proper modeling of irrigation load through agricultural data. The gap addressed adequately in this research was two pronged. Two models were

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

required to depict the problem. The agricultural model used to determine the Irrigation Water Needs (IWN) was the initial, required for specific crops grown at the corresponding irrigation site. In second phase, detailed analysis of pump model so that pump load profile matched with pump power. The uniqueness of this research was proper irrigation load modeling done in many crop situations as well as for different irrigation sites in Kenya[1]. The irrigation water needs modeled from the agricultural parameters [22] given in Equation 1 below.

$$Q = \frac{[\rho(0.46T_{mean}+8)K_c+P_p-P_e]*10^4*A_{land}}{10^3*T_{pump}} m^3/\mathrm{s} \quad (1)$$

The equivalent circuits as shown in Fig. 1 below [23] characterize induction Machines.

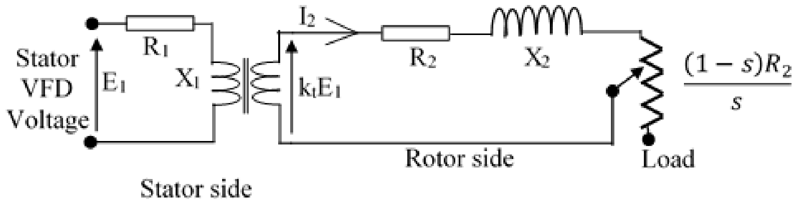


Fig. 1. Per-phase equivalent circuit of induction machine

Equation 2 below shows the corresponding load current. The output power is given in the form of $P=I^2R$ and can be shown to be as follows[1]

$$I_2 = \frac{s k_t E_1}{\sqrt{(R_2)^2+(sX_2)^2}} \quad (2)$$

$$= N\,x\,\frac{3{k_t}^3 E_1^2 s(1-s)R_2}{[(R_2)^2+(sX_2)^2]x1000} \quad (3)$$

$$P_{motor} = \frac{P_{pump}}{\eta_{motor}}$$

$$= \frac{\rho.g.H_{TDH}.Q}{\eta_{motor}\eta_{pump}\,x\,3.6\,x\,10^6} kW$$

$$= N\,x\,\frac{3{k_t}^3 E_1^2 s(1-s)R_2}{[(R_2)^2+(sX_2)^2]x1000} \quad (4)$$

Following pump affinity laws it can be shown that [1]

$$\frac{P_1}{P_2} = \frac{\omega_1^3}{\omega_2^3} = \frac{k_{Q1}k_{H1}f_{e1}^3}{k_{Q2}k_{H2}f_{e2}^3} \quad (5)$$

Energy source modeling was as shown in Equations 6, 7 and 8 below. An assumption was that H_{GHI} was 6.5 sun-hours in Kenya, an equatorial country

$$P_{wind} = \frac{\frac{1}{2}C_p\eta_{turbine}\rho_{air}AV^3}{1000} kW \quad (6)$$

$$P_{solar} = \frac{A_{panel}\,x\,rx\,PRx\,H_{GHI}}{6.5} kW \quad (7)$$

$$P_{motor} \le P_{wind} + P_{solar} \quad (8)$$

A_{panel} is solar panel area (m^2), $A_{turbine}$ is wind turbine blade area (m^2), and C_p is coefficient of performance of wind turbine (%). f_e is variable frequency (Hz), g is acceleration due to gravity (9.81kg/m^3), and H_{GHI} is solar irradiance (kW/m2). k_Q is discharge pumping constant, k_H is head pumping constant, N is number of irrigation

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Pumps (units), and $P_{deficit}$ is power deficit (kW) and P_e is precipitation (effective rainfall) (mm). $P_{generated}$ is power generated (kW), p_p is percolation (mm), PR is performance ratio of the solar system (%), $P_{utilized}$ is power utilized(kW), P_{wind} is power output of the wind turbine(kW), and r = yield factor of solar panels (%). V is wind speed (m/s), η_{motor} is pump efficiency (%), η_{pump} is pump efficiency (%), $\eta_{turbine}$ is turbine efficiency (%), ρ_{air} is the actual air density (kg/m)], and ρ_w= density of water (1000kg/m^3)

3 Methodology

In this research, three models were developed and used. They were a physical model, mathematical model, and MATLAB/Simulink models. The details of the models are as described in the following subtitles.

3.1 Physical Site Model

This was as shown in Fig. 2 was used. It was a typical physical irrigation site as postulated by [1]. It was possible to install at least solar PV panels and wind turbines in the sites selected. The optimum number, rating, and ratio of these components had been determined utilizing Hybrid Optimization Modeling for Electric Renewables (HOMER) software. The considered size of land was 10000 acres (4047Ha).

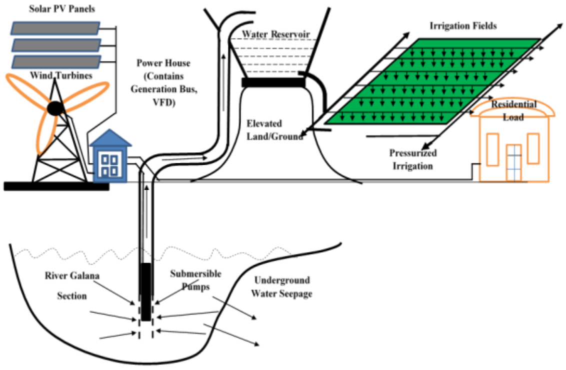


Fig. 2. Typical Model of the Irrigation Site

The figure above was extracted from [1], in the research for "*Optimized Optimized Hybrid Wind-Solar Energy System Structures For Irrigation Pump Load Sites In Kenya*". This research conducted in the first phase where the optimal structure of wind and solar PV system corresponding to irrigation sites and crops was prerequisite.

3.2 Mathematical Model

The mathematical model for the research shown in Fig. 3 below. The upper part of the model (Fig. 3) represented the RES power generation, while the lower part represented the induction motor load. Note that the discharge required defined in the term $kQkHfe^3$ in the model was key point in the research. This term represented the Head (H) and Discharge (Q) as shown in affinity laws (Equation 5)[1]. The difference between the generated and utilized power gave the surplus or deficit. In adapted systems with stepped VFDs, the surplus or deficit expected to be perfect because of a perfect load curve fitting to DIL or RES curves was also key in this research. In a stepped VFD system, induction motor pumps that make the significant irrigation load, were not only switched according to the approximate number required (N) but also operated at a critical frequency (f_e) which was varied to consequently vary Q as demanded by irrigation water need (IWN) (Equation 1)

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

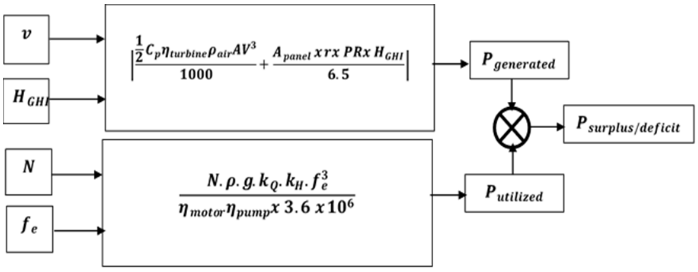


Fig. 3. The Mathematical Model

3.3 MATLAB/Simulink Model

The corresponding MATLAB/Simulink block and simulation diagrams shown in Fig.4 and Fig. 5 below were the operating models. On the left-hand side was the RES generation system whose output fed a common DC bus. A short transmission line used to evacuate the generated power to the load side was included. On the load side, the irrigation pumps switched ON in sequence as the VFD variable frequency output acted to control the speed of the pumps.

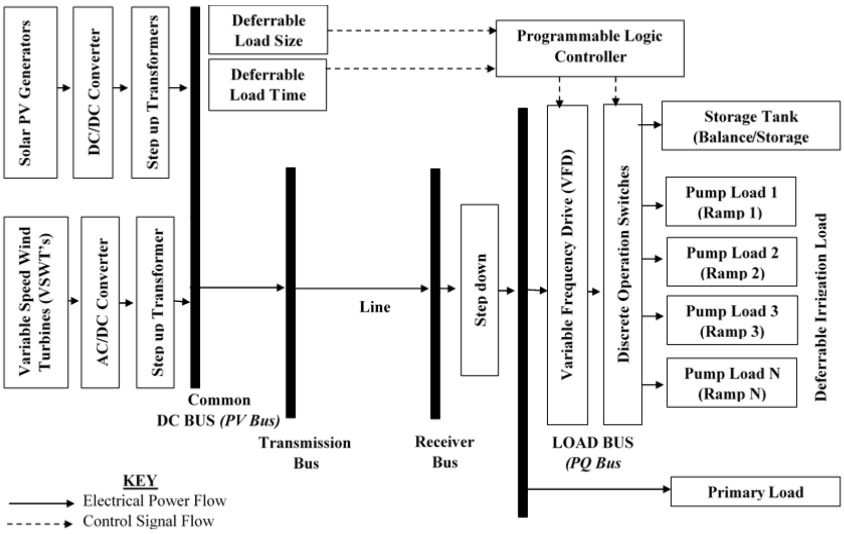


Fig. 4. The Block Diagram of MATLAB/Simulink Model

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

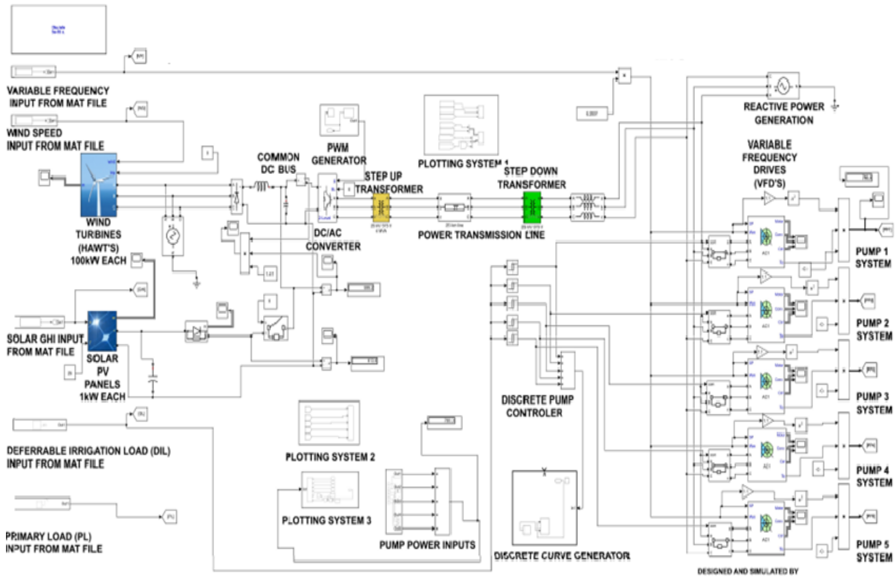


Fig. 5. The MATLAB/Simulink Simulation Model

3.4 Results

The models run on MATLAB/Simulink software for these two scenarios (i) one-site-many-crops scenario (Fig. 6) and (ii) five-sites-one crop scenario (Fig. 7). The results also shown were for discrete and VFD systems adapted to sufficient and insufficient energy resources (Fig. 8). The results in the figures showed that the adapted pump systems to DIL was a successful strategy. The adapted load curve (Red Curve) was observed to be between the anticipated DIL curve (Blue Curve) and the discrete pump load (Brown Curve). A curve fitting improvement from a discrete curve was therefore evident. There was a smoother transition between steps albeit with significant oscillations. Higher cyclic crops– crops that grown more than 3 times in a year–like spinach and radish were shown to have more stepped switching than low cycle crops like sugarcane. Cash crops for instance sugarcane and cotton had significantly stable peak demand compared to food crops such as maize beans and spinach. In all cases, the adapted pump load was lowest in the period around the 26th week. This was the period between May and August were coincidentally there was significant precipitation (Rainfall) at the Galana-Kulalu site. This in effect reduced the irrigation water need. The reservoir levels had the greatest oscillations or instability whenever there was a peak demand. There was no notable relationship between the variable frequency curve and reservoir levels. There was no relationship between the size of the load and variable frequency since it was determined based on the critical load at each point in the system. There was a near-perfect curve fit when a stepped VFD pump system acted to adapt the load to sufficient and insufficient RES (Fig. 8).

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Table 1. Table of Figures for MATLAB/Simulink simulation results (one-site-six-crop scenario)

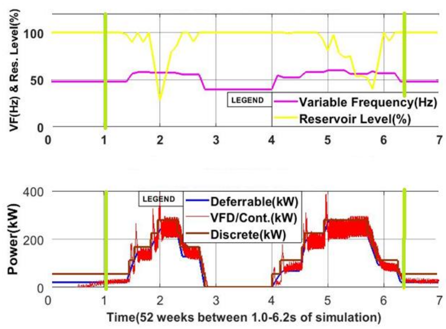


Fig. 6(a). Galana-Kulalu: Maize Irrigation

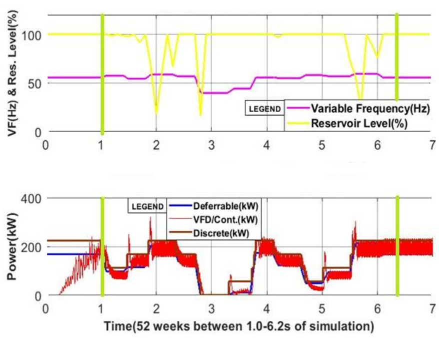


Fig. 6(b). Galana-Kulalu: Beans Irrigation

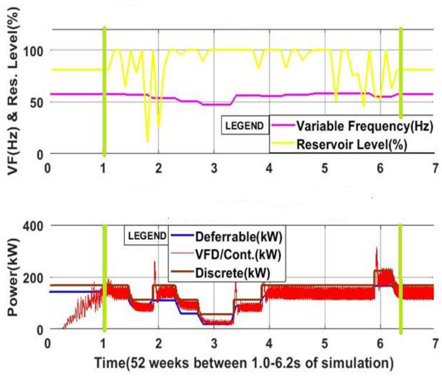


Fig. 6(c). Galana-Kulalu: Sugarcane Irrigation

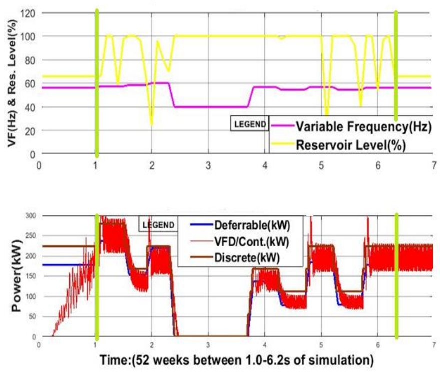


Fig. 6(d). Galana-Kulalu: Radish Irrigation

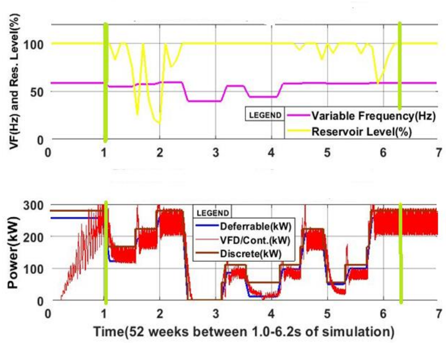


Fig. 6(e). Galana-Kulalu: Spinach Irrigation

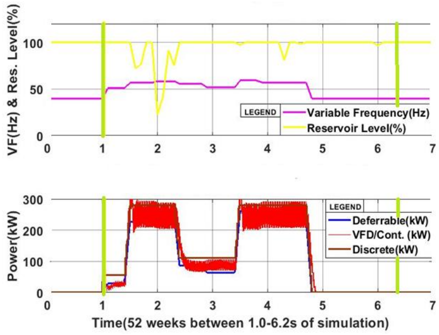


Fig. 6(f). Galana-Kulalu: Cotton Irrigation

Note that the Galana-Kulalu: Maize Irrigation does not appear in the following set of results (Fig. 7.) because it is the common scenario between the two sets of figures.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Table 2. Table of Figures for MATLAB/Simulink simulation results (five-site-one-crop scenario)

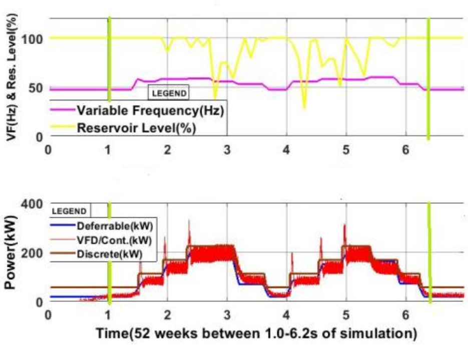


Fig. 7(a). Lotikipi: Maize Irrigation

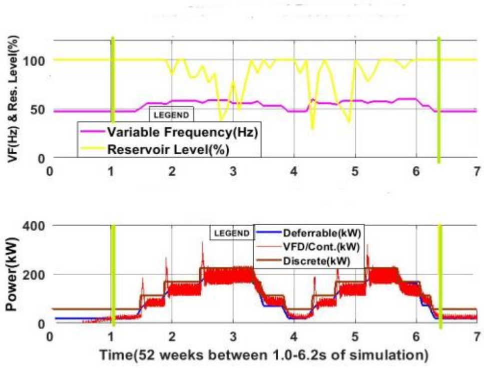


Fig. 7(b). Perkerra: Maize Irrigation

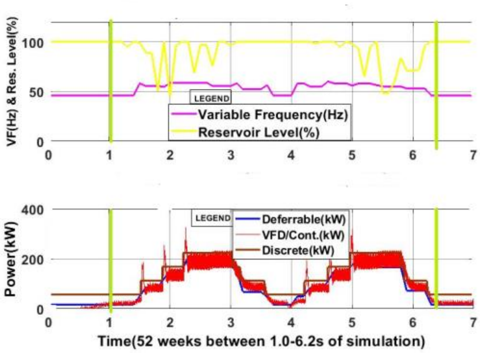


Fig. 7(c). Rahole: Maize Irrigation

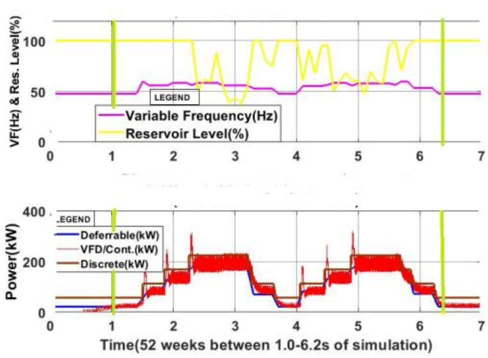


Fig. 7(d). Wei Wei: Maize Irrigation

Table 3. MATLAB/Simulink simulation results in sufficient and insufficient RES conditions

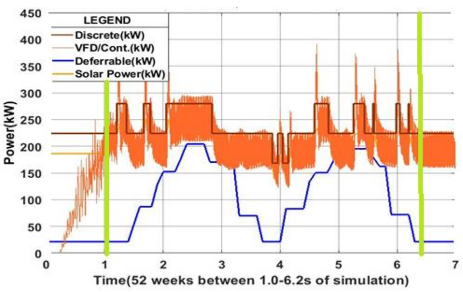


Fig. 8(a). Wei Wei: Maize Irrigation in sufficient (scaled-up) solar PV

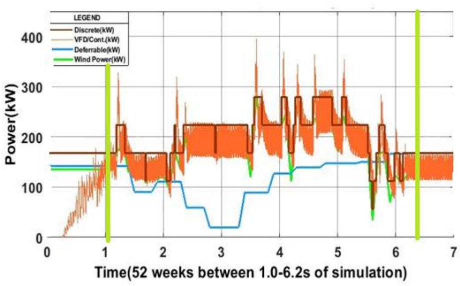


Fig. 8(b). Galana-Kulalu: Sugarcane Irrigation in sufficient (scaled-up) wind power

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

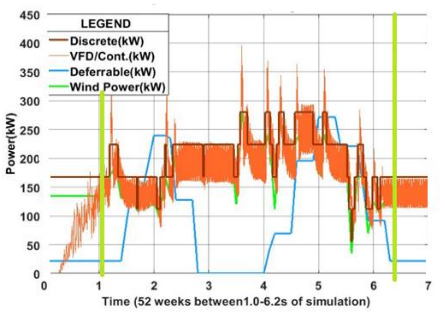


Fig. 8(c). Galana-Kulalu: Maize Irrigation in insufficient(scaled-down) wind power

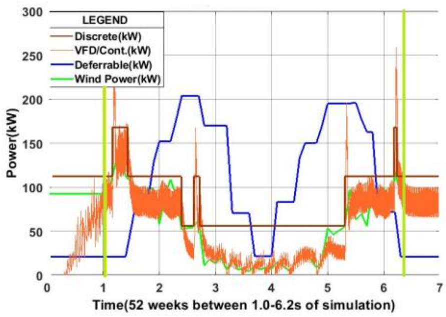


Fig. 8(d). Wei Wei: Maize Irrigation in very low (scaled down too much) wind power

4 Analysis

The system variable frequency successfully maintained itself between 40Hz and 60Hz as shown by the Variable Frequency (VF) curve in Fig. 6 and Fig.7. The reservoir level indication was unique for each case. The observed disturbance on reservoir levels was great and unique during peak demands in each case. Highly cyclic crops like spinach and radish had more steps compared to lower cyclic crops like sugarcane and cotton. The longer cyclic crops had stable energy requirements compared to short cycle crops.

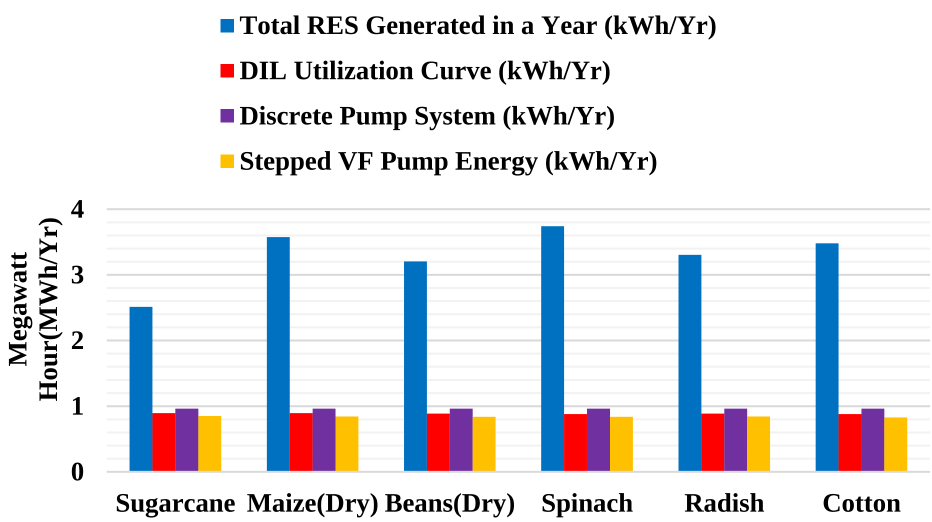


Fig. 9(a). Results analysis for discrete and stepped VFD pump systems adapted to DIL(one-site-six-crop-scenario). The one-site is the Galana-Kulalu Irrigation Site

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

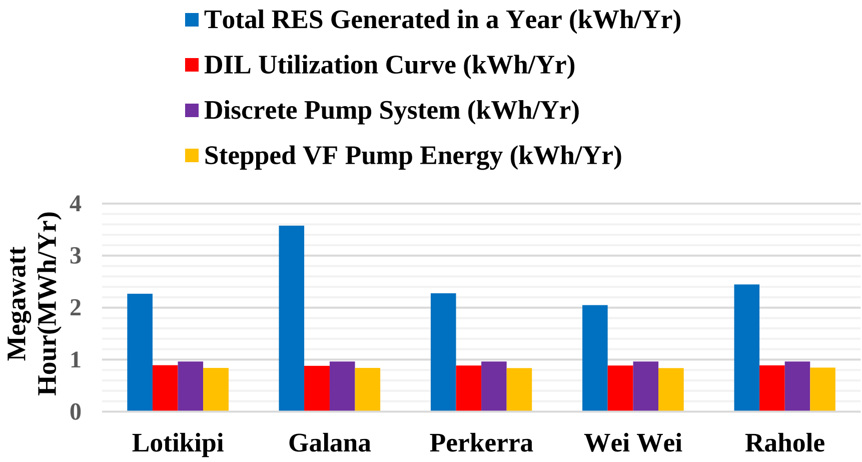


Fig. 9(b). Results analysis for discrete and stepped VFD pump systems adapted to DIL(five-site-one-crop-scenario). The one-crop is maize.

Fig. 9(a) below showed analysis of the results for generated verses utilized energy for one-site-six-crop-scenario. It was clear that the generated energy was very high as compared to utilized energy. The generated energy for spinach irrigation system was the highest (3.7MWh/Yr) compared to the lowest, that of sugarcane (2.5MWh/Yr). The average generated energy was 3.3MWh/Yr. The utilization in terms of anticipated DIL, discrete pump system and adapted (stepped frequency) pump system were all between 0.8-1MWh/Yr therefore indicating a surplus of slightly over 2.7MWhr/Yr. **Fig. 9(b)** shows the five-site-one-crop-scenario, where the crop referred to here is maize. Galana-Kulalu site had the possibility of very high renewable energy generation (3.6MWh/Yr) and corresponding highest surplus (2.7MWH/Yr) compared to a Wei Wei site low of 2.0MWh/Yr. The average RES possible to generate at the Galana-Kulalu site was approximately 3.30MWhrs while the possible average utilized energy was 0.89MWhrs in a given year. This meant that there was a generation surplus of 2.41 MWhrs. For the other sites, it was 3.22MWhrs against an anticipated utilization of 0.96 to yield an expected surplus of 2.26MWhrs. The surplus created by using the adapted load through stepped VFD was higher than that of the discrete system in each scenario above.

Fig. 10(a) below shows the analysis of the results for the one-site-six-crop-scenario and. The analysis showed that there was a significant improvement in the use of VFDs as opposed to discrete-only systems. In all cases studied the stepped frequency strategy was much better that the discrete system. For the one-site-six-crops scenario, the variable frequency curve fitting to DIL was 96.9% against the discrete system having 91.3%. Fig. 10(b) showed the case of five-site-one-crop scenario. There was a slight improvement in stepped variable frequency of 93.9% against 91.4% when irrigation sites were changed. An overall improvement of 95.4 curve fit was observable against a 91.4% curve fit for the discrete-only system. The location of RES irrigation system significantly affected the surplus energy generation.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

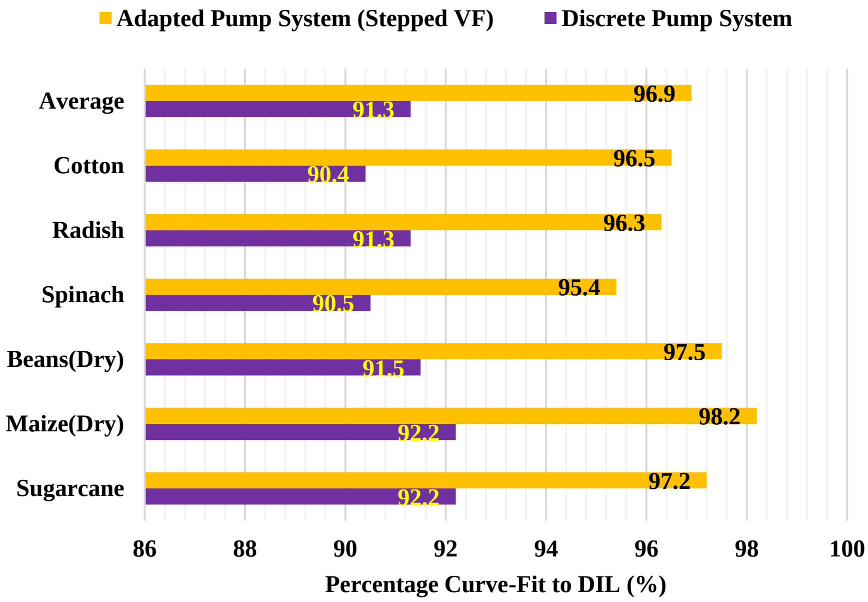


Fig. 10(a). Results analysis for discrete and stepped VFD pump systems adapted to DIL

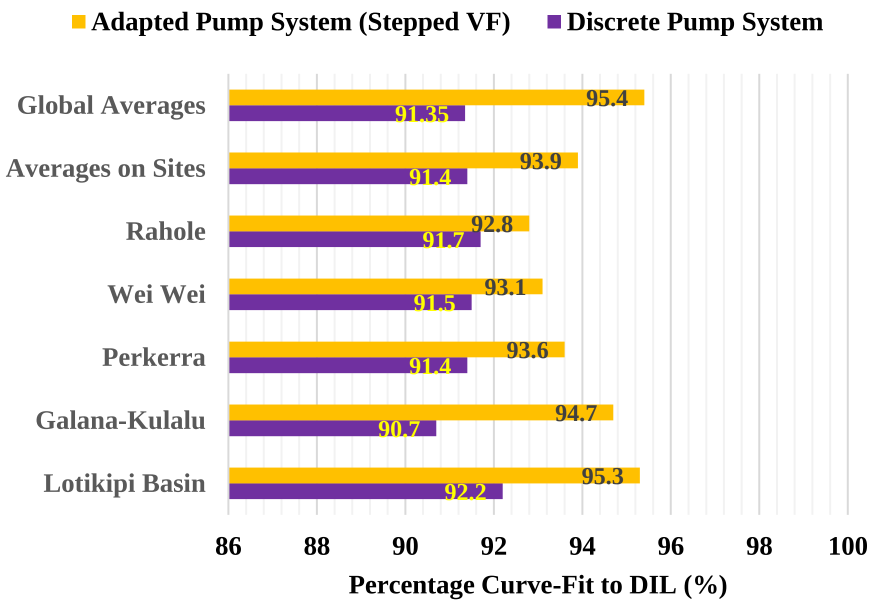


Fig. 10(b). Results analysis for discrete and stepped VFD pump systems adapted to DIL

5 Conclusion

The adapted irrigation pump system in the wind and solar PV energy systems through the stepped variable frequency drives was an excellent strategy in ensuring that the irrigation pump load was a near-perfect fit (95.4%) to the anticipated Deferrable Irrigation Load (DIL). This was an improvement of 4.5% as compared to discrete only system having 91.35% curve fit. The results showed that it was not tenable to scale down solar PV or wind energy systems to reduce the surplus energy in irrigation energy systems. The scale-down strategy in effect did not adequately serve the irrigation load, in other words, it was not possible to irrigate satisfactorily with a scaled-down energy system rather than an optimized one. This was because pumping of irrigation water was schedulable or deferrable event, yet the RES were not. In an irrigation system, a curve-fitting technique to RES with adapted pump load through VFDs was excellent meaning that this strategy was best applicable as a demand-side management strategy for a power system. For curve fitting to RES, the improved efficiency of energy utilization meant that energy generated was readily utilizable in irrigation with a high surplus, which was available for other agricultural uses or energy export. The research therefore recommended additional energy-intensity agricultural uses of RES such as electric drying and other value-added farm processes. Another recommendation is investment in large food processing factories near potential irrigation sites if RES harnessed for large-scale irrigation farms was possible. Other high-energy use solutions like in the production of hydrogen alongside irrigation plans were quite considerable. Where it is not possible, a combination of irrigation systems with large water users, for example, a municipal or city or an energy buying utility company entity was sustainable so that excess energy was utilizable for pumping water, sewerage, or direct use instead.

6 Acknowledgment

We would like to acknowledge the support we got from Mr. Meshaki Shake. Mr Shake was helpful in the installation and maintenance of simulation softwares and was available any time I faced a challenge. We would like to appreciate EssenSolar (FSP Group (NGO) in India); Comax Solution (Trina Solar Ltd in China) Argolabe Ingeniena(a private company in Spain); and Pedrollo (a private company in Italy) for availing product information and resources online. Others are NIA and NIB Government irrigation bodies in Kenya. Their product information or data were valid and easily accessible online. Kenya Society of Environmental, Biological and Agricultural Engineers (KeSEBAE), TUM Multi-disciplinary conferences, and Institution of Engineers of Kenya (IEK) for giving me opportunity to disseminate findings in their conferences.

7 References

[1] S. Soshyo, M. Saulo, and L. Mukhongo, "OPTIMIZED HYBRID WIND-SOLAR ENERGY SYSTEM STRUCTURES FOR IRRIGATION PUMP LOAD SITES IN KENYA," *J. Eng. Agric. Environ.*, vol. 8, no. 3, 2022, doi: 10.37017/jeae.v8i3.28.

[2] S. Mandelli, J. Barbieri, L. Mattarolo, and E. Colombo, "Sustainable energy in Africa: A comprehensive data and policies review," *Renew. Sustain. Energy Rev.*, vol. 37, pp. 656–686, 2014, doi: 10.1016/j.rser.2014.05.069.

[3] A. N. Al-shamani *et al.*, "Design & Sizing of Stand-alone Solar Power Systems A house Iraq," *Des. Sizing Stand-alone Sol. Power Syst. A house Iraq Ali*, pp. 145–150, 2013.

[4] A. Ahmad and S. Khan, "Water and Energy Scarcity for Agriculture: Is Irrigation Modernization the Answer?," *Irrig. Drain.*, 2017, doi: 10.1002/ird.2021.

[5] B. Mainali, S. Pachauri, N. D. Rao, and S. Silveira, "Assessing rural energy sustainability in developing countries," *Energy Sustain. Dev.*, vol. 19, no. 1, pp. 15–28, 2014, doi: 10.1016/j.esd.2014.01.008.

[6] National Irregation Board, "Galana Kulalu Irrigation Development Project," *nib.or.ke*, 2018.

[7] M. Hiller *et al.*, *Solar pumping for irrigation: Improving livelihoods and sustainability*, no. June. 2016.

[8] I. Boldea, "Electric generators and motors: An overview," *CES Trans. Electr. Mach. Syst.*, vol. 1, no. 1, 2020, doi: 10.23919/tems.2017.7911104.

[9] R. S. Krishnan *et al.*, "Fuzzy Logic based Smart Irrigation System using Internet of Things," *J. Clean. Prod.*, vol. 252, 2020, doi: 10.1016/j.jclepro.2019.119902.

[10] A. Moubarak, G. El-Saady, and E.-N. A. Ibrahim, "Variable Speed Photovoltaic Water Pumping Using Affinity Laws," *J. Power Energy Eng.*, vol. 05, no. 11, 2017, doi: 10.4236/jpee.2017.511005.

[11] N. Naval and J. M. Yusta, "Optimal short-term water-energy dispatch for pumping stations with grid-connected photovoltaic self-generation," *J. Clean. Prod.*, vol. 316, 2021, doi: 10.1016/j.jclepro.2021.128386.

[12] W. Wu, A. R. Simpson, H. R. Maier, and A. Marchi, "Incorporation of Variable-Speed Pumping in Multiobjective Genetic Algorithm Optimization of the Design of Water Transmission Systems," *J. Water Resour. Plan. Manag.*, vol.

138, no. 5, 2012, doi: 10.1061/(asce)wr.1943-5452.0000195.

[13] M. C. Morani, A. Carravetta, G. Del Giudice, A. McNabola, and O. Fecarotta, “A comparison of energy recovery by pATs against direct variable speed pumping in water distribution networks,” *Fluids*, vol. 3, no. 2, 2018, doi: 10.3390/fluids3020041.

[14] V. B. da S. Baptista, J. I. Córcoles, A. Colombo, and M. Á. Moreno, “Feasibility of the use of variable speed drives in center pivot systems installed in plots with variable topography,” *Water (Switzerland)*, vol. 11, no. 10, 2019, doi: 10.3390/w11102192.

[15] I. A. Abdaljlel, A. Y. Georgi, and A. H. Shaker, “Study The advantage of variable speed pumps Economically in pumping water lines using genetic algorithms,” *Assoc. Arab Univ. J. Eng. Sci.*, vol. 27, no. 3, 2020, doi: 10.33261/jaaru.2020.27.3.014.

[16] B. D. Vick, “Developing a hybrid solar/wind powered irrigation system for crops in the great plains,” in *39th ASES National Solar Conference 2010, SOLAR 2010*, 2010, vol. 1.

[17] I. Widiastuti and D. S. Wijayanto, “Developing a hybrid solar/wind powered drip irrigation system for dragon fruit yield,” in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 180, no. 1. doi: 10.1088/1757-899X/180/1/012034.

[18] H. Murty and M. F. Fauzan, “Automated Water Irrigation System for Urban Farming,” *MATEC Web Conf.*, vol. 335, 2021, doi: 10.1051/matecconf/202133503004.

[19] L. J. Hagen and M. Sharif, “Wind-Powered Irrigation Tailwater System: Sizing the Wind Turbine and Storage Pit,” *Trans. ASAE*, vol. 24, no. 1, 1981, doi: 10.13031/2013.34207.

[20] M. Harries, “Disseminating wind pumps in rural Kenya - Meeting rural water needs using locally manufactured wind pumps,” *Energy Policy*, vol. 30, no. 11–12, 2002, doi: 10.1016/S0301-4215(02)00060-5.

[21] T. Aized, S. M. Sohail Rehman, S. Kamran, A. H. Kazim, and S. Ubaid ur Rehman, “Design and analysis of wind pump for wind conditions in Pakistan,” *Adv. Mech. Eng.*, vol. 11, no. 9, 2019, doi: 10.1177/1687814019880405.

[22] S. Song and J. Niu, “Potential assessment on wind-powered water pumping for irrigated agriculture in Southern Xinjiang,” *Nongye Gongcheng Xuebao/Transactions Chinese Soc. Agric. Eng.*, vol. 37, no. 2, 2021, doi: 10.11975/j.issn.1002-6819.2021.2.015.

[23] R. Sridevi, C. Kumar, P. Suresh, S. Ganesan, S. Subramanian, and A. Suresh, “Development of a pedagogical framework to analyze the performance of induction machines,” *Int. J. Electr. Eng. Educ.*, vol. 58, no. 2, 2021, doi: 10.1177/0020720919828993.

8 Authors

Samson Sing’oei Soshyo is a member of Faculty of Engineering and Technology at Technical University of Mombasa. He holds a Bachelor of Technology Degree (B. Tech, Moi) in Electrical and Communications Engineering and a Master of Technology (M. Tech, TUM) Degree in Sustainable Energy Engineering. He has over 20 years’ experience as a career competency-based trainer for TVET programmes in the Institution. He therefore facilitates training for both Diploma and Undergraduate students at the Institution, mainly in the areas of green building, energy, and electrical power systems. His main passion is sustainable energy engineering especially at the nexus between energy food and water, and practices on the same areas. Address: P.O. Box 90420-80100 Mombasa; E-Mail: ssoshyo@tum.ac.ke

Sameer Kamrudin Bachani, is the Dean of the Faculty of Engineering and Technology at the Technical University of Mombasa, He is a senior lecturer in the department of Mechanical Engineering. He holds a Doctor of Philosophy in Material Science field of National Taiwan University of Science and Technology. He specifically researches currently on high operating temperature metals. Address: P.O. Box 90420-80100 Mombasa. E-Mail: sameerbachani@tum.ac.ke

Michael Juma Saulo, is a Senior Lecturer in the Faculty of Engineering and Technology, the Department of Electrical and Electronic Engineering at the Technical University of Mombasa. He holds a Doctor of Philosophy in Power Systems Design and Analysis of University of Cape Town. His current research are in power systems and renewable energy Address: P.O. Box 90420-80100 Mombasa. E-Mail: michaelsaulo@tum.ac.ke

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Lawrence Manyonge Mukhongo is a Senior Lecturer in Faculty of Engineering and Technology, the Department of Electrical and Electronic Engineering at the Technical University of Mombasa. He holds a Doctor of Philosophy in Industrial Manufacturing. His current researches are in Mechatronic Engineering. Address: P.O. Box 90420-80100 Mombasa. E-Mail: mukhongo@tum.ac.ke

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

Neural Network Approach to Pitch Angle Control in Wind Energy Conversion Systems for Increased Power Generation

Titus O. **AJEWOLE**
Osun State University, Osogbo, Nigeria

Mutiu K. **AGBOOLA**
Federal Polytechnic, Ede, Nigeria; agboolamutiu10@gmail.com

Kabiru A. **HASSAN**
Federal Polytechnic, Ede, Nigeria

Adedapo O. **ALAO**
Osun State Broadcasting Corporation, Osogbo, Nigeria

Omonowo D. **MOMOH**
Purdue University Fort Wayne, Fort Wayne, USA

Received: 09 December 2023

Review: 18 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: Presented in this study is an artificial intelligence approach to pitch angle control in wind turbine for the enhancement of power generation efficiency of wind energy conversion systems. A two-input neural network model was developed, trained using backward propagation technique and employed in adjusting the pitch angle of the turbine in response to the speed of the turbine generator and the rate of change of the speed. Ten-year real-life data on the wind speeds of a study location was used to validate the approach. At a peak performance, power output of 1300 W was obtained through the NN-based control as compared to 950 W from the non-NN adjustment. This shows that the method performs well in controlling the power above the turbine's rated wind speed. The approach is thus recommended for an effective management of the wind energy conversion systems towards improving reliability in electric power supply.

Keywords—*pitch control, wind turbine, neural network, model training, model validation*

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

1 Introduction

Electric power systems hold the key to national development. Adoption of renewable energy resources, among which wind energy is prominent, is thus persistently gaining attention as the world experiences unabated increase in demand for electricity. Wind energy becomes most popular renewable energy option due to its cleanliness and minimal maintenance requirements of the energy's conversion facilities [1]. Wind energy conversion (WEC) technology has expanded significantly over several decades and has become the most cost-effective approach to renewable energy harvesting at present [2–4]. In the technology, WEC systems transform the kinetic energy of wind-flow to electricity. The kinetic energy then converts to mechanical power by the rotation of wind turbine blade, while the turbine generator, in turn, employs the mechanical power to generate electricity [5].

Since the flow of wind fluctuates, there is a corresponding fluctuation in the developed mechanical power, with consequential fluctuations in the magnitude of the electric power generated. To this end, wind turbines are intended to only function within wind power availability constraints [6, 7] to avoid severe weather that may cause damage to them. Proper wind turbines control is thus critical in the deployment of the technology as this promotes efficient use of the capacity of WEC systems and alleviates aerodynamic and mechanical stresses [8].

Turbines with variable speeds perform in two distinct areas: above-rated and below-rated power; to capture the most wind speed whenever the power output falls under the expected values. Whenever the flow rate of the wind is less than the cut-in speed, the rotational speed of the wind turbine generator (WTG) is zero and thus produces no power [9, 10]. If the wind is below the rated speed and above the cut-in, maximum power can be collected from the wind by some controlling mechanism call maximum power point tracking (MPPT) technique [11]. At the above-rated-speed range, the primary goal becomes maintaining consistent power output without damage to the system. This is usually done by reducing the amount of wind energy collected, which is performed by adjusting the pith angle of the blades [12, 13]. Therefore, in addition to alleviating mechanical stress, robust power quality management and manipulation of reactive resource usage are other reasons for system control in WEC systems.

Oscillation in the output energy, as a result of changing wind speed, is a major challenge of WEC systems; and adjustment of the blade angle has been the major solution to this fluctuation of power [14]. By adjustment, wind speed beyond the rated value is checked by triggering pitch angle control mechanism [8] in order to keep the power output constant at its rated value. Management of the pitch angle is a method in which the turbine blade angle is varied as the power control variable beyond the wind speed rated value [15]. Proportional-integral (PI) controller has been commonly used as pitch angle adjuster; but despite its simplicity, [14, 15] submit that the controller cannot reach the optimized performance due to the non-linear dynamics of WTG. Therefore, different control structures like nonlinear PI (N-PI) [15] and fractional order PI (F-PI) [16]; have been in use. As well, structural cascade control [13] and the control fault tolerant [17] are used in compensating unknown time-varying nonlinearity and disturbances. Some other available techniques are observer-based blade pitch control [18] and fuzzy logic control [19–21]. In addition, pitch angle control has been improved through model predictive control (MPC) approach, but with related prediction computing complexity [22]. Another way by which pitch control has been improved is that instead of relying on prediction, the control is accomplished using a future knowledge of wind conduct and the wind speed data sent to WTG from one another [23]. Such signal may then be provided for the MPC to ensure best possible response [18–19]. Information on future wind conditions aids MPC to provide optimal solutions while considering system constraints [20]. The MPC can also predict future behavior using a plant model, and as a result, the WTG control system has shown significant gains [21]. From a practical standpoint, however, the online solution of quadratic program is the main drawback of the MPC [20, 21]. As a result, a better method for controlling pitch angle is required; hence, this present study proposes the use of artificial neural networks (ANN) for the control.

At the core of the concept of the approach presented in this study is the design of an MPC-based controller that is capable of constantly maintaining minimum fluctuation in the power output of WEC systems [22]. The strategy

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

involves providing wind speed data to the wind turbine ahead of time using backward propagation neural networks (BPNNs). In the literature, neural networks (NNs) have been used to build nonlinear control systems. It is therefore employed in this study for pitch control in WEC system to maintain a constant power output level in the region over the rated output power. The controller is designed to perform an advance optimal control action and minimize undesired power fluctuations [24–26]. This proposed method is demonstrated using a software-based simulation platform with wind turbine model and a real-life windspeed data.

The remaining parts of this paper are arranged as follows: while methodology of the study and materials used are presented in Section 2, Section 3 contains and discusses the results of the demonstration of the approach, and Section 4 draws the conclusion of the study.

2 Methodology

A model of the WEC system whose pitch angle was controlled using neural network (NN), was developed on the simulation environment of MATLAB/Simulink. Figure 1 is a blocked diagram that depicts the modeling. While inputs to the NN are the current speed of the turbine generator and the change rate of the speed, its singular output is the shifting angle of the differential pitch of the wind turbine. The mechanical power developed by this turbine is thus a product of the varying angle of the pitch.

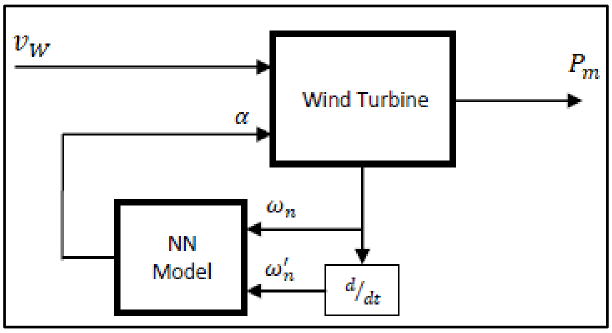


Fig.1. Block diagram of the NN-based control of pitch angle in WEC system

The operational characteristics of a typical WEC system are as represented by the plots in Figure 2 that show the relationship among the parameters of the system. WEC system is generally characterized by tip speed ratio (λ) and power coefficient (C_p) that is described in [27] as:

$$\lambda = \frac{\text{Hub Speed}}{\text{Wind Speed}} = \frac{\omega R}{v_W} \text{ and } C_p = k_1\left[\frac{k_2(\gamma - k_9\lambda)}{\lambda(\alpha^3+1)-\Lambda} - \beta\right]\exp^{-\frac{k_7(\gamma-k_9\lambda)}{\lambda(\alpha^3+1)-\Lambda}} \quad (1)$$

Where ω represent turbine speed, R stands for radius of the swept area of the turbine rotor, v_W is the wind speed, α is the pitch angle, $\beta = k_3\alpha + k_4\alpha^{k_5} + k_6$, $\gamma = \alpha^3 + k_8k_9\alpha + 1$, and $\Lambda = k_8(\alpha^3+1)\alpha$.

By general description, approximately mechanical power, P_m, developed by the turbine blades from the wind flow is [31–33]:

$$P_m = 0.5\rho A C_p v_W^3 \quad (2)$$

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

Where ρ stands for the air density and A for the swept area of turbine rotor blade. If ω stands for the turbine speed, then $\omega_{\max}$ represents the maximum turbine speed at which maximum mechanical power is developed from wind flow. Therefore, the wind speed, v_W^*, at which the maximum mechanical power is harvested is [27]:

$$v_W^* = \omega_{\max} R \left[\frac{(\alpha^3 + 1)(k_1 k_7 \beta + k_1 k_2) + k_1 k_2 k_7 k_9}{k_1 k_2 k_7 \gamma + \Lambda (k_1 k_7 \beta + k_1 k_2)} \right] \quad (3)$$

Thus, the maximum mechanical power accruable from the wind by the turbine is a function of α and $\omega_{\max}$ as [27]:

$$P_{m_{\max}} = 0.5 \rho \pi R^5 \left\{ k_1 \left[\frac{k_2(\gamma - k_9 \lambda)}{\lambda(\alpha^3 + 1) - \Lambda} - \beta \right] \exp^{-\frac{k_7(\gamma - k_9\lambda)}{\lambda(\alpha^3+1) - \Lambda}} \left[\frac{(\alpha^3 + 1)(k_1 k_7 \beta + k_1 k_2) + k_1 k_2 k_7 k_9}{k_1 k_2 k_7 \gamma + \Lambda (k_1 k_7 \beta + k_1 k_2)} \right]^3 \right\} \omega_{\max}^3 \quad (4)$$

Adapting the turbine speed to rotational speed of the turbine generator requires a gear system with ratio $r_g = \frac{\omega_n}{\omega}$, where ω_n is the generator speed. This generator speed thus relates with mechanical power as [27]:

$$P_{m_{\max}} = \frac{0.5 \rho \pi R^5}{r_g^3} \left\{ k_1 \left[\frac{k_2(\gamma - k_9 \lambda)}{\lambda(\alpha^3 + 1) - \Lambda} - \beta \right] \exp^{-\frac{k_7(\gamma - k_9\lambda)}{\lambda(\alpha^3+1) - \Lambda}} \left[\frac{(\alpha^3 + 1)(k_1 k_7 \beta + k_1 k_2) + k_1 k_2 k_7 k_9}{k_1 k_2 k_7 \gamma + \Lambda (k_1 k_7 \beta + k_1 k_2)} \right]^3 \right\} \omega_{n_{\max}}^3 \quad (5)$$

Thus, from equation (3), the relationship among wind speed, pitch angle and generator speed is obtained as [27]:

$$v_W^* = \frac{\omega_{n_{\max}}}{r_g} R \left[\frac{(\alpha^3 + 1)(k_1 k_7 \beta + k_1 k_2) + k_1 k_2 k_7 k_9}{k_1 k_2 k_7 \gamma + \Lambda (k_1 k_7 \beta + k_1 k_2)} \right] \quad (6)$$

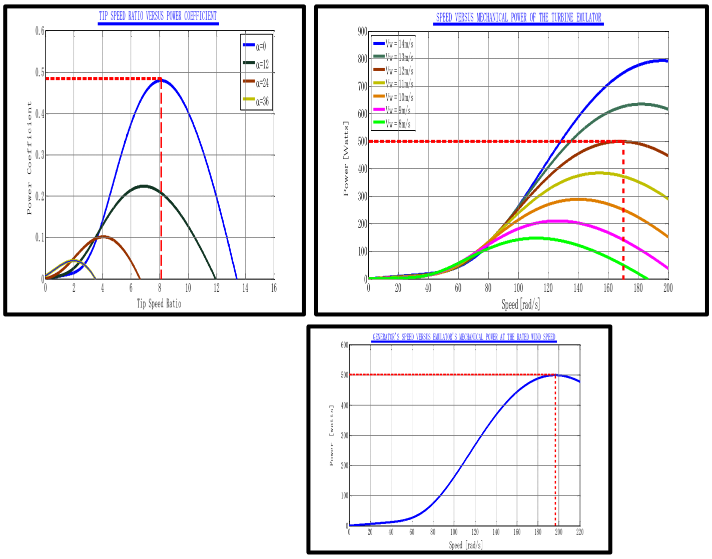


Fig. 2. Operational characteristics of a typical WEC system. Adapted from [27]

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

Training procedures and computations in neurons and layers of the NN model are carried out using Levenberg-Marquardt (LM) algorithm. LM is a second-order algorithm [28, 29] that can solve complex problems [30]. The block diagram of the NN model developed with two hidden layers of 16 neurons altogether is display in Figure 3. Present generator speed, ω_n , and rate of change of the speed, ω_n' are the two inputs into the model; while the output is the varying pitch angle which determines the power quality generated. Generally, NN is expressed as [30]:

$$Y = X^T W \quad (7)$$

Where;

X represent input;

W for the weight, and

Y for the target / output.

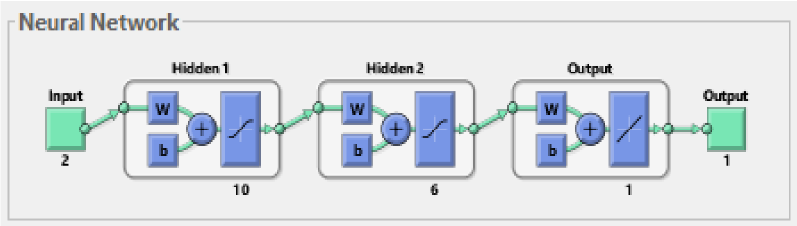


Fig. 3. Block diagram of the NN model

The procedures followed for the multi-layer perceptron learning are:

Step one: Data propagation layer to the output from the input; forward propagation

Step two: The actual and the predicted outcome differences are determined as; calculative error on the output bases.

Step three: The network and updated model with respect to each weight are obtained as derivative error; error back-propagation.

Step four: Steps 1to3 were to learn ideal weight over multiple epochs; and

Step five: to obtain the predicted class labels, the output via a threshold function is taken.

The hidden layer activation unit $a_1(h)$ is calculated in the first step as [30]:

$$Z_1(h) = a_0(in)w_{0,1}(h) + a_1(in)w_{1,1}(h) + \cdots + a_i(in)w_{k,1}(h) \quad (8)$$

$$a_1 h = \emptyset\big(Z_1(h)\big) \quad (9)$$

The activation unit results is the application of activation function, ∅, to the *z* value. This is differentiable for weight learning using gradient descent. The activation function is mostly the sigmoid (logistic) functions.

$$\emptyset(z) = \frac{1}{1+e^{-z}} \quad (10)$$

In order to solve complex problems like image processing, the nonlinearity needed is allowed. The hidden layer activation is also represented as [30]:

$$z(h) = a(in).w(h) \quad (11)$$

Where the output later is:

$$Z(out) = A(h).w(out) \quad (12)$$

Wherein,

$a(in)$ = i^{th} value is the input layer

$a_i(h)$ = i^{th} unit is the hidden layer

$a_i(out)$ = i^{th} value in the output layer

$a_0(in)$ = The corresponding weight w_0 with bias unit

$w_{k,j}(i)$ = from layer *1* to layer *i+1* is the weight coefficient

Training, validation, and testing of the NN algorithm was achieved using 70%, 15% and 15% respectively, of the wind speeds data; while mean square error (MSE) was used as evaluation index. The data, which is ten-year real-life wind speeds in the city of Ibadan (Nigeria) as recorded per minute for the period, was obtained from Climate Hazards Group Infrared Precipitation Station (CHIPPS). Performances of the proposed control mechanism are evaluated by investigating the behavior of the turbine to the wind speeds that are greater than the rated capacity of the turbine. The output mechanical power relates to the variations in the pitch angle, which is a function of the turbine generator's speeds.

3 Results and Discussion

Results obtained from the demonstration of the pitch controller are here presented and discussed. Regression analysis, training, and validation of the NN model, as well as mechanical power output behavior of the WEC system based on the approach of this study are described.

Shown in Figure 4 are the regression analysis curves wherein outputs are plotted against targets. The four plots: training, validation, test, and all; are presented, with the all-plot giving an overall performance of the algorithm. The closer the target to the output, the better the regression plots. Likewise, the more the regression value is to 1, the better. The output value represents the equation of a straight line. The coefficient of the target is the gradient, and the constant value is the intercept on output axis. Also, the more the slope is to unity and the intercept to zero, the better the regression plot. The curves show regression values of 0.97343, 0.97512, 0.99185 and 0.97651 for the training, validations, tests, and all, respectively. The all-plot's regression of 0.97651 was considered to be good value, and so the algorithm was deployed for the pitch angle control.

In Figure 5 is revealed the performances of the algorithm. The best validation performance of the NN model was 22.1343 at epoch 91. This validation value implied that the model could be deployed for the proposed prediction.

.

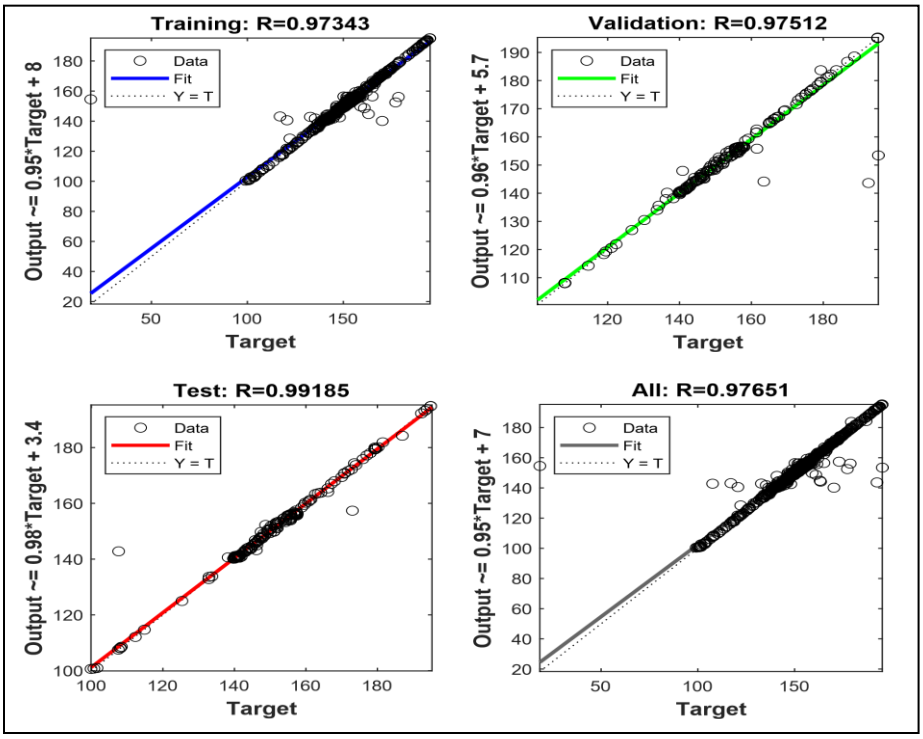


Fig. 4. Plots showing the results of regression analysis.

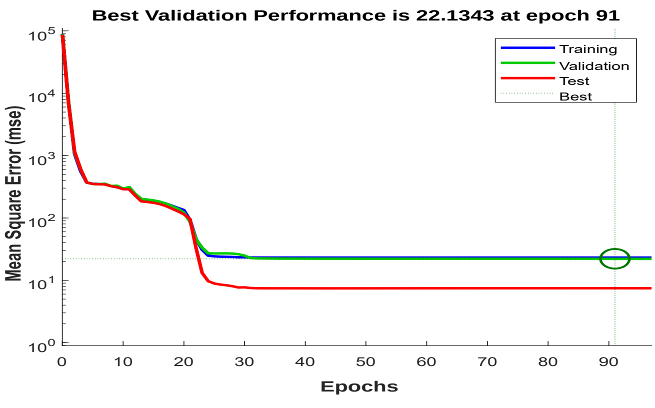


Fig. 5. Performances of the model at training and validation

Figures 6 and 7 respectively show the pitch angle adjustment using the NN-based controller and the corresponding mechanical power developed, as compared with the defaults. While in Figures 6 the actual and the predicted values of the pitch angle are compared, the mechanical power developed in response to the pitch adjustment is presented in Figure 7. At a peak performance on the figure, power output of 1300 W was obtained through the NN-based control as compared to 950 W from the default method. This shows 38.89% increase in the power developed by the turbine.

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

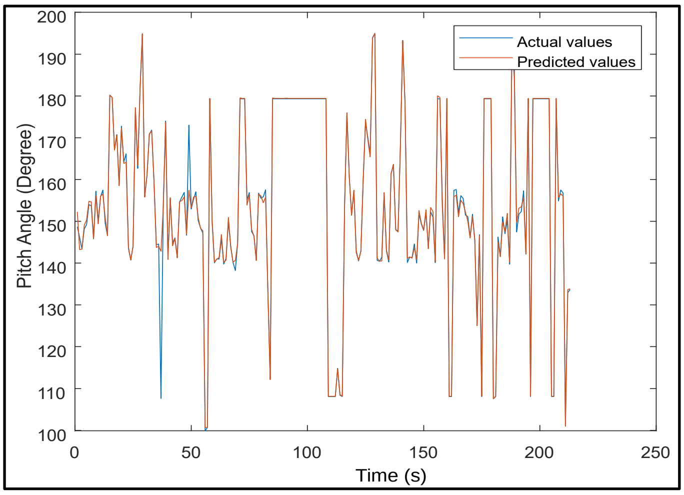


Fig. 6. Comparison between the actual and the NN predicted pitch angle.

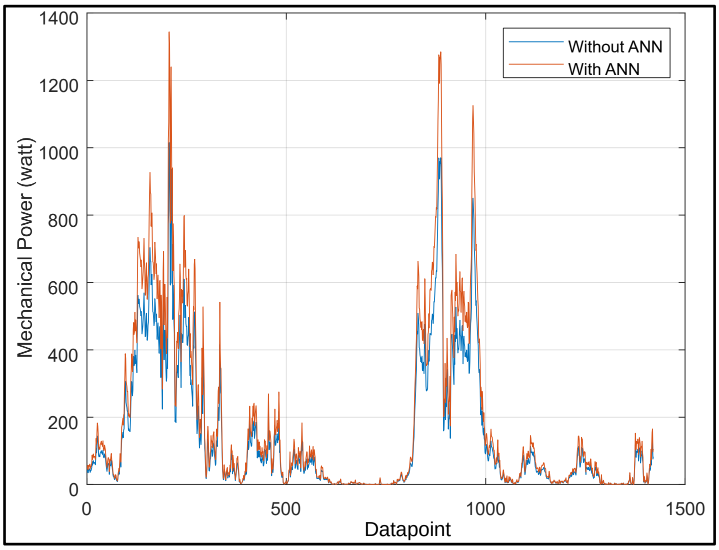


Fig.7. Mechanical power developed using the NN-Based pitch angle controller.

4 Conclusion

With the simulation experiments carried out, this study has found out that the NN-based pitch angle control of wind turbines performs well in controlling the mechanical power developed by wind energy conversion systems above the turbine's rated wind speed. The control mechanism performs well in the above-rated-wind-speed region of operation, with increase in the mechanical power developed by the turbine. The approach is thus recommended for the enhancement of pitch angle control and the overall efficiency of wind energy conversion systems for better reliability of electric power supply. For hierarchy of decision-making, however, the control mechanism can be developed further using deep neural network.

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

5 Acknowledgment

There was no funding received for this work. However, the Department of Electrical and Electronic Engineering, Osun State University, Osogbo, Nigeria; and the Department of Electrical and Electronics Engineering, Federal Polytechnic, Ede, Nigeria are hereby appreciated for providing enabling environments for this study.

6 References

[1] R. Sitharthan, C. Sundarabalan, K. Devabalaji, T. Yuvaraj, A.M. Imran, Automated power management strategy for wind power generation system using pitch angle controller, Measurement and Control 52 (3) (2019) 169–182. https://doi.org/10.1177/0020294019 827330.

[2] T.O. Ajewole, M.O. Lawal, M.O. Omoigui, Development of a Lab-demo facility for wind energy conversion systems, International Journal of Energy Conversion 4 (1) (2016) 1–6. https://doi.org/10.15866/irecon.v4i1.8572.

[3] T.O. Ajewole, O. Kayode, M.O. Omoigui, W.A. Oyekanmi, Demonstration of power factor improvement in wind energy conversion systems using wind turbine emulator, Nigerian Society of Engineers Technical Transactions 50 (1) (2016) 108–123.

[4] T.O. Ajewole, K.O. Alawode, M.O. Omoigui, W.A. Oyekanmi, Design Validation of a laboratory-scale wind turbine emulator, Cogent Engineering 4 (2017) 1 – 13. https://dx.doi.org /10.1080/23311916.2017.1280888.

[5] I.K. Okakwu, O.E. Olabode, A.S. Alayande, T.E. Somefun, T.O. Ajewole, Techno-economic assessment of wind turbines in Nigeria, International Journal of Energy Economics and Policy 42 (2) (2021) 197–204. https://doi.org/10.22581/muet1982.2302.20.

[6] T.O. Ajewole, W.A. Oyekanmi, K.O. Alawode, O.D. Momoh, M.O. Omoigui, Performance assessment of the distribution sub-system in the deregulated Nigerian power sector, Proceedings of the 6th IEEE PES/IAS PowerAfrica Conference (2019) 1–5. https://doi.org/10.1 109/PowerAfrica.2 019.8928916.

[7] T.O. Ajewole, W.A. Oyekanmi, A.A. Babalola, M.O. Omoigui, RTDS modeling of a hybrid-source autonomous electric microgrid, International Journal of Emerging Electric Power Systems 18 (2) (2017) 1–13. https://doi.org/10.15 15/ijeeps-2016-0157.

[8] T.O. Ajewole, O.D. Momoh, O.D. Ayedun, M.O. Omoigui, Optimal component configuration and capacity sizing of a mini-integrated power supply system, Environmental Quality Management 28 (4) (2017) 57–62. http://doi.org/10.10 02/tqem.21639.

[9] L. Cavanini, M.L. Corradini, G. Ippoliti, G. Orlando, A control strategy for variable-speed variable-pitch wind turbines within the regions of partial- and full-load operation without wind speed feedback, Proceedings of the 2018 European Control Conference (ECC) (2018) 410–415.

[10] D. Ochoa, S. Martinez, Frequency-dependent strategy for mitigating wind power fluctuations of a doubly-fed induction generator wind turbine based on virtual inertia control and blade pitch angle regulation, Renewable Energy 128 (2018) 108–124.

[11] H. Matayoshi, A.M. Howlader, M. Datta, T. Senjyu, Control strategy of PMSG based wind energy conversion system under strong wind conditions, Energy Sustainable Development 45 (2018) 211–218.

[12] A. Dahbi, N. Nait-Said, M.S. Nait-Said, A novel combined MPPT-pitch angle control for wide-range variable speed wind turbine based on neural network, International Journal of Hydrogen Energy 41 (22) (2016) 9427–9442.

[13] M.B. Smida, A. Sally, Smoothing wind power fluctuations by particle swarm optimization-based pitch angle controller, Transactions on Instrumentation, Measurements and Control 41 (3) (2019) 647–656.

[14] Y.J. Joo, J.H. Back, Power regulation of variable speed wind turbines using pitch control based on disturbance observer, Journal of Electrical Engineering Technology 7(2) (2012) 273–280.

[15] Y. Ren, L. Li, J. Brindley, L. Jiang, Nonlinear PI control for the variable pitch wind turbine, Control Engineering Practice 50 (2016) 84–94.

[16] M. Oussama, A. Choucha, L. Chaib, Fractional order PI controller design for control of wind energy conversion system using bat algorithm, Lecture Notes in Networks and Systems 62 (2019) 270–278.

[17] J. Lan, R.J. Patton, X. Zhu, Fault-tolerant wind turbine pitch control using adaptive sliding mode estimation, Renewable Energy 116 (2018) 219–231.

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

[18] M.L. Corradini, G. Ippoliti, G. Orlando, An observer-based blade-pitch controller of wind tur bines in high wind speeds, Control Engineering Practice. 58 (2017) 186–192.
[19] T.L. Van, N.K. Dang, X.N. Doan, T.H. Truong, H.N. Minh, Adaptive fuzzy logic control to enhance pitch angle controller for variable-speed wind turbines, Proceedings of 10th International Conference on Knowledge and Systems Engineering (KSE) (2018) 225–229.
[20] Z. Civelek, M. Lüy, E. Çam, H. Mamur, A new fuzzy logic proportional controller approach applied to individual pitch angle for wind turbine load mitigation, Renewable Energy 111 (2017) 708–717.
[21] K.A. Naik, C.P. Gupta, Fuzzy logic-based pitch angle controller for scig based wind energy system, Proceedings of Recent Developments in Control, Automation & Power Engineering (2017) 60–65.
[22] M.D. Spencer, K.A. Stol, C.P. Unsworth, J.E. Carter, S.E. Norris, Model predictive control of a wind turbine using short-term wind field predictions, Wind Energy 16 (3) (2013) 417–434.
[23] J. Bahasa, I. Ngamroo, Model predictive control-based wind turbine blade pitch angle control for alleviation of frequency fluctuation in a smart grid, Proceedings of 2014 International Electrical Engineering Congress (2014) 1–4.
[24] D. Song, J. Yang, M. Su, A. Liu, Z. Cai, Y. Liu, Y.H. Joo, A novel wind speed estimator integrated pitch control method for wind turbines with global power regulation, Energy 138 (2017) 816–830.
[25] A.G. Alexandrov, V.N. Chestnov, V.A. Alexandrov, Identification based control for wind turbine, IFAC-Papers On-Line 50 (1) (2017) 2272–2277.
[26] O. Oluseyi, O. Richard, K. James, M. Julius, O. David, A. Adekunle, Wind energy study and energy cost of wind electricity generation in Nigeria: Past and recent results and a case study for southwest Nigeria, Energies 7 (2014) 8508–8534. https://doi.org/10.3390/en 7128508.
[27] T.O. Ajewole, Modelling and simulation of a hybrid-source autonomous electric microgrid system. Doctor of Philosophy Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria (2014).
[28] H. Yu, B.M. Wilamowski, Levenberg–Marquardt training, Intelligent Systems, Boca Raton CRC Press (2018) 12–11.
[29] T.O. Ajewole, O. Oladepo, K.A. Hassan, A.A. Olawuyi, O. Onarinde, Comparative study of the performances of three metaheuristic algorithms in sizing hybrid-source power system, Turkish Journal of Electric Power and Energy Systems 2 (2) (2022) 134–146. https://doi.org/10.5152/tepes.2022.22012.
[30] T.O. Ajewole, A.A. Olawuyi, M.K. Agboola, O. Onarinde, A comparative study on the performances of power systems load forecasting algorithms, Turkish Journal of Electric Power and Energy Systems 1 (2) (2021) 99–107. https://doi.org/10.5152/tepes2021.21043.
[31] M. Negnevitsky, P. Johnson, Short-term wind power forecasting using hybrid intelligent systems, Master Dissertation, University of Tasmania, Hobart, Australia (2006).
[32] M. Fatemeh, L. Taha, Short-term wind power forecast for economic dispatch, Master Thesis, American University of Sharjah, Sharjah, United Arab Emirates (2013).
[33] S. George, D.H. Nikos, An advanced statistical method for wind power forecasting, IEEE Transactions on Power Systems 22 (1) (2007) 68–77.

7 Authors

Titus O. Ajewole has the memberships of the Institute of Electrical and Electronic Engineers (IEEE) and the Nigerian Society of Engineers (NSE). He is a Fellow of the Nigerian Institute of Electrical and Electronic Engineers (NIEEE) and registered as an Electrical Engineer by the Council for the Regulation of Engineering in Nigeria (COREN). He is currently with the Department of Electrical and Electronic Engineering, Osun State University, Osogbo, Nigeria as an Associate Professor of Energy Transition and Electric Microgrid.

Mutiu K. Agboola is a member of the Nigerian Institute of Electrical and Electronic Engineers (NIEEE), a Registered Engineer and a Principal Technologist at Federal Polytechnic, Ede, Osun State, Nigeria.

JDFEWS 4 (2): 72-82, 2023
ISSN 2709-4529

Kabiru A. Hassan is a member of the Nigerian Institute of Electrical and Electronic Engineers (NIEEE), a Registered Engineer and an Assistant Chief Instructor at Federal Polytechnic, Ede, Osun State, Nigeria.

Adedapo O. Alao is a member of the Nigerian Society of Engineers (NSE), a Registered Engineer and a Deputy Director (Transmission), Osun State Broadcasting Corporation, Osogbo, Osun State, Nigeria

Omonowo D. Momoh is a member of the Institute of Electrical and Electronic Engineers (IEEE) and a Professor at Purdue University Fort Wayne, Fort Wayne, USA

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

A Feasibility Study on the Implementation of a Solar Powered Water Desalination Plant

John A. ADEBISI

[1]Department of Electrical and Computer Engineering, University of Namibia, Namibia; adebisi_tunji@yahoo.com

Eliaser INDONGO

[1]Department of Electrical and Computer Engineering, University of Namibia, Namibia; eliaser760@gmail.com

Taiwo Olumuyiwa AMUSAN

[2]Department of Electrical and Computer Engineering, University of Lagos, Nigeria,
[2]Department of Electrical and Electronics Engineering Science, University of Johannesburg, South Africa; muyiwia.amusan@yahoo.com

Received: 08 December 2023

Review: 18 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: Water desalination plants powered by solar energy represent a viable solution for addressing a part of the water needs in areas without reliable water supply. In this case extending the electric grid and water delivery to remote communities remain challenging for some countries. Using Namibia as a case study, this work carried out a feasibility study on the extent of which, solar energy could be used to power the entire desalination process thereby aiding groundwater usable for human consumption. This process includes but not limited to desalination of underground wells and boreholes as solution to the water shortage problem in remote areas. In this study, a solar-powered desalination technique that could enhance the process of clean water provision to villagers is proposed with the aim of implementation. It further compares and analyzed various desalination technologies to determine the best fit based on the dryness of areas. Ohawuwanga Village in Namibia was used for evaluation purpose with a sampling instrument-questionnaire which determine the village's daily water consumption and corresponding power required. Modelling, simulation, and analysis of the system was carried out using MATLAB Simulink in terms of energy consumption. Other parameters considered in this research are cost, water recovery ratio, salt removal factor, durability, and market analysis. The research revealed that electrodialysis is the best technology for desalination in terms of efficient power consumption amidst other factors compared.

Keywords: *Energy, Electrodialysis, MATLAB, Solar power, Water Desalination*

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

1. Background to the study

Sustainable development goal six (6), came with the responsibility to ensure that water and sanitation access is guaranteed [1]. Hygiene is one of the very important needs for human healthy living therefore access to clean water is access to good life [2]- [3]. The demand for good water is on the rise in line with the increasing world population. In addition, good water is also required for cultivation purpose, industrialization in various sectors such as energy, mining, mechanical and the rest. Some developed countries are still faced with the challenge of clean water. Ohawuwanga is a village in Namibia's northern Ohangwena region with a very little population, located on longitude and latitude of 17.4026° S, 16.7508° E respectively as shown in figure 1[4]. Based on the findings of this research, villagers of this community are still relying on naturally brackish water from boreholes and hand-dug wells, making it one of the many areas where clean water scarcity remains a challenge [5] – [7]. Renewable energy sources are fast becoming very popular especially in communities that are not connected to the grid. Due to this condition, one of the alternative accesses to clean and desalinated water is to implement a solar powered process of water desalination. Common source of water in the case study are wells and boreholes which is naturally brackish and unfit for human consumption.

Figure 1: Map of Namibia showing Ohawuwanga

The term used for the description of water salinity with a mix of fresh and marine water is called brackish. It is a formative part the sea water. Natural brackish water is dangerous for human health because it contains pollution or salt levels that are higher than the allowable minimums [8]. The alternative to obtaining clean water from brackish sources is to desalinate the water as indicated by Mousa in [9]. A typical brackish water is indicated in figure 2.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

Figure 2: Typical brackish water [8]

The life expectancy has been significantly decreased [10], especially in developing and underdeveloped countries, reason not also far from unhealthy water consumption as currently experienced by Ohawuwanga village dwellers. Many diseases can be avoided through sanitation, which calls for the provision of a better water supply. However, fair consideration of financial incentives including low initial expenditures, simplicity of operation, and low maintenance requirements for water treatment technologies are among factors making it difficult to ensure clean water supply in vulnerable areas. Nevertheless, in order to meet the needs of most of the population in remote areas. The choice of desalination technology is influenced by several factors. The salinity of the feed water, the salinity of the generated water, the energy requirements, the environmental impact, and the cost of building the plant are some of these criteria. Desalination systems can use a variety of technologies, including membrane distillation (MD), electrodialysis (ED), and reverse osmosis (RO). However, a desalination plant's total performance is significantly impacted by the technology used in the facility. Since many technologies have a variety of limitations, such as high-power consumption, poor efficiency, low output water capacity, among others. This research investigates various methods of purifying unclean water using Ohawuwanga village in the Ohangwena Region of Namibia as a case study of solar PV water desalination system technology. The overall aim is to find out the suitability of implementing solar powered desalination plant using any of the existing technologies such as membrane distillation (MD), electrodialysis (ED), and reverse osmosis (RO). Figure 3 is an illustration of the desalination process of a brackish water flowing from the well through the various ocean barrier levels to the ground level. For cleansing, such water passes through the desalination plant before subsequent flow to homes and industries for utilization. Again, in urban locations where electricity supply is connected to the grid powering the desalination plant is pretty easier unlike the situation being addressed in this work where rural areas and villages especially in dry terrains such as Namibia are not connected to the grid. Alternative, energy sources are required to power such plants to safe the communist from the disaster associated with bad water consumption. As reflected in the sustainable development goals six (6), for smooth evolvement of human society success and sustainability, securing a steady supply of energy and freshwater is essential. Provision of freshwater to everyone in sufficient quantities is paramount for human survival.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

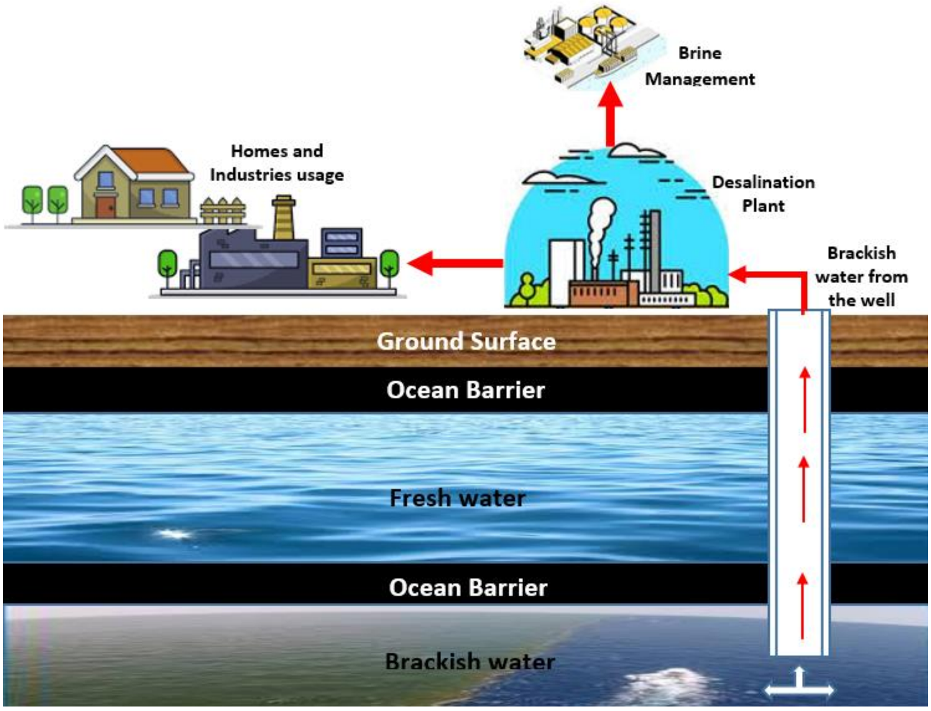


Figure 3: Brackish water extraction and desalination process [8]

The decreasing availability and quality of accessible fresh and brackish water sources is further aggravating the issue of water scarcity. This occurs as a result of both poor water resource management and a lack of an all-encompassing viewpoint in policymaking [11] - [12]. Large-scale infrastructure projects that are implemented quickly, such as dams and irrigation systems for supply-side management, initially mobilize more water resources but ultimately result in a reduction in the amount of freshwater available. While groundwater levels are falling in significant aquifers and fewer rivers are flowing into the ocean. Moreover, Industrial and agricultural enterprises are polluting very significant quantity of freshwater sources [13] - [14]. Water scarcity is a complex issue that involves stakeholders from all facets of society especially the power sector. Engineers are entrusted with creating solutions that address the demands of the developing world as it emerges from poverty as well as the challenges of the rich, unsustainable developed world. Experts in water resource management, however, promote a more nuanced and inclusive strategy, emphasizing the complexities of water policy and the interrelationship between the society, economics, ecology, and engineering. Although experts in water resource management suggest that effective water policies should be prioritized over technology solutions. Seawater desalination is a rapidly developing technological option that may be able to address the water scarcity situation.

Historically, fossil fuel-powered power plants are energy efficient, but recent price instability, erratic availability, and growing environmental concerns have caused new desalination plants to explore for alternative energy sources, such as nuclear or renewable energy. Large-scale nuclear seawater desalination has the potential to be a key component of supplying a secure, economical, and consistent supply of fresh water [15] - [16]. Securing a consistent supply of freshwater is more crucial than ever with the world population expected to reach approximately ten billion people by 2050 [17] – [19]. Meanwhile, the global demand for freshwater is on the rise. The novelty of this research work is to carry out a feasibility study using a case study to determine the total daily water requirement in m^3/day of a typical village under water scarcity condition, evaluate three desalination technologies namely reverse osmosis, electrodialysis and membrane distillation in terms of their energy consumption, cost, water recovery, salt removal factor, durability, market analysis and determine the most optimal desalination technology to be implemented for providing consumable water that will make this solution feasible.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

This research is significant to the relevance of alternative and renewable energy source while helping to alleviate the water scarcity issues and enhancing quality life. However different desalination technologies require a significant amount of energy to operate. Ohawuwanga Village is not connected to the grid therefore an alternative water desalination technology that uses a form of renewable energy is applicable. This study further provides recommendations for the most optimal desalination technology to be used for a solar-powered desalination system in the case study. Although, the desalination technology employed for water desalination in specific plant has a great effect on the overall performance and effectiveness of the desalination plant. A cost analysis is also carried out as part of the feasibility study as well as other optimization techniques to ensure that productivity, strength, reliability, longevity, efficiency, utilization and operational factors are maximized.

2.0 Review of Literature

This section discusses the performance of reverse osmosis (RO), Electrodialysis (ED), and membrane distillation (MD) based on previous literatures. The results of the performance factors for the three technologies under discussion from other studies are explored. Some of the factors of interest include energy consumption, costs, water recovery, membrane efficiency and others. The principle of operation of the three technologies had been reviewed to ascertain their general performance for optimal recommendation. Although the focus of our review is more on the impact of energy consumptions and alternative energy sources especially renewables. Summary of literatures and findings are presented in table 1.

Table 1: Summary of literatures

Author	Year	Aim	Analysis
[20]	2023	worked on a small-scale desalination system towards improving provision of freshwater.	the authors incorporated non-renewable hybrid energy sources using series of combinative methodologies for freshwater productivity. They further analyzed the market share of various desalination technologies vis-a-vis renewable energy systems
[21]	2023	aim at investigating nanomaterials concepts around desalination systems based on current and future standpoints.	considered a bibliometric method to identify future trends and recent development in various desalination processes with respect to their power sources. The comprehensive analysis of the authors also considers water filtration which makes the approach different from other studies however also limited to highly populated regions such as China and some part of the United Kingdom. it does not consider membranes or electrodialysis.
[22]	2022	carried out findings on advance technologies on seawater desalination with focus on membrane distillation.	proposed a method called solar powered membrane distillation with minimum electricity cost using renewable energy technologies. The work is a complete review of integrated system and does not evaluate or compare with other existing methods.
[23]	2021	proposed three different strategies for improving evaporation rate of alternative water sources.	the authors introduced principles of solar driven water desalination technologies called solar-thermal membrane desalination and solar driven electromechanical desalination. A

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

			further summary of comprehensive review and using a strategic method was presented without major proposal of new solution
[24]	2020	aim at providing an eco-friendly and effective freshwater production with minimal cost.	Used a solar vapour evaporation technique to design a controllable energy conversion system for solving challenges associated with water evaporation. The authors enumerated key challenges at the end and provide a more practical approach to water purification process
[25]	2019	work towards determining integration measures for solar powered desalination to combat freshwater issues in China.	the study is limited to China as a country but a wholistic consideration of reducing greenhouse gas emission was checked using coupling technologies and sustainable energy approach especially considering the very high population in China. The author facilitated diverse perspective and understanding of energy consumption for freshwater production.
[26]	2019	discussed powering desalination process as a sustainable solution. s	emphasized on the growing concerns of merging solar technologies with desalination focusing on improving energy efficiency. The method used by authors is more review oriented with focus various methods.
[27]	2012	provided a wide-range review of desalination technologies within Saudi Arabia context.	embraced a poly-generation method with more emphasis on environmental and economic impacts of renewable energy sources but limited to Saudi Arabia. At the end the authors provided guidelines that are generic in nature for desalination to be considered using alternative energy sources

A comprehensive review of literature reveals that cost analysis modeling and optimization techniques were not considered in most of the previous works which emphasis the significance and the novelty of this work and its contribution to knowledge. Further concepts are presented in the following subsection.

2.1 Operating principles of desalination technologies

Three major desalination technologies are considered for this study ED, RO, and MD. They have different operation principles which is also integrated with their power consumption rate amidst other technical and social economical consideration towards achieving a freshwater production. First is electrodialysis (ED) which, is an electrochemical separation method that runs at atmospheric pressure and employs direct electrical current to transport salt through an ion-selective membrane, leaving freshwater behind. ED differs from all other major desalination procedures in that the dissolved salts are transported away from the supply saltwater, rather than the other way around. When positive salt is fed into the system, ions travel through the cation-permeable membrane to the negative electrodes, whereas negative salt ions migrate to the positive electrode via the anion-permeable membrane. To maintain the system's condition, ED systems can periodically reverse the direction of ion movement by reversing the polarity of the applied electric current. It's called Reverse Electrodialysis in this scenario. Figure 4 depicts a simple sketch of the electrodialysis process.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

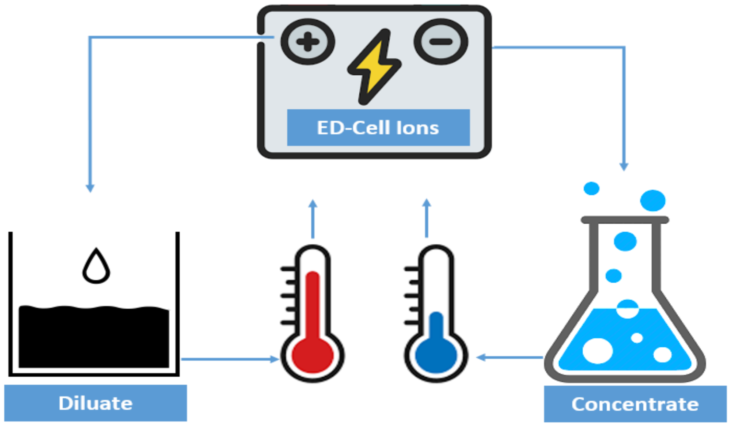


Figure 4: Simple representation of Electrodialysis (ED) process.

Another concept considered in this work is the membrane distillation. This is an evaporative process in which water vapour passes through a hydrophobic membrane and later separated from the feed water phase by a difference in pressure (temperature). MD is a kind of desalination that combines thermal distillation and membrane desalination. Due to greater pressure and vapour, steam molecular water can be transferred across membrane in form of exchange between the compartment of warmer and the cooler. As divergent of other technologies, the membrane driven machinery primary energy is thermal in nature, which is also used for distillation because electricity is required for supplementary facilities [28] - [29]. (sensors, controllers and pumps). The difficulty of making membranes with equal efficiency is one of the major setbacks for MD to compete with other options. Reviewed literatures revealed that it is more energy-efficient and a preferable alternative to other desalination methods although not commercially viable. The third method considered in this research work is the Reverse Osmosis (RO). This is a process that uses a permeable membrane to separate a solvent (in this case, water) from a solution, leaving behind a concentrated solution. However, the osmotic pressure is ensured is kept below the seawater leaving behind solid salt particles letting the desalinated water to go through semi-permeable membranes. This will further reduce the chances of the membrane precipitation and other substances based on the applicable pressure as limits. In other words, there is a limited amount of feed water that can be recuperated as clean water is reduced because of the limited quantity of feed water passing though the membrane to the RO units.

Physical or chemical filtration and clarity of saltwater can be accomplished using coagulation chambers, flocculation chambers, or dissolved air flotation chambers. Membrane filtration, such as ultrafiltration and microfiltration, can remove bigger particles and colloids, allowing for filtration and clarifying. Chemical pre-treatment may be unnecessary with certain membrane techniques. The incoming water will then be pressured by the pump station. The needed pressure depends on the supply water's quality, which ranges from 17 to 27 bars for brackish water to 55 to 82 bars for seawater [15]. RO uses membranes to separate freshwater from saline or brackish feedwater in the main desalination process (Figure 5). Cellulosic, completely aromatic polyamide, and thin-film composite RO membranes are the three main varieties.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

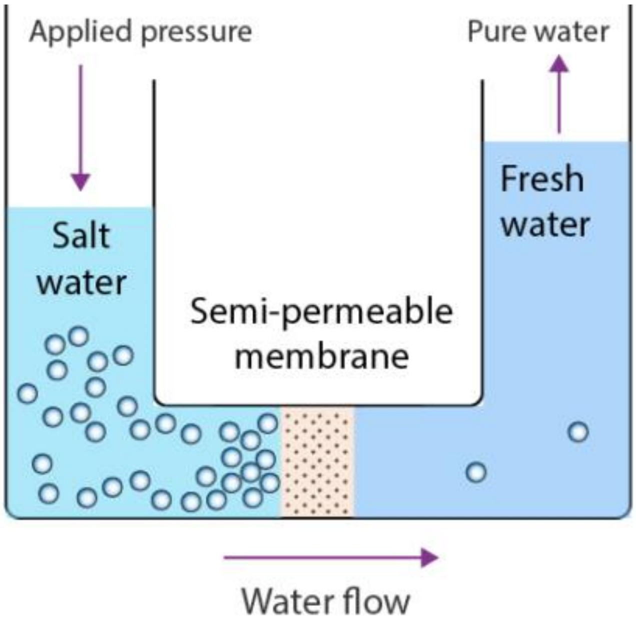


Figure 5: Experimental representation of Reverse Osmosis[30] .

In the past few decades most of the factors considered has witness great improvement to increase the operating pressures and active regions, giving rise to greater rejection and recovery. The maintenance of split between the feed-spacer and the membrane sheets offers an open channel for the feed water flow. In addition, rejected compounds are allowed to be mixed away from the surface of the membrane. The most frequent feed spaces planning in RO modules are the biplanar extruded net [31]. The cost of feed-spacers is usually below $1 per square meter. They are manufactured from polypropylene, chemical inertness, extrudability and a thickness value ranging from 0.6 to 0.9 mm [32]. There could be an increase in fouling as well as decrease in salt rejection due to poor mixing [33]. The permeate spacer usually results in a canal for receiving and moving permeate from the membrane to a tube through the mechanical assistance. The significance is not to lower feed channel pressure that will impact the overall system performance rather to lower the trans-membrane pressure due to permeate production. The permeate spacer is important for element efficiency while the woven polyester is the most prevalent permeating spacer material. Although there are huge old facilities that can be used for spiral wound membrane modules to improve desalination process but the use of Thin Film Composite membranes (TFC) to replace cellulose acetate improved membrane technology by allowing for lower working pressures, larger fluxes, and higher efficiency is fast becoming popular [34] – [36].

Additionally, RO uses solely electrical energy, whereas thermal desalination uses both thermal and electrical energy. Besides, Forward Osmosis (FO) is a revolutionary concept that also uses the principle of osmosis. It uses natural osmosis to dilute a seawater feed stream by utilizing a draw solution with a higher osmotic pressure than the feed, which pulls water from the feed solution across a semipermeable membrane. Using a modest heat source (40°C), the draw solutes are removed from the diluted draw solution and recycled. A combination of ammonia and carbon dioxide gas is commonly employed as a solute. For the membrane phase of the process, specific energy consumption of less than 0.25 kWh/m3 has been documented. When it comes to the amount of thermal energy necessary to regenerate the draw solution, FO is not more efficient than RO [37]. However, because forward osmosis does not require significant hydraulic pressure, it has a lower fouling proclivity.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

2.2 Performance of the desalination technologies

Desalination technologies performances are very critical and holistic based on energy consumption, water recovery, membrane efficiency and salt removal. Operational performance has a major impact on how much energy is used to produce a given volume of water. Different desalination technologies operate based on to various principles. As a result, different quantities of energy are needed to generate a given volume of freshwater. [38] discussed about the benefits and drawbacks of the primary membrane desalination systems. The size of the particles that are trapped or permitted to flow through the membrane was said to be the main distinction between each desalination technologies. Results from desalination systems were acquired and compared, including the ability of groundwater and saltwater to remove salt and contaminants. Based on findings in the works of [30] – [32], [37], RO osmosis removes 25–45% of seawater and 90% of brackish water, while groundwater and seawater have corresponding ED values of 95% and 99%. In the work of [38] the power usage and energy production costs of RO technology depend on certain system elements such the membrane configuration, system effectiveness, total amount of dissolved salt in the input water, and so on. The work of [38], further evaluated the three desalination systems in terms of the efficiency and the use of their membranes. Reverse osmosis was found to be the most effective desalination process by [38], who also analyzed the capabilities of the desalination systems.

The functionalities of the technologies were not assessed in relation to a single type of renewable energy source; hence the comparison fell short of being credible. The result was also reached based solely on the technology's initial cost, which is not the only criterion in determining the technology to be used at a particular site. The determination of the best technology or a combination differs from location to region, claims [39]. As a result, caution must be applied while choosing a technology for a particular desalination system in a certain region. The capital cost, operational and maintenance costs, the type and availability of renewable energy sources, energy efficiency, as well as environmental implications, are important variables that influence the choice of the preferred technology. According to Lucas in [40], the combination of RO technology and solar PV energy sources is preferred among other methods. It is important to state that; mechanical auxiliary systems can be driven by RO using only electrical energy, making it the most energy-efficient commercially accessible technology. Although RO is now the most energy-efficient desalination technique commercially accessible, based on the findings of [40]. This logic may or may not given the development of technologies new technologies. Additionally, the specifics of the case study of this research will also either conform with this outcome or provide a new direction.

Authors in [41] – [43] highlighted the importance of the final water cost as a deciding element in the choice of the best technology. The costs of various technologies were recorded in the findings for [42] and [38]. In comparison to MD, computer models conducted in [44] by Pietrasanta et al. based on ten different locations provided an indication that the climate and feed water salinity are key factors in permeate yield. The study also included the production capacity for RO ranges from 0.1 m3/day for marine and domestic uses to 395.000 m3/day for commercial applications, whereas the capacity for ED ranges from 2 to 145.000 m3/day. [31], has several advantages over competing technologies, including a theoretical rejection rate of 100% none volatiles coupled with salts with lower temperatures below the traditional distillation ranges from 60^0C – 90^0C. The pressure is lower in terms of operation when compared with respect to other membrane processes. Furthermore, it requires less space requirements, few equipment among other thermal processes. In contrast, RO and MD does not require pre-treatment. It is also possible to operate the module intermittently. If the membrane becomes dry, there is no risk of membrane damage. The salinity of the feedwater is not depending on the quality of water, product rate and the theoretical system efficiency. Javed et al. [45] conducted a techno-economic study of a hybrid solar-wind-battery for a stand-alone system and investigated the influence of a low loss of power supply probability, finding that it had an enormous influence in direct, and indirect cost.

The Canary Islands were used as a case study by [46] to examine the relationship between energy and desalination methods and to demonstrate the energy and financial implications of desalination. On the other hand, it is noted

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

that there aren't enough research comparing actual investment scenarios of projects to create an analysis of the investment decision. The authors objectives, ambition, predicted impacts, implementation, and methods to maximize impact stand out as some of the characteristics of interest in the first place. In addition, a sensitive analysis was conducted to determine whether the proposed technologies met the requirements for applying for desalination technologies, the dimensions of the facilities, and the impact on the investment decision for the target output. Furthermore, the MD process also has drawbacks, such as membrane wetting, which results in water of poor quality, the use of microfiltration membranes in MD experiments, and lower flow rates as compared to other desalination methods. Additionally, MD requires both heat energy and electrical energy, compared to other membrane technologies. Thermal energy is the primary energy needed for membrane distillation, while electricity demand is minimal and is only required for auxiliary services like pumps, sensors, and controllers.

Norihiko Ishimaru conducted an experimental investigation for remote areas using a solar PV driven ED desalination system [47], while the effectiveness of ED membranes was found to range from 6.0% to 8.2%, that of RO membranes was found to vary between 6.8% and 10.5%. The amount of water generated by RO and ED was discovered to range between 200 mTM and 375 m^3/d, respectively, and the amount of electricity used to create the water was discovered to be less than the intended figure of 1.92 kWh/m3. In Table 2 is a presentation of summary of findings of literature regarding performances of the three major desalination technologies with respect to energy consumption considered in this research.

Table 2: Summary of findings with respect to performance

Desalination technology	**capacity(m/day) of plant**	**Consumption of energy specifically for a (kWh/m³)**	**Gain output ratio/ performance ratio (GOR/PR)**	**Efficiency (%)**	**Ratio of recovery (%)**
Reverse osmosis	>600	1.5-6.0	0.5-8.1	NA	10-51
Electrodialysis	<600	0.8-1.0	NA	8.5	20-95
Membrane distillation	NA	1,2-3.5	NA	NA	NA

Authors in [48] – [51] analyzed the energy usage of the three methods, resulting to a summary of energy required solely depend on the plant's design, the temperature of the feed water, the use of energy recovery devices, and the desired quality of the produced water. However, the quantity of energy needed mostly depends on the salinity of the feed water, the volume of feed water that is converted to freshwater, and the rejection rate, which gauges how effectively the membrane removes salts from the feed water. Various energy consumption results found in, [48] – [51] are tabulated in Table 3 only with the available record on findings.

Table 3: Energy consumptions of main commercial desalination technologies.

Energy consumption	**RO**	**ED**	**MD**
Electrical energy consumption (kWh/m3)	1.5-2.5	0.8-2.5	2-2.5
Thermal Energy consumption (MJ/m3)	-	-	4.5-6.50
Equivalent electrical to thermal energy (kWh/m3)	-	-	12.2-19.1
Total energy consumption (kWh/m3)	1.5-2.5	0.8-2.5	1.45-4.35

The essential performance metrics for brackish water desalination were listed by [52] with respect to the effectiveness of RO using a common evaluation process. To determine the required salinity removal ratio, first define the feedwater salinity (Co), then measure the three indicators that are primarily related to the technology's cost-effectiveness. Specific energy consumption, water recovery ratio, and the output of clean water from processes are the three indicators. The performance of ED and Membrane Capacitive Deionization were compared

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

in [53]. When evaluating ED's performance, several factors were considered, which include energy consumption, thermodynamic efficiency, SEC – a real scale, salt removal, water recovery, and others. The SEC method was employed as the main parameter to assess ED performance in this study. SEC stands for the quantity of energy needed to create a unit volume of product water.

$$SEC = \frac{(NVc+Vel)\times I\times Am}{Nd} \quad (1)$$

Where N denotes the number of cell pairs in the stack, V denotes the voltage between the cell pairs, V_c denotes the electrodes' redox reaction potential, I denotes the average current density within a cell pair, A_m denotes the area of the ion-exchange membrane, and Q_d denotes the dilute volumetric flow rate per cell pair. A numerical solution of the 2-D Nernst-Planck model was used to calculate the cell pair voltage and the average current density for a given separation. The thermodynamic energy efficiency, n, was another variable that was used to assess ED's effectiveness. The minimum specific energy consumption of separation (SEC_{min}), which is normalized by the SEC, and is represented by equation (2), which is thermodynamic energy efficiency.

$$\text{Declination angle, } \delta = 23.45 \times sin\left(\frac{360}{360}\right) \times (n-1) \quad (2)$$

2.3 Review of costing parameters

An estimated average capital costs that was used in this feasibility study to evaluate the capital costs for the three technologies for the Ohauwanga Village in Namibia is presented in Table 4. The performance parameters were thoroughly investigated to ascertain their impact on the general performance of a desalination unit in order to assess the performance of the three desalination methods (RO, ED, and MD). Examples of such factors include energy requirement, capital expenses, water costs per unit of product, water recovery, and salt removal membrane efficiency. Each technology's performance characteristics were determined and calculated using distinct sets of data. Data from the locations were collected in some cases; part of these data came from simulations and others from experimental outcomes. Studies have revealed that the salinity of the site feed water and the technology's membrane have a significant impact on a desalination technology's performance. For example, RO technology is a pressure-based technology, thus it consumes more energy compared to ED and MD.

Table 4: Estimated average capital costs per cubic meter.

Technology	Estimated average cost (N$/m^3)
RO	207.22
MD	148.69
ED	156.50

A summary of literatures and findings on various methods and approaches used in earlier research have provided indications on approaches that are preferable and appropriate for current investigation. The next section will discuss mathematical models and the design specifically for this feasibility study.

3.0 Materials and Methods

The methodology employed in this research covers reverse osmosis, electrodialysis, and membrane distillation as the three desalination technologies evaluated as proposed. This study utilized a quantitative analysis technique. The three technologies' performances were compared, and the preferred technology is suggested for usage in the cases study - Ohauwanga Village's desalination system. To figure out how well the technologies perform, mathematical models were formulated. A MATLAB-Simulink model was also carried out using the package to determine the SEC of each technology. The simulation in MATLAB was used to obtain the SEC of each

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

technology. The research design is illustrated in figure 6. It contains the procedural block diagram of the main procedures that were followed to carry out this research. Data gathered for the desalination plant in the village of Ohauwanga, as well as the design parameters generated from actual secondary data and equations, are the foundation of this study. Each technology's performance factor was identified, and the technologies were compared.

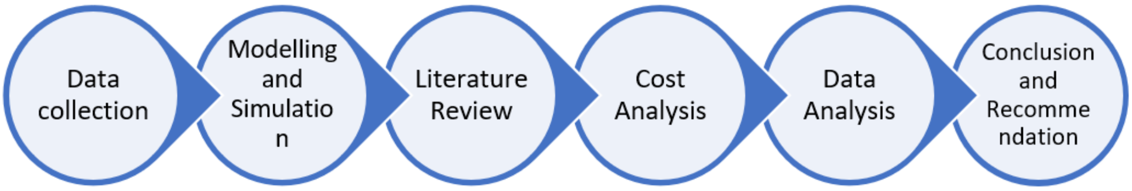


Figure 6: Flow of Methodology and research design

Data collection for this study involved the use of a questionnaire, the feedback received were later used for simulation of the technologies using MATLAB-Simulink model for proper analysis. A total of 157 questionnaires were handed to the households and the main targets were the household owners. Some of the site parameters for Ohauwanga Village were collected. These parameters were: plant capacity, total dissolved salts, expected time of operation of the desalination plant, latitude angle, solar irradiance and hours of full sun with specific energy consumptions, SEC (kWh/m^3). The SEC for each technology was obtained from the simulations done in Simulink from the Renewable Energy Desalination (REDs) library. Furthermore, the cost of the desalination unit and the Photovoltaic (PV) power plant are included in the capital/investment cost. The unit cost obtained by prior studies was used to compute the total capital cost needed for each desalination unit. The Direct Current (DC) power needed for the desalination plant and the PV plant was sized for each technology. The total daily demand for each unit was determined using the SEC for each technology as indicated in section 2. It was expected that ground-mounted systems will cost 51067.80 N$/kW to install. These costs cover the PV array as well as the installation, electrical equipment, and balance-of-system elements for each system.

3.1 PV plant Sizing

First is the determination of the tilt angle of PV, Equation (3) – (5) were used for this sizing accordingly with reference to equation (2).

$$\text{Altitude angle } \beta = 90 - (L + \delta) \tag{3}$$

$$tilt\ angle = 90 - \beta \tag{4}$$

where, L is the latitude angle and n are the days number of the year. The total daily energy demand and the DC peak power were calculated by using (6) and (7) respectively.

$$total\ daily\ energy\ demand = \frac{SEC\left(\frac{Wh}{m^3}\right)}{daily\ plant\ capacity\left(\frac{kWh}{m^3}\right)} \tag{5}$$

$$Pdc(kW) = \frac{daily\ energy\ demand}{derate\ factor \times \frac{h}{day} of\ full\ sun} \tag{6}$$

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

In addition, to calculate capital cost is equation (8)

$$Cost = Pdc(kW) \times \frac{1000W}{kW} \times 2.94\frac{\$}{W} \quad (7)$$

These calculations also considered water recovery for the three technologies which is assumed to be constant (75%) for membrane efficiency/salt removal. Production of water cost per unit volume, Levelized Cost of Water (LCOW) function uses the formulation in equation (8) to determine the unit water cost per cubic meter of product water. This same method was adapted from the United States Department of Energy and water cost. It was employed as a cost function for the desalination system[54].

$$LCOW = \frac{[(I_{Pj}+F_{Pj})+(I_{xj}+M_{xj})+(I_{tankj}+M_{tankj})[\div(1+r)^{j})}{\sum\frac{Qwj}{(1+r)^{j}}} \quad (8)$$

Where: I_p , M_P, and F_p represent the investment, maintenance and operation costs (M&O), and fuel costs (in this case it is a constant for units, hence assumed to be 1), I_{tank} and M_{tank} are the water tank and Investment and maintenance (also assumed to be 1), Q_w and r is the annual quantity of water produced over the analysis period (5 years in this case) and discount rate (3%) respectively. In terms of data comparison, the performance factors for the three technologies were compared. The analysis and comparison were done in terms of energy consumption, water recovery ratio, efficiency, cost, durability, and market analysis of each technology. This section presented the methodology that was carried out to undertake the research. The detailed procedural tasks and equations that were used to evaluate the performance of RO, ED and MD were highlighted and the detailed results and discussion is presented in the next session.

4.0 Discussion of Results

Since this research focus more on feasibility study due to lack of freshwater and reduced water consumption levels for the residents of the case study - Ohawuwanga village. The questionnaire was precisely asking respondents about the estimated normal daily water use for their families. The survey results showed that each home used between 40 and 320 litres of water per day or in some cases an average of 139.2 litres. Additionally, based on the household size of seven people, it can be shown that the daily water consumption per person in Ohawuwanga is 19.9 litres, or nearly 20 litres. It's important to note that the fact that 100% of respondents claimed they augmented their freshwater consumption with rainfall and salt-contaminated well water raises the possibility that the typical person's daily freshwater consumption may really be lower than the reflected values captured in the questionnaire. Table 5 contain the survey's findings in this regard.

Table 5: Questionnaire responses

Respondents (n)	Mean daily consumption (litres/household)	minimum (litres)	Maximum (litres)
157	139.2	40	320

Some of the challenges, based on this feasibility study reflects, 78% of the respondents are having issues with their water supply and either the respondent directly or a member of their household had saline water difficulties. Due to the distance, they must drive to and from town, some inhabitants only purchase potable water when they visit, which is only once a month. Considering the technical feasibility of solar power desalinated plant, from the analysis – this work carefully considered willingness to pay for desalinated water and its processes using modern

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

technologies. This work further investigated to determine how much people in Ohauwanga were generally willing to pay for desalinated water. Residents were initially asked in the survey if they would be willing to pay for dependable, clean freshwater from Ohauwanga Village and, if so, how much they would be willing to pay in total. Additionally, a key premise of the query was that no people accessed any freshwater that came from the village and that all wells and boreholes were salt-contaminated. Ohauwanga village residents are prepared to pay for the dependable and hygienic freshwater, as shown in Table 6 reported at 88% of those surveyed said they would purchase freshwater from the Village if available. Moreover, it was determined that the mean willingness to pay for a 20-liter bottle was 1.92 N$.

Table 6: Readiness and willingness to pay for desalinated water.

Respondents	percent of respondents	mean WTP for clean and reliable water N$/20L	standard deviation	minimum WTP N$/20 L	Maximum WTP N$/20 L
157	88	1.92	1.18	0.37	3.74

Nevertheless, very few percentages of the respondents indicated fresh water should be free for the villages irrespective of the process involved to make it available. Other site parameters considered during the feasibility study at Ohawuwanga Village's was the water demand which is calculated to be 7.93 m^3/day. The optimum concentration of treated water was compared to the solid concentration of the water from the case studies boreholes in accordance with acceptable drinking water standards for the country. The table 7 summarizes the case study site parameters.

Table 1: Site parameters of Ohauwanga Village

Parameter	Value
Plant capacity (m^3/day)	7.93
Total Dissolve Solids - TDS (ppm)	567
Expected time of operation(h/day)	8
Irradiance (kWh/m^2)	6.6
Hours of full sun (h/day)	5.5

Other factors considered towards obtaining accurate energy consumption specifications uses the SEC for each technology by obtaining MATLAB Simulink results based on the available data using mathematical models formulated in previous sections. The SEC, which is the measure of the amount of energy needed to generate one cubic meter of water, is a crucial component in desalination technology. The energy needed to create portable water increases with a technology's SEC. Therefore, a low SEC desalination process is chosen over a higher SEC technology. The SEC for ED was found out to be 2.563 kWh/m^3 as shown in figure 7 while the SEC for MD was found to be 3.102 kWh/m^3 as shown in figure 8.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

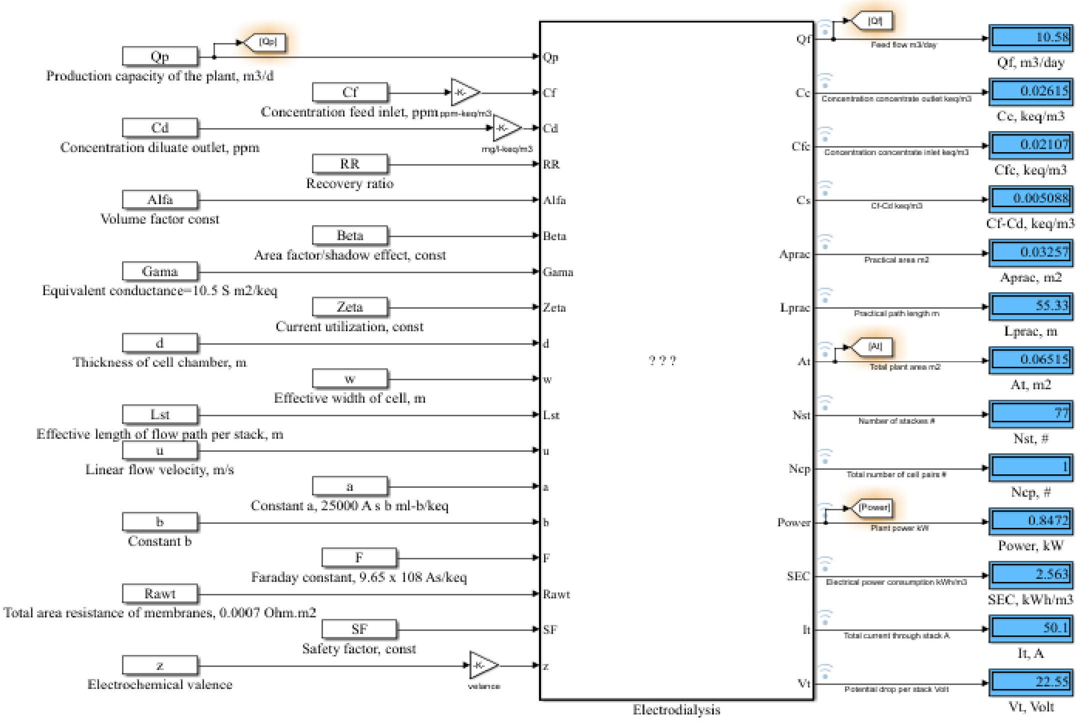


Figure 7: Simulation of Electrodialysis (ED) in MATLAB Simulink

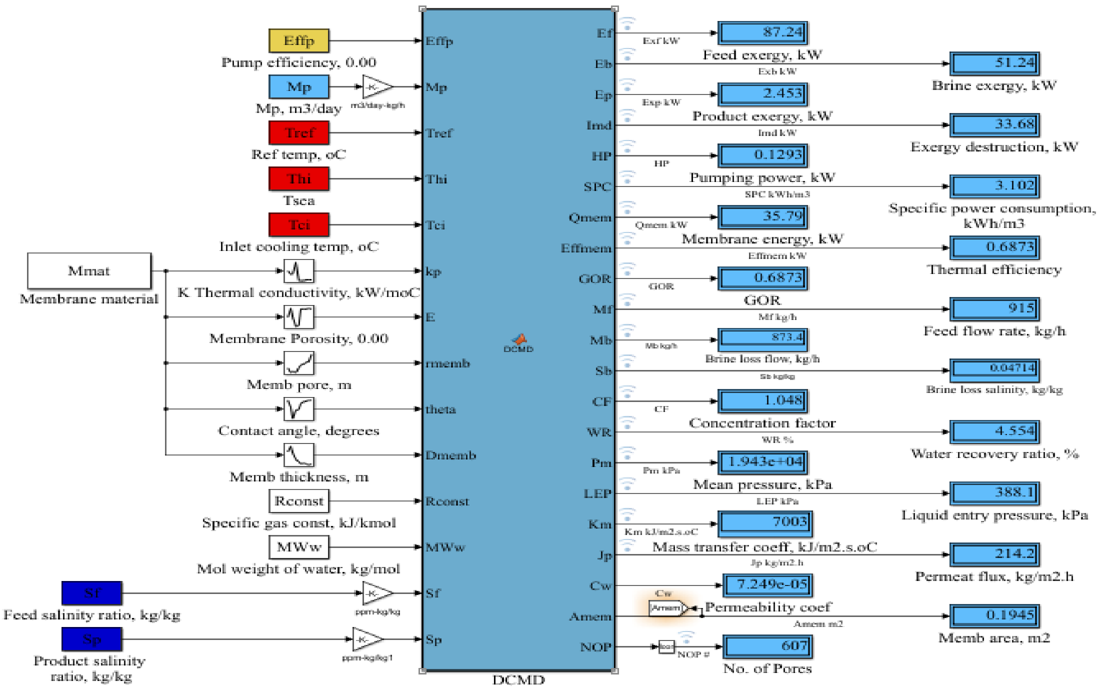


Figure 8: Simulation of Membrane Distillation (MD) in MATLAB Simulink

Similarly, the SEC for RO was found out to be 4.484 kWh/m^3 as shown in the simulation result obtained in figure 9.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

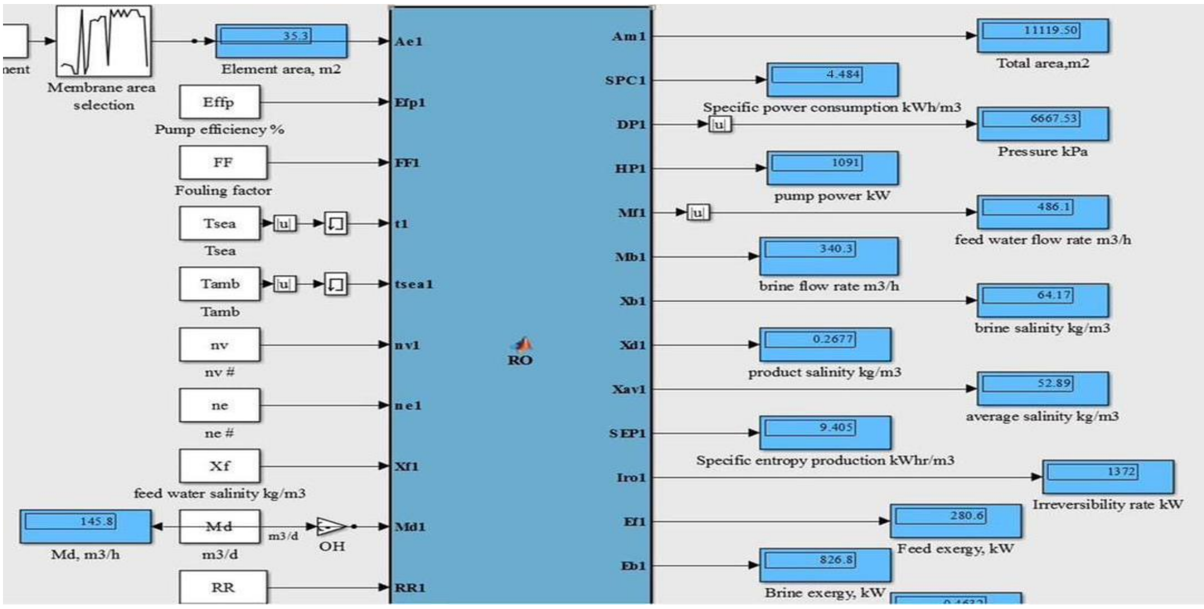


Figure 9: Simulation of Reverse Osmosis (RO) in MATLAB Simulink

The specific energy consumption for each technology was obtained from the simulations carried out in MATLAB Simulink. The SEC for each technology is tabulated in table 8.

Table 2: SEC of each technology as obtained from the simulation.

Technology	Specific Energy Consumption (kWh/m^3)
Electrodialysis (ED)	2.563
Membrane distillation (MD)	3.102
Reverse osmosis (RO)	4.484

4.1 Recovery ratio and Cost Analysis

The brackish water recovery ratio used in this investigation was set at 75% for all methods. Any technology can have a variable water recovery ratio. It is a variable value that varies as the plant runs. This factor is therefore constant for the three technologies under consideration. Also, the cost analysis is this study is the sum of four major components i.e. cost of the desalination process, the second component is the cost of the PV plant, storage tank and as well as fuel cost. The capital cost for the desalination process include desalination membranes, pumps, and labour. The estimate of the capital cost per cubic meter of fresh water is presented in table 9.

Table 3: Capital cost of each of desalination plant foe each technology

Technology	Estimated average cost (N$/m^3)
Reverse osmosis (RO)	207.22
Membrane distillation (MD)	148.69
Electrodialysis (ED)	156.50

The daily capacity for the case study was found to be 7.94 m^3/day. Therefore, the total capital costs for the three

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

desalination technologies were calculate and the results are shown in table 10.

Table 4: Estimated average cost of water.

Technology	Estimated average cost (N$)
Membrane distillation (MD)	1645.32
Electrodialysis (ED)	568.27
Reverse osmosis (RO)	1242.61

4.2 Capital cost for PV power Plant

It is worthy to note that the desalination technology had a different SEC. As a result, it was discovered that each technology had a varied daily energy requirement. In order to accommodate each technology's daily energy needs, the PV plant was sized uniquely for each technology. The costs of the PV modules and inverters were factors considered while determining the cost of the PV plant. To power the plant, the sizing was carried out for all the three technologies used; Daily solar irradiance = 6.6 kWh/m² which is estimated to 5.5 hours of full sun. Therefore, the PV plant sizing for electrodialysis is**;**

$$\text{Total daily energy} = 2.563\text{kWh/day} \times 7.9344\text{kWh/day} = \ 20.3359\ \ \text{kWh/day}$$

$$\text{Pdc(kW)} = \frac{\text{daily energy demand}}{\text{derate factor} \times \frac{\text{h}}{\text{day}}\text{of full sun}}$$

$$= \frac{20.3358\ \text{kWh}}{0.76 \times 5.5\frac{\text{h}}{\text{day}}\text{of full sun}}$$

$$= 4.865\ \text{kW}$$

Similarly, the PV Plant sizing for membrane distillation is;

$$\text{Total daily energy} = 3.104\text{kWh/day} \times 7.9344\text{kWh/day} = \ 24.628\ \ \text{kWh/day}$$

$$\text{Pdc(kW)} = \frac{\text{daily energy demand}}{\text{derate factor} \times \frac{\text{h}}{\text{day}}\text{of full sun}}$$

$$= \frac{24.922\ kWh}{0.76 \times 5.5\frac{h}{day}of\ full\ sun}$$

$$= 5.8919\ kW$$

And the third PV plant sizing for reverse osmosis is given by;

$$\text{Total daily energy} = 4.484\text{kWh/day} \times 7.9344\text{kWh/day} = \ 35.578\ \ \text{kWh/day}$$

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

$$Pdc(\text{kW}) = \frac{\text{daily energy demand}}{\text{derate factor} \times \frac{\text{h}}{\text{day}} \text{of full sun}}$$

$$= \frac{35.578\ \text{kWh}}{0.76 \times 5.5 \frac{\text{h}}{\text{day}} \text{of full sun}}$$

$$= 8.511\ kW$$

With the analysis presented, it infers that the solar panels must be able to produce a power of 8.511 kW. It also gave room for assumption of ground-mounted systems cost to an estimated value of 51,067.80 N$/kW watt to install. These costs cover the PV array as well as the installation, electrical equipment, and balance-of-system elements for each system. Table 11 summarizes the electrical energy requirement and cost of the PV plant for each technology.

Table 11: Electrical energy requirement cost summary for the three desalinated technologies.

Technology	Total Energy Demand (kWh/m^3)	peak watts of DC (kW)	Cost ($)
Electrodialysis (ED)	20.336	4.865	248444.85
Membrane distillation (MD)	24.628	5.892	300891.50
Reverse osmosis (RO)	35.578	8.511	434638.05

Taking reference from related works, the cost of water storage tank per m^3 is also considered to be at N$ 4429.35, the tank total cost is 4429.35×7.94 = N$ 35169.04. The maintenance costs for PV plant and storage tanks were estimated to be 3% of the capital costs, while the maintenance costs for the desalination processes were estimated to be 10% of their initial costs. The membrane life of the three technologies was found to be more than five years. In this study the durability of the desalination plant was anticipated to be to be ten years. The cost of maintenance of the PV plant, desalination unit and the storage tank are given in table 12.

Table 12: Maintenance cost of PV plant, desalination process and storage tank

Technology	PV plant(N$)	Desalination process(N$)	Storage tank(N$)
Electrodialysis (ED)	74533.45	115185.68	9314.49
Membrane distillation (MD)	91342.75	109444.90	9314.49
Reverse osmosis (RO)	130391.41	152516.94	9314.49

RO desalination process requires a lot of maintenance due to membrane fouling, which is the build-up of salt on the effective membrane area. On the other hand, ED requires more maintenance than MD due to build-up of ions on the ion exchange membrane. MD requires minimum maintenance, hence the lower maintenance costs. The efficiency range of the three desalination technologies are shown in table 13.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

Table 135: The range of efficiencies of the three technologies

Technology	Salt removal/membrane efficiency (%)
Electrodialysis (ED)	65-85
Membrane distillation (MD)	54-85
Reverse osmosis (RO)	65-95

The LCOW equation (8) was used to calculate the unit cost of water at a rate, r of 3% for 10 years each technology: When the required parameters were obtained in the previous sections the results are presented in table 14 as the cost of water production.

Table 6: The levelized cost of water (LCOW) of each technology

Technology	Levelized cost of water-LCOW (N$/m^3)
Electrodialysis (ED)	4.38
Membrane distillation (MD)	3.77
Reverse osmosis (RO)	4.35

Having discussed the results obtained from the methodology formulations, data collected and simulation. The three-desalination unit's growth rate and demand rate are covered in this section of the research. The general effectiveness of the three technologies is covered in this part. In general, RO's performance is preferred for the case study based on the feasibility for large-scale applications and locations with greater feedwater salinities. The extensive literature review also showed that, desalinating feedwater with a salinity of greater than 5000 mg/L using RO is economical. On the other hand, due to its affordability, ED is preferred for small-scale and sites with lower feedwater salinity (5000 mg/L) due to its low energy requirements, low operating pressure and temperature, and status as a low-cost alternative to established technologies like RO and MD. Membrane distillation is thought to have enormous potential but for some of its identified drawbacks in the literature section, it is not commercially viable. Drinking water can be effectively purified using the MD method, which can get rid of all kinds of non-volatile ions. However, in terms of market share based on the peculiarity of areas under consideration, the RO holds a significant market share in terms of technology, and it is anticipated to dominate the market for water desalination plants in terms of volume throughout the forecast period. The RO process's supremacy can be due to its higher efficiency and lower energy needs. However, MD is leading in terms of growth. ED was the first membrane-based desalination technology to be commercialized. Albeit the preferential adoption of RO ensures supplies in a minor portion of the drinking water industry today.

5.0 Conclusion and Recommendations

It is economically and technically viable to deploy a solar powered desalination system based on the study carried out in this research considering the nature of data obtained in the village used as case study. The outcome of this research is applicable for other similar terrains with common parameters. The installation of a solar-powered desalination system in areas where freshwater is a serious challenge would enable residents to access safe, clean water for consumption and lessen the health problems caused by brackish water. It is feasible that the Village may experience financial gains from owning, developing, and operating a solar powered desalination plant after analyzing the cost of the solar powered desalination technology taken into consideration in this study. It is clear from the energy usage data that RO requires more energy to produce a volume of 7.94 m3/day. It takes 21.3% less energy for ED to produce 7.93 m^3 per day than it does for RO. It has been shown that MD uses the least amount of energy to create the same amount of water. It was discovered that the energy requirements for MD were roughly 13% fewer than those for ED and 16.8% less than those for RO. As a result, it was determined that

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

RO needs more inverters and PV panels to meet its energy needs. As a result, RO often has greater capital expenses than ED and MD. On the other hand, the number of PV panels, as well as inverters required for ED and MD, were found to be relatively less than that of RO.

The unit cost of product water for RO was discovered to be greater than the unit cost of product water for ED and MD as a result of higher SEC. The higher energy needs of RO are brought on by the high osmotic pressure pumps. For all three systems, it was expected that the water recovery would remain constant. For all the analyses that were done, it was maintained at 75%. Based on how RO functions in general. For each technique, the range for salt removal from feed water was determined. The findings indicate that MD has the greatest range and the lowest potential for salt removal from feed water. In terms of salt removal, RO was determined to have the highest membrane efficiency. Following the analysis, it was determined that RO was economical in facilities with feed salinities more than 5000 mg/L. The cost-effective technology for plants with a feed salinity less than 5000 mg/L was ED. The market study that was conducted based on literatures and alignment with the realities led to the conclusion that MD is still used at an experimental level but has not yet reached a commercial or industrial level. The contents of the case study borehole water contain more cations and anions than the other two, as indicated in previous sections. It was also discovered that ED has a good ion removal ratio compared to the other two. These factors led to the conclusion that ED was the best technology for the desalination plant in the area of study if this will be considered in isolation. Irrespective of the factor of interest, it was discovered that; close attention should be paid to the pre-treatment equipment for a more cost-effective RO plant. Pre-treatment requires more power, which raises the cost. Although, the use of energy recovery devices can lower the specific energy consumption of a desalination technology. A reduction of the power drawn by a desalination unit leads to a significant reduction in capital costs and as a result, lowers the cost of freshwater which makes water affordable by most of the people living in villages prone to the problem addressed in this work.

Finally, it is important to state that energy consumption increases with the membrane's/salt removal's efficiency. The outcomes of the MD and RO tests had demonstrated that MD had the lowest daily energy demand and the lowest salt removal ratio. On the other hand, RO was found to be the most effective at removing salt content; as a result, RO used more energy to generate 7.94 m3/day. The ideal desalination unit for different sites can be found using the results of this study. With the results of this work, the desalination site parameters can always serve as inputs for proper comparism of outputs in accordance with the identical procedures used in this study before subsequent construction and implementation. Capital expenses can be reduced by using the best or most appropriate desalination technology for every facility. Further study could focus on the use of hybrid energy source such as solar and wind or any other power source to power the desalination plant. An incorporation of plant optimization configuration, team turbine design as well as any other optimisation techniques could also be considered in future to ensure maximum productivity, strength, reliability, efficiency, and reduction of operational limitations. Hence this research has fulfilled its objectives by considering environmental effects of having an alternative powered desalination plants towards providing vulnerable communities with clean water which is an essential factor of development.

References

[1] M. Sadiq, T. Q. Ngo, A. A. Pantamee, K. Khudoykulov, T. Thi Ngan, and L. P. Tan, “The role of environmental social and governance in achieving sustainable development goals: evidence from ASEAN countries,” *Economic Research-Ekonomska Istrazivanja* , vol. 36, no. 1, 2023, doi: 10.1080/1331677X.2022.2072357.

[2] Md. S. Khan and S. K. Paul, “Sanitation-hygiene Knowledge, Practices and Human Health Impacts: Insights from Coastal Bangladesh,” *Geosfera Indonesia*, vol. 8, no. 2, 2023, doi: 10.19184/geosi.v8i2.39584.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

[3] P. K. M. Jensen, Z. Z. Hossain, R. Sultana, J. Ferdous, S. Almeida, and A. Begum, "Introduction of the Personal Domain in Water Sanitation and Hygiene (WASH), a New Approach to Identify Missing Health Impacts," *Trop Med Infect Dis*, vol. 8, no. 5, 2023, doi: 10.3390/tropicalmed8050252.

[4] G. Christelis and W. Struckmeier, *Groundwater in Namibia - an Esplanation to the Hydrogeological Map*. 2011.

[5] Md. S. Khan and S. K. Paul, "Sanitation-hygiene Knowledge, Practices and Human Health Impacts: Insights from Coastal Bangladesh," *Geosfera Indonesia*, vol. 8, no. 2, 2023, doi: 10.19184/geosi.v8i2.39584.

[6] P. K. M. Jensen, Z. Z. Hossain, R. Sultana, J. Ferdous, S. Almeida, and A. Begum, "Introduction of the Personal Domain in Water Sanitation and Hygiene (WASH), a New Approach to Identify Missing Health Impacts," *Trop Med Infect Dis*, vol. 8, no. 5, 2023, doi: 10.3390/tropicalmed8050252.

[7] M. S. Mohsen and O. R. Al-Jayyousi, "Brackish water desalination: An alternative for water supply enhancement in Jordan," in *Desalination*, 1999. doi: 10.1016/S0011-9164(99)00101-0.

[8] John Woodard, "What is Brackish Water and How Do You Treat It?," https://www.freshwatersystems.com/blogs/blog/what-is-brackish-water-and-how-do-you-treat-it.

[9] M. S. Mohsen and O. R. Al-Jayyousi, "Brackish water desalination: An alternative for water supply enhancement in Jordan," in *Desalination*, 1999. doi: 10.1016/S0011-9164(99)00101-0.

[10] M. Sadiq, T. Q. Ngo, A. A. Pantamee, K. Khudoykulov, T. Thi Ngan, and L. P. Tan, "The role of environmental social and governance in achieving sustainable development goals: evidence from ASEAN countries," *Economic Research-Ekonomska Istrazivanja* , vol. 36, no. 1, 2023, doi: 10.1080/1331677X.2022.2072357.

[11] L. Ohlsson, "Water conflicts and social resource scarcity," in *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere*, 2000. doi: 10.1016/S1464-1909(00)00006-X.

[12] W. A. Jury and H. J. Vaux, "The Emerging Global Water Crisis: Managing Scarcity and Conflict Between Water Users," *Advances in Agronomy*, vol. 95. 2007. doi: 10.1016/S0065-2113(07)95001-4.

[13] P. H. Gleick, *Environment, and Security, and S. E. Institute, Water in Crisis: A Guide to the World's Fresh Water Resources*. 1993.

[14] F. R. Rijsberman, "Water scarcity: Fact or fiction?" in *Agricultural Water Management*, 2006. doi: 10.1016/j.agwat.2005.07.001.

[15] J. Kupitz and M. J. Crijns, "Perspectives of nuclear energy for seawater desalination," *Desalination*, vol. 99, no. 2–3, 1994, doi: 10.1016/0011-9164(94)00185-5.

[16] J. Kupitz and M. J. Crijns, "Perspectives of nuclear energy for seawater desalination," *Desalination*, vol. 99, no. 2–3, 1994, doi: 10.1016/0011-9164(94)00186-3.

[17] Naciones Unidas, "World Population Prospects: The 2017 Revision," *Econ Soc Aff*, vol. 1–53, no. December 2017.

[18] United Nations, "World Population Prospects: The 2017 Revision, custom data acquired via website.," *Department of Economic and Social Affairs, Population Division*, no. June 2017.

[19] UN DESA, "World Population Prospects: The 2017 Revision, Key Findings and Advance Tables," *United Nations*, 2017.

[20] H. Kariman, A. Shafieian, and M. Khiadani, "Small scale desalination technologies: A comprehensive review," *Desalination*, vol. 567. 2023. doi: 10.1016/j.desal.2023.116985.

[21] M. N. AlMallahi, S. M. Asaad, A. Inayat, K. Harby, and M. Elgendi, "Analysis of solar-powered adsorption desalination systems: Current research trends, developments, and future perspectives," *International Journal of Thermofluids*, vol. 20, 2023, doi: 10.1016/j.ijft.2023.100457.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

[22] M. A. H. M. Hanoin, F. N. Zainuddin, and N. M. Mokhtar, "A review of solar-powered membrane distillation system: Concept design and development," in *Eurasia Proceedings of Science, Technology, Engineering and Mathematics*, 2022. doi: 10.55549/epstem.1224549.

[23] Z. Li *et al.*, "Solar-Powered Sustainable Water Production," *ACS Nano*, 2021.

[24] F. Zhao, Y. Guo, X. Zhou, W. Shi, and G. Yu, "Materials for solar-powered water evaporation," *Nature Reviews Materials*, vol. 5, no. 5. Nature Research, pp. 388–401, May 01, 2020. doi: 10.1038/s41578-020-0182-4.

[25] C. Chen, Y. Jiang, Z. Ye, Y. Yang, and L. Hou, "Sustainably integrating desalination with solar power to overcome future freshwater scarcity in China," *Global Energy Interconnection*, vol. 2, no. 2, 2019, doi: 10.1016/j.gloei.2019.07.009.

[26] F. E. Ahmed, R. Hashaikeh, and N. Hilal, "Solar powered desalination – Technology, energy and future outlook," *Desalination*, vol. 453. 2019. doi: 10.1016/j.desal.2018.12.002.

[27] A. M. K. El-Ghonemy, "Future sustainable water desalination technologies for the Saudi Arabia: A review," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 9. 2012. doi: 10.1016/j.rser.2012.07.026.

[28] A. Al-Karaghouli and L. L. Kazmerski, "Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes," *Renewable and Sustainable Energy Reviews*, vol. 24. 2013. doi: 10.1016/j.rser.2012.12.064.

[29] S. M. Alawad, R. Ben Mansour, F. A. Al-Sulaiman, and S. Rehman, "Renewable energy systems for water desalination applications: A comprehensive review," *Energy Conversion and Management*, vol. 286. 2023. doi: 10.1016/j.enconman.2023.117035.

[30] BuyJus, "What is Reverse Osmosis?" https://byjus.com/chemistry/reverse-osmosis/#:~:text=Reverse%20osmosis%20(%20RO)%20is%20a,pass%20to%20the%20other%20side.

[31] S. Bou-Hamad, M. Abdel-Jawad, M. Al-Tabtabaei, and S. Al-Shammari, "Comparative performance analysis of two seawater reverse osmosis plants: Twin hollow fine fiber and spiral wound membranes," *Desalination*, vol. 120, no. 1–2, 1998, doi: 10.1016/S0011-9164(98)00206-9.

[32] M. G. Buonomenna and J. Bae, "Membrane processes and renewable energies," *Renewable and Sustainable Energy Reviews*, vol. 43. 2015. doi: 10.1016/j.rser.2014.11.091.

[33] Mohamed A. Sharaf, "Design and Simulation of Solar Desalination Systems," 2007.

[34] K. A. Abdulsalam, K. C. Ijike, and J. A. Adebisi, "An Improved Energy Saving Technique for Wireless Power Transfer in Near Field Communication Systems," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, vol. 11, no. 1, pp. 61–76, 2023.

[35] O. M. Adebisi, J.A, Denwigwe, I.H, Babatunde, "Hydrogen storage for micro grid application:a framework for ranking fuel cell technologies based on technical parameters," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 2, pp. 1221–1320, 2023, doi: http://doi.org/10.11591/ijece.v13i2.pp1221-1230.

[36] J. Adebisi, P. Ibili, M. Emezirinwune, and K. Abdulsalam, "Comparative Study of Hybrid Solar Photovoltaic-Diesel Power Supply System," *African Journal of Inter/Multidisciplinary Studies*, vol. 5, no. 1, pp. 1–15, 2023.

[37] B. L. Pangarkar, M. G. Sane, and M. Guddad, "Reverse Osmosis and Membrane Distillation for Desalination of Groundwater: A Review," *ISRN Materials Science*, vol. 2011, 2011, doi: 10.5402/2011/523124.

[38] D. Borge-Diez, F. J. García-Moya, P. Cabrera-Santana, and E. Rosales-Asensio, "Feasibility analysis of wind and solar powered desalination plants: An application to islands," *Science of the Total Environment*, vol. 764, 2021, doi: 10.1016/j.scitotenv.2020.142878.

[39] M. Shatat, M. Worall, and S. Riffat, "Sustainable Cities and Society 9 (2013) 67-80 Opportunities for solar water desalination worldwide: Review," *Sustain Cities Soc*, vol. 9, 2013.

JDFEWS 4 (2): 83-105, 2023
ISSN 2709-4529

[40] J. A. A. Lucas, “The dynamics of a horizontal cylinder oscillating as a wave energy converter about an off-centred axis.,” *The University of Edinburgh*, no. April, 2011.

[41] R. Makabe, T. Ueyama, H. Sakai, and A. Tanioka, “Commercial pressure retarded osmosis systems for seawater desalination plants,” *Membranes (Basel)*, vol. 11, no. 1, 2021, doi: 10.3390/membranes11010069.

[42] F. Esmaeilion, A. Ahmadi, S. Hoseinzadeh, M. Aliehyaei, S. A. Makkeh, and D. Astiaso Garcia, “Renewable energy desalination; a sustainable approach for water scarcity in arid lands,” *International Journal of Sustainable Engineering*, vol. 14, no. 6. 2021. doi: 10.1080/19397038.2021.1948143.

[43] K. Elmaadawy *et al.*, “Optimal sizing and techno-enviro-economic feasibility assessment of large-scale reverse osmosis desalination powered with hybrid renewable energy sources,” *Energy Convers Manag*, vol. 224, 2020, doi: 10.1016/j.enconman.2020.113377.

[44] A. M. Pietrasanta, M. F. Shaaban, P. A. Aguirre, S. F. Mussati, and M. A. Hamouda, “Simulation and Optimization of Renewable Energy-Powered Desalination: A Bibliometric Analysis and Highlights of Recent Research,” *Sustainability (Switzerland)*, vol. 15, no. 12. 2023. doi: 10.3390/su15129180.

[45] M. S. Javed, A. Song, and T. Ma, “Techno-economic assessment of a stand-alone hybrid solar-wind-battery system for a remote island using genetic algorithm,” *Energy*, vol. 176, 2019, doi: 10.1016/j.energy.2019.03.131.

[46] J. Schallenberg-Rodríguez, J. M. Veza, and A. Blanco-Marigorta, “Energy efficiency and desalination in the Canary Islands,” *Renewable and Sustainable Energy Reviews*, vol. 40. 2014. doi: 10.1016/j.rser.2014.07.213.

[47] N. Ishimaru, “Solar photovoltaic desalination of brackish water in remote areas by electrodialysis,” *Desalination*, vol. 98, no. 1–3, 1994, doi: 10.1016/0011-9164(94)00175-8.

[48] E. T. Sayed, A. G. Olabi, K. Elsaid, M. Al Radi, R. Alqadi, and M. Ali Abdelkareem, “Recent progress in renewable energy based desalination in the Middle East and North Africa MENA region,” *Journal of Advanced Research*, vol. 48. 2023. doi: 10.1016/j.jare.2022.08.016.

[49] H. Sharon and K. S. Reddy, “A review of solar energy driven desalination technologies,” *Renewable and Sustainable Energy Reviews*, vol. 41. 2015. doi: 10.1016/j.rser.2014.09.002.

[50] J. M. Ortiz, E. Expósito, F. Gallud, V. García-García, V. Montiel, and A. Aldaz, “Photovoltaic electrodialysis system for brackish water desalination: Modeling of global process,” *J Memb Sci*, vol. 274, no. 1–2, 2006, doi: 10.1016/j.memsci.2005.08.006.

[51] J. M. Ortiz, E. Expósito, F. Gallud, V. García-García, V. Montiel, and V. A. Aldaz, “Desalination of underground brackish waters using an electrodialysis system powered directly by photovoltaic energy,” *Solar Energy Materials and Solar Cells*, vol. 92, no. 12, 2008, doi: 10.1016/j.solmat.2008.07.020.

[52] S. Y. Pan, A. Z. Haddad, A. Kumar, and S. W. Wang, “Brackish water desalination using reverse osmosis and capacitive deionization at the water-energy nexus,” *Water Research*, vol. 183. 2020. doi: 10.1016/j.watres.2020.116064.

[53] S. K. Patel, M. Qin, W. S. Walker, and M. Elimelech, “Energy Efficiency of Electro-Driven Brackish Water Desalination: Electrodialysis Significantly Outperforms Membrane Capacitive Deionization,” *Environ Sci Technol*, vol. 54, no. 6, 2020, doi: 10.1021/acs.est.9b07482.

[54] G. D. Kim, L. Toy, Z. Hendren, Y. C. Choi, M. Lesemann, and H. Buisson, “Integrated forward osmosis/membrane distillation process technology for industrial water treatment and reuse,” in *American Society of Mechanical Engineers, Power Division (Publication) POWER*, 2017. doi: 10.1115/POWER-ICOPE2017-3767.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

An IoT-Based Hydroponic Monitoring and Control System for Sustainable Food Production

Omolola A OGBOLUMANI
University of Lagos, Lagos, Nigeria; oaogbolumanischolar@gmail.com

Bonginhlanhla MABASO

University of Johannesburg, Johannesburg, South Africa

Received: 01 December 2023

Review: 20 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: In recent years, declining soil fertility and unsustainable farming practices have led to pressing challenges for the agricultural sector. This has historically been the primary food source for the world. Meeting the escalating food demand economically necessitates intensified growing practices. To cultivate food and arable crops sustainably, this study introduces a type of smart farming which emphasizes the interconnectedness of food and water resources. A farming technique called hydroponics, which involves growing plants in nutrient water solutions, aligns with the food-water nexus by creating a controlled environment independent of soil. The development of a hydroponic system that monitors the temperature, humidity, pH, water, and light levels of the plants is essential to optimal growth and productivity. Nutrients are released as needed, thus preventing water waste. Finally, the system will provide real-time feedback on the environmental parameters. Leveraging Internet of Things (IoT) technologies, real-time data transmission from these sensors to Amazon Web Services (AWS) and an Android mobile app powered by a Raspberry Pi3 facilitates remote monitoring and control, automating the system and minimizing human intervention. Experimentation validated sensor network accuracy. The findings underscore the potential for widespread adoption of hydroponic farming to enhance global food security while addressing water use in agriculture. Future advancements might involve incorporating additional sensors, like carbon dioxide (CO2) sensors, for real-time plant growth monitoring. The integration of IoT with sensors has revolutionized hydroponic food production through precise and automated environmental monitoring. The resulting technological synergy, which combines real-time data collection, analysis, and automated adjustments, maximizes yields, accelerates plant growth cycles, and enhances agricultural quality. This research represents a pivotal step towards sustainable agriculture, within the food-water nexus system. Offering a technology-driven approach that will transform food production methods and ensure a more reliable and sustainable global food supply in the future.

Keywords: *Food-water nexus, global food security, hydroponics, IoT, sensors, smart farming, sustainable agriculture.*

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

I.0 Introduction

Agriculture is essential for sustainable livelihood development [1]. Without well-practiced agriculture, which is the key source of healthy food production, living a good life may be a mirage [2]. There are two (2) known basic techniques to grow plants. It is imperative to critically investigate these techniques and propose the more sustainable, affordable, and reliable one for adoption [3]. When practicing commercial farming, the traditional method adopted globally is the use of soil to carry out farming which is currently being overburdened because of planting seasons which come periodically. Consequently, farmlands have lost their nutrients, and food security has constantly been threatened [4], [5][6]. Recent years have seen the use of smart farming to innovate crop production and enhance crop quality[7] [8]. Given the previous, the adoption of alternative, smart farming techniques known as Hydroponics [9] is necessary. In this method, farmers use nutrient solvents to grow plants instead of farming by the traditional way of using soil [10]. According to the literature, hydroponics is based on applying Information and Communication Technology in agriculture [9]. It is a system that is gradually taking up space in agricultural practice. The system uses water nutrient solution without the use of soil that is sometimes over-polluted or contaminated with chemicals coming from different industries such as manufacturing, agriculture, pharmaceutical and oil and gas [11]. Smart farming techniques, such as hydroponics, allow key parameters to be adjusted for optimal plant growth. A variety of factors are taken into consideration, including precise control of the nutrient solution, water recirculation, environmental factors like temperature, humidity, and light, continuous monitoring of pH and nutrients, sensor-based growth monitoring, and automated yield optimization. By implementing smart farming methods, resources can be utilized more efficiently, precise control can be achieved, and crop yields can be increased. Crop yields can be increased.

An IoT network connects computers, machinery, objects, living beings, and individuals. With their unique IDs, these devices exchange data autonomously with each other and computers without any human or computer intervention. The systems are connected via the internet and have sensors, tools, and online networks that allow them to evaluate and control themselves automatically [12]. Internet of Things (IoT) is reshaping industries, integrating internet connectivity with everyday items, transforming work, lifestyle, and technology[13]. In addition to reshaping industries, automation faces challenges such as high costs and intricate maintenance, which IoT might solve.[14]

The hydroponic farming technique has been the subject of several research studies using various methodologies to achieve successful results. Notable among them is the work in cited Ref. [15], by utilizing a microcontroller, the hydroponics control system developed regulates nutrients and monitors air and water temperature, as well as water levels. A mobile app collects sensor data, and a wireless sensor network transmits it to a central computer. In a related study in cited Ref.[16], the scholars studied a Nutrient Film Technique (NFT) hydroponic system for lettuce propagation using different wireless sensors. According to the study, the sensors measuring pH and electrical conductivity, which directly affect plant growth and nutrient uptake, had an error of 0.4 ms/cm and 5.1 ms/cm, respectively. The work in cited Ref. [17] used an Arduino UNO R3 board to automate nutrient feeding for a scaled-down NFT hydroponics setup. By integrating a servomotor with a faucet, it detects low levels of water and nutrient solution conductivity. The system automatically delivers water and adds nutrients when the water level falls below 800 ppm. The research in cited Ref. [18] developed a state-of-the-art IoT system called the Hydroponics Management System (HMS) to provide remote irrigation, pH, humidity, temperature, and water level monitoring. Urban residents can cultivate and manage their food more easily this way. The cited work in Ref. [19] explores a hydroponic gardening system using an IoT-based application tool. The author describes it as an affordable, adaptable system suitable for hydroponics. Its flexibility allows users to personalize their setup for their desired output, even without prior knowledge of the system. Authors in cited Ref. [20] developed an affordable DIY sensor-based mobile app for

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

hydroponics. This indoor system is designed for small to medium-scale farming, particularly in subsistence farming. It includes temperature, humidity, and light sensors for managing and controlling the process. The authors in the cited Ref. [21] described a technique combining traditional farming with a nutrient-controlled, web-monitored hydroponic system. The prototype included sensors, cloud-based data analysis, and LED indicators for water levels, making it possible to cultivate hydroponic plants in small spaces at home. LED indicators confirm the system works effectively. The proposed work is to design a system that monitors and controls remotely some environmental parameters of a hydroponic smart farming system. This is to improve food security. Through an Android mobile application and the cloud service offered by Amazon Web Services (AWS), this automation made possible by IoT technology will ensure that users can monitor and control various environmental parameters. Among these measures are regulating water levels in the growth medium, managing temperature and humidity, pH levels, and regulating light usage to facilitate uninterrupted photosynthesis. The proposed system offers several contributions to knowledge: Sensor integration within the system enables data-driven decision-making. Secondly, through the incorporation of automation and control elements, the system empowers clients to monitor and adjust environmental parameters remotely. Additionally, the hydroponic system is evaluated by analyzing extensive sensor data using Amazon Web Services.

The rest of the paper is sectioned as follows: Section II describes the design requirements and specifications; Section III describes the proposed system in detail. The paper concludes with Section IV which gives step by step experimental situations with results and concludes with future work.

II Design Requirements and Specifications

The proposed hydroponic system integrates essential hardware and software components alongside intelligent sensors to monitor pH, light intensity, nutrient solution, and humidity levels. Specific criteria outlined in tables and schematics guide the selection of these sensors, with each sensor playing a critical role in enhancing the system's performance and functionality. The tables specify individual details of sensors such as the DHT11 Temperature and Humidity Sensor [11], Analog pH meter Sensor [12], Total Dissolved Solid (TDS) Sensor [13], and Ambient Light Intensity Sensor [14]. A Raspberry Pi 3 Micro-controller manages these vital components, while a Water Pump circulates the nutrient solution. Detailed hardware specifications appear in Tables 1 through 6.

Table 1. Specifications of the DHT11 Temperature and Humidity Sensor

Temperature and Humidity Sensor	**Model: DHT11**
Operating Voltage	3.5V to 5.5V
Connection Protocol	One wire
Output	Serial data
Temperature Range	0°C to 50°C
Humidity Range	20% to 90%

The temperature and humidity sensor specification are shown in Table 1. This sensor is highly sensitive with tolerance value of plus or minus one percent (±1%).

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Table 2. Specifications of the Analog pH meter Sensor

Analog PH Sensor	**Model: SEN1061**
Module Voltage	5V
Measuring Range	1-14PH
Accuracy	±0.1PH (25^{0}C
Connection Protocol	Three (3) Wires

Shown in Table 2 is the specification of analog PH sensor with a level of stream accuracy of 0.5PH

Table 3. Specification of the Total Dissolved Sensor (TDS)

TDS sensor	**Model: DF Robot SEN0244**
Input Voltage	3.3V to 5.5V
Output Voltage	0-2.3V @3-6Ma
Measurement Range	0-1000ppm
Accuracy	±10% @ 25°C
Connection Protocol	Two wires
Module Interface	PH 2-3P

For the measurement of dissolved solid solution nutrient level, a sensor called Total Dissolved Sensor is used. It indicates how many milligrams of solids have been dissolved in one liter of water. The sensor's specification as employed in the design is shown in Table 3

Table 4. Specifications of the Ambient Light sensor

Ambient Light Intensity Sensor	**Model: Adafruit VEML77**
Operating Voltage	3-3.6V
Digital Output	16 Bit 12C fast mode at 400kHz
Lighting Ripple Reaction	50/60Hz
Pin	Programmable Interrupt pin and function
Resistors	12C pull-up

To measure light intensity within the house, the ambient light intensity is used. Table 4 is the specification of the ambient light intensity sensor as deployed in the system's design.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Table 5. Specifications of the Raspberry Microcontroller unit (MCU)

Raspberry pi 3	**Model: Pi 3**
Input Voltage	5V via USB and 5V DC via GPIO header
Operating temperature	0-50°C
Compliance	ICASA Approved
Memory	4GB
Processor	Broadcom BCM2711, quad-core cortex A72
GPIO	Standard 40pin GPIO header

The microcontroller is the heart of the entire system as it coordinates the activities of all the sensors and other devices operating within the system. Its specification is shown in Table 5. The type of Microcontroller as indicated in the Table is Raspberry Pi3 having high speed and large memory.

Table 6. Specifications of the water pump

Water Pump	**Model: water pump f700**
Power	10W
Flow Rate	700 Lit,/hr
Wiring protocol	3 core/10m long electrical cable

The specification of the water pump deployed solely for the purpose of pumping water and nutrients solution to the growing tray of the plants is shown in Table 6.

The following assumptions guided this study:

- The control system shall act independently and shall not affect the environment.
- The components used in the hydroponics system shall not conflict with the environment.
- The components shall be environmentally friendly and will not contain any toxins that shall harm the environment in any manner.

III Hydroponics System Design

System design and implementation follow the proposed subsystems in Fig. 1. As shown in the subsystems configuration, the physical system relates to the data collection sub-system, and the control system uses the data

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

to execute decisions based on past and present data. Sub-systems operate independently, but when they are all connected, they form one hydroponic system.

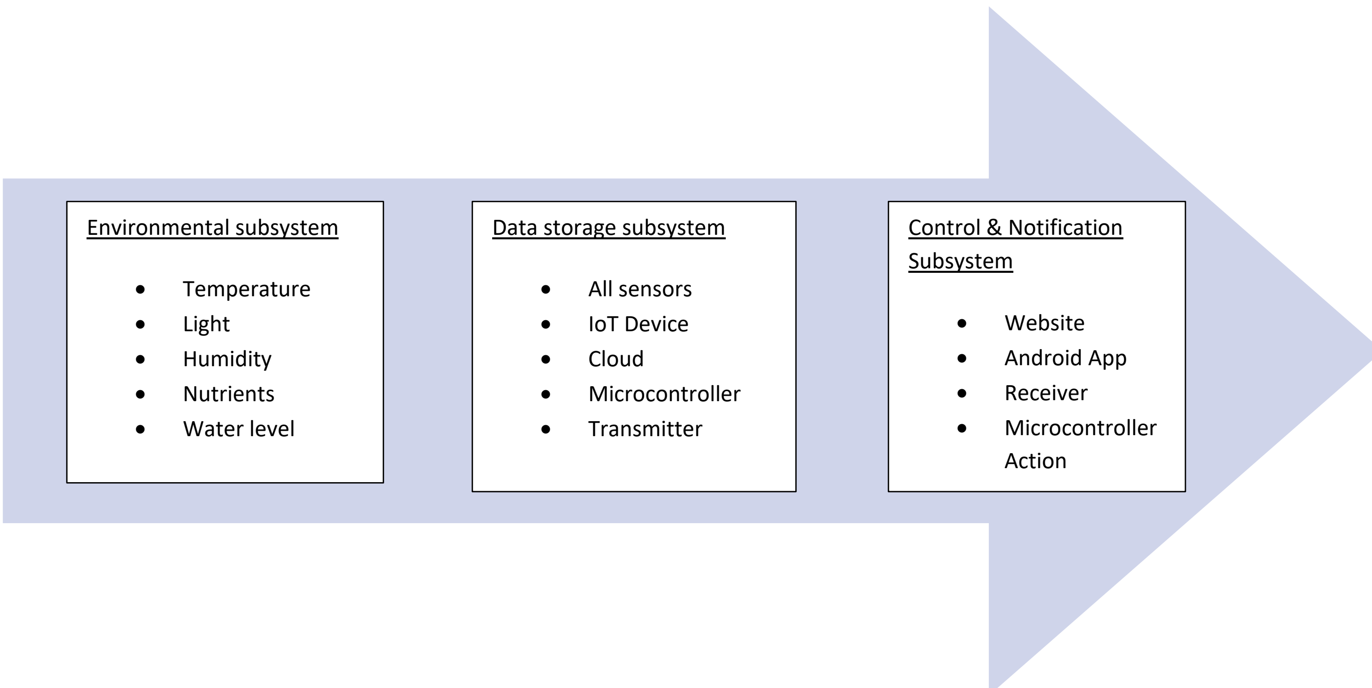


Fig. 1. Subsystems configuration of the hydroponic system.

Given the requirement of monitoring the temperature, humidity and other sensors of the hydroponics system, high level functionalities and performances are expected of the system when fully implemented.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

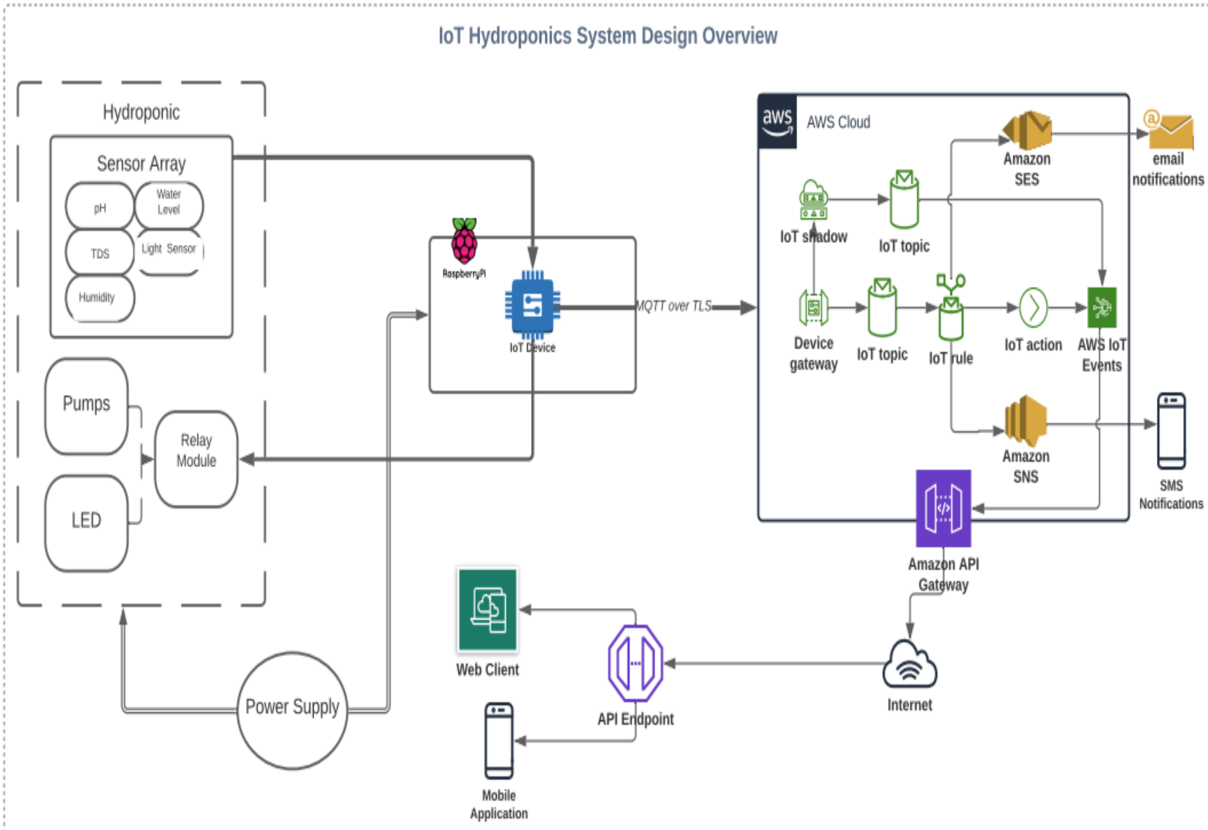


Fig. 2. The design concept of hydroponics system

There are multiple advantages to the chosen hydroponics design, including but not limited to:

- Cost-effectiveness
- Simple construction
- Easy-to-use and learn Amazon Web Services deployment.
- The absence of a timer eliminates the need for a dedicated power supply.
- Simple cloud connectivity through IoT using the Raspberry Pi 3 microcontroller.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

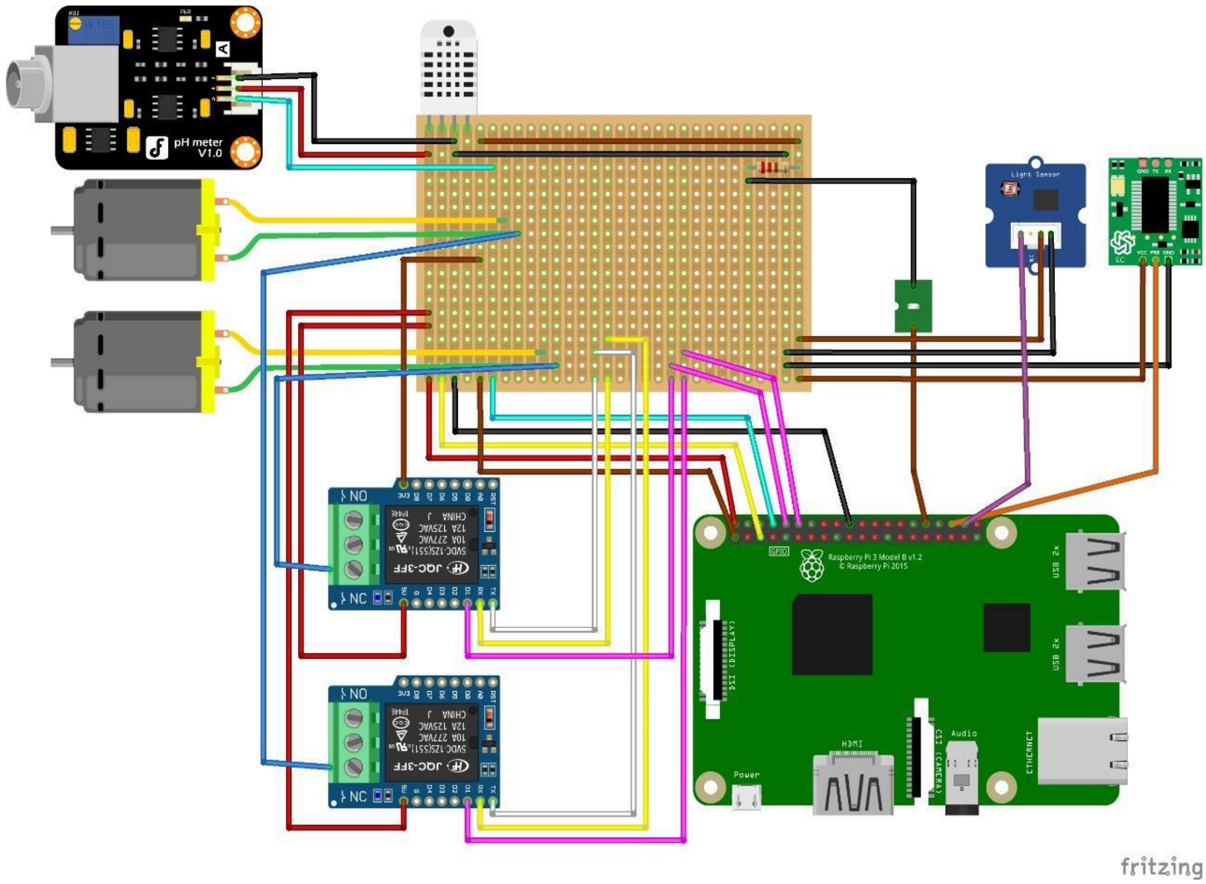


Fig. 3. System design schematic

Fig. 3 depicts the schematic diagram of the proposed hydroponics system drawn using Fritzing application.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

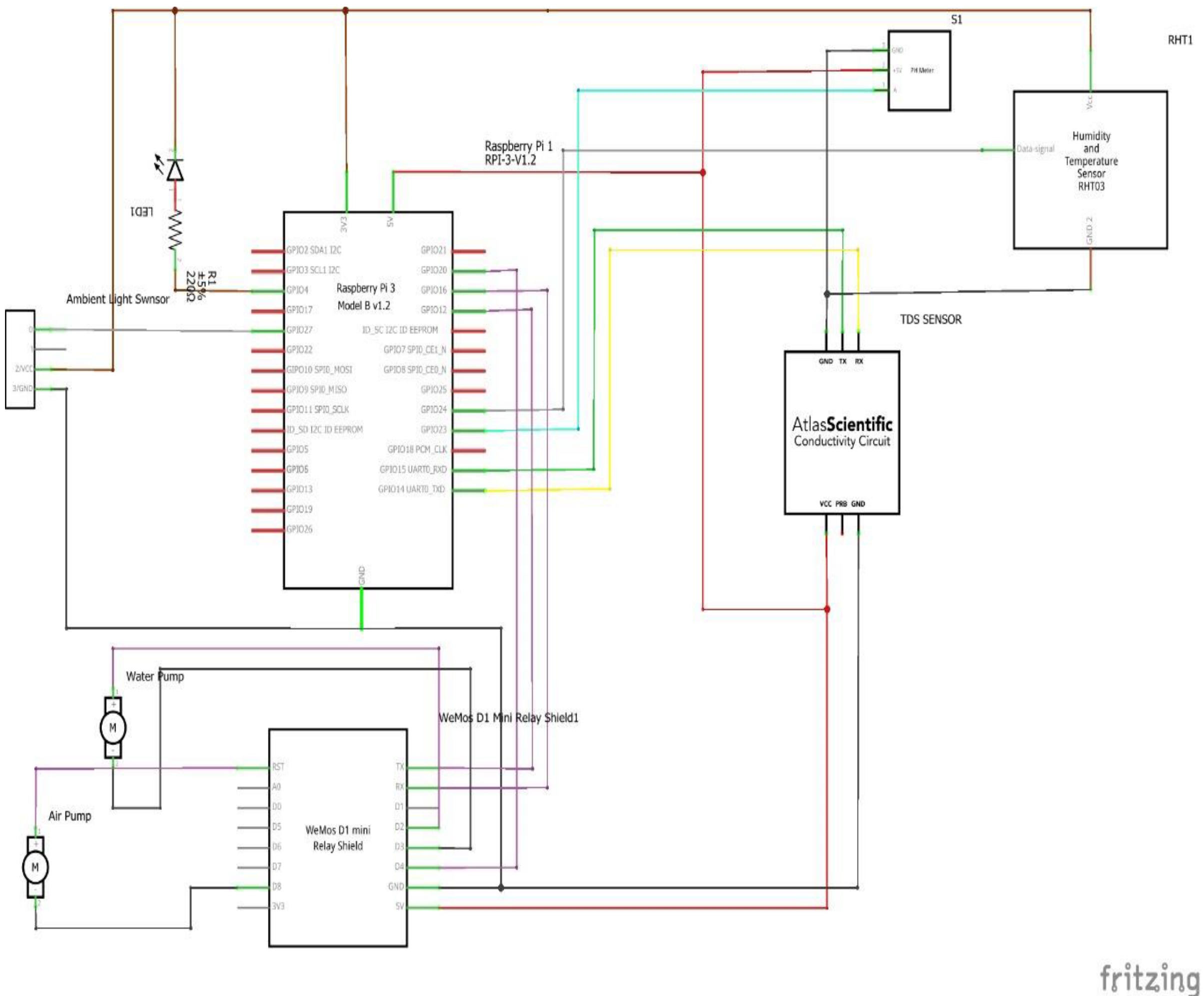


Fig. 4. Equivalent Circuit Diagram of the Hydroponics System

Both the schematic diagram and equivalent circuit diagram have been produced based on the system design requirements and specifications as shown in Tables 1 – Table 6.

IV Laboratory Experiments and Results

The step-by-step experimental situations as conducted in the lab to establish the compliance of each sensor with the specification as stated in section II of this research is elaborately discussed in this section. Each sensor was subjected to laboratory test one after the other according to the established rules and norms for testing sensors.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

i. Water level Test

The system was designed to have its valve closed when the water level reaches a set threshold; in the same vein, the water level sensor indicates that water has been detected at a stipulated level. The setup of the experiment is shown in Fig. 5.

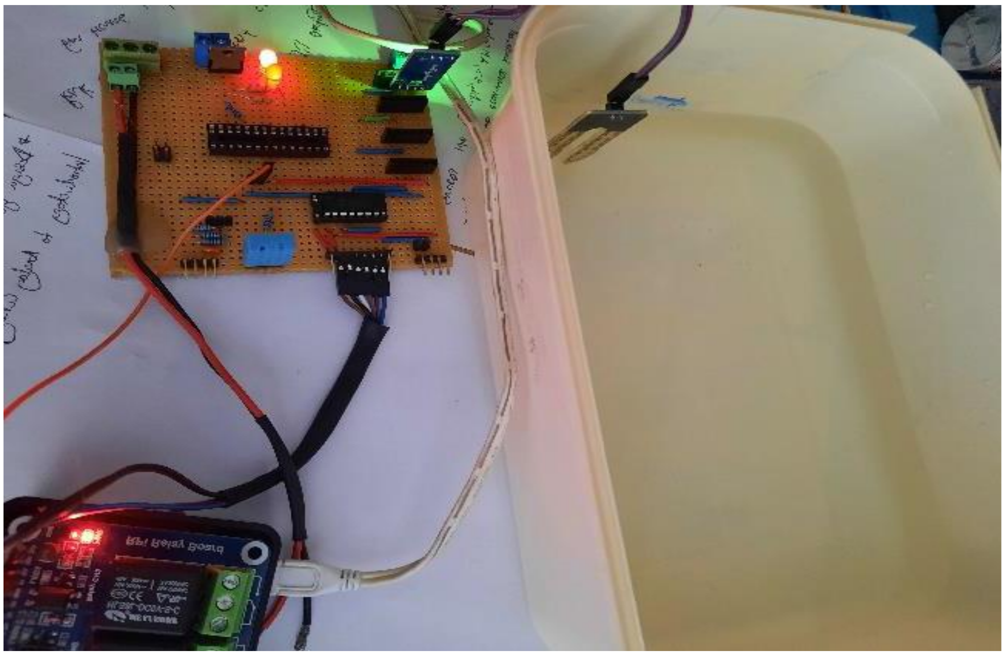


Fig. 5. Water level Sensor setup

- Results

The measurements results generated by the water level sensor are displayed as evident in Fig. 6 to indicate the water level. The water level height was also measured to show the water level measurement at each height.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

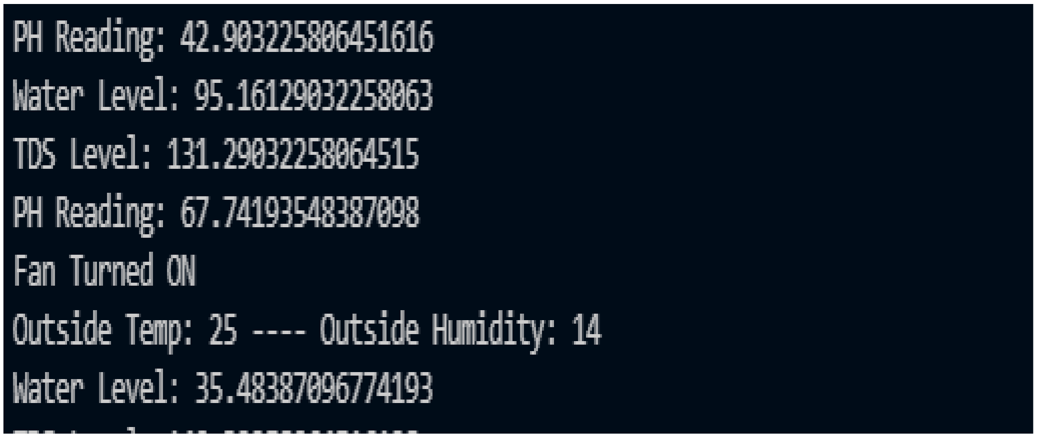


Fig. 6. Terminal window for the display of the results of water level sensor.

It is imperative to show in tabular form, the relationship between the water level height and the water level sensor reading; this is shown in Table 7.

Table 7. Water level and sensor data

Water Level (mm)	Sensor Readings
No water (0 mm)	255
20mm	130
30mm	100
40mm	80
50mm	70
>55mm	50

- Analysis

The sensor readings displayed a number on the meter of 0-255, 255 indicates that, there was no water detected by the sensor at that time. As the water level began to increase as detected by the sensor, the value also began to decrease indicating the amount of water that had been detected. Since the application of the water level sensor was to determine when the water level had reached a certain level, it was sufficient to use the water level sensor in this regard. From the results

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

obtained from the experiment conducted and the test repeated for consistency, the water level could be obtained by mapping the 0-255 range to the height of the sensor which was sufficient since at the given level any value below 130 would be considered as the water being present at that height.

ii. DHT11 Temperature and Humidity Sensor Test

The DHT11 sensor set up was configure onto the main system as shown in Fig. 5, The Sensor values were taken on for 5 days at 3-hour step intervals and were compared to the readings that were obtained from the weather bit for the same period. [15]

- Results

The plot in Fig. 7 shows the temperature results from the DHT11 sensor and compared with the weather station temperature to establish the accuracy of the DHT11 sensor.

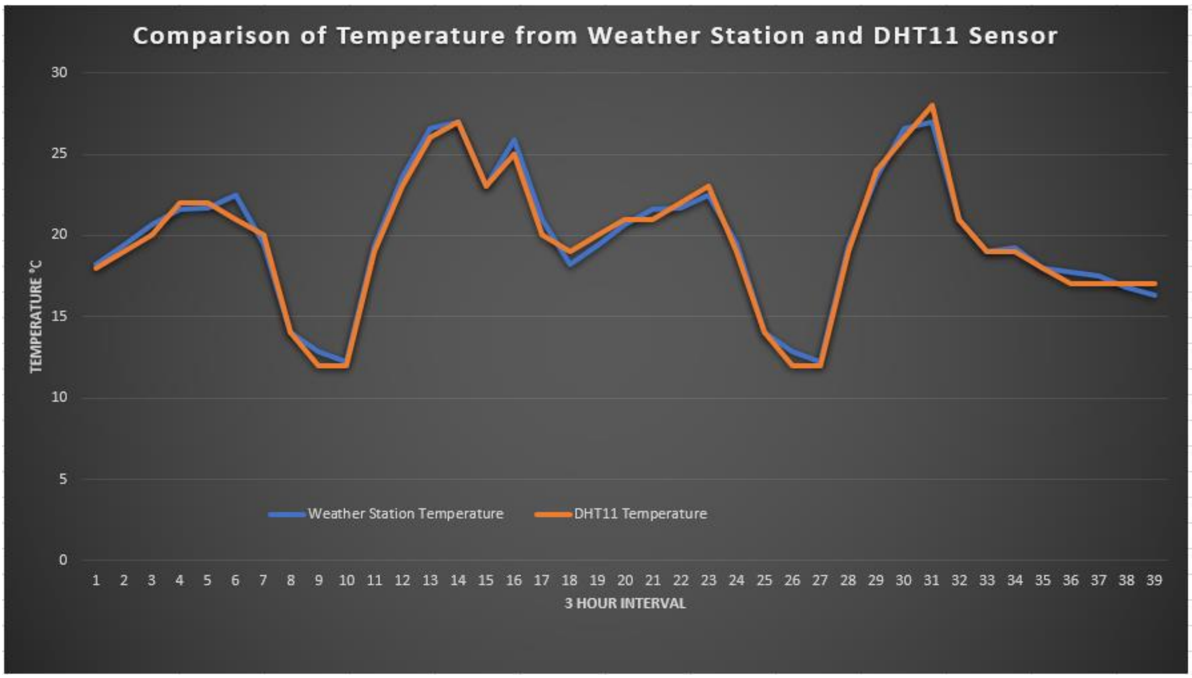


Fig. 7. Comparison of weather station temperature with DHT11 sensor temperature

The plot in Fig. 8 shows the humidity results from the DHT11 sensor and compared with the weather station humidity to establish the accuracy of the DHT11 sensor.

.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

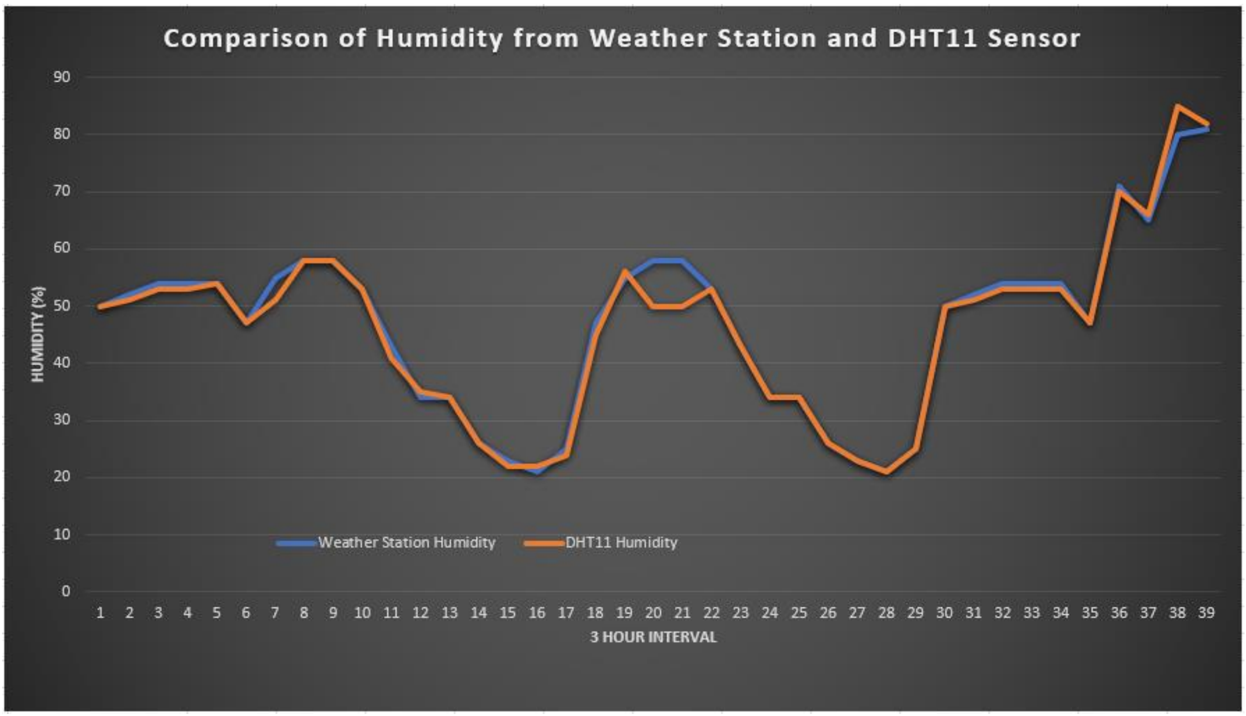


Fig. 8. Comparison of weather station humidity with DHT11 sensor humidity

To further establish the accuracy of DHT11 sensor, the temperature and humidity data generated by DHT11 was compared with the data generated by the Johannesburg CITY weather station[22] using ANOVA analysis as shown in Tables 8 and 9 respectively.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Table 8. ANOVA analysis comparing DHT11 sensor temperature data with weather station temperature data.

Temperature Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Weather Station	39	774.15	19.85	16.36127		
DHT11 Temp Sensor	39	768	19.69231	16.95547		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.484904	1	0.484904	0.029109	0.864982	3.96676
Within Groups	1266.036	76	16.65837			
Total	1266.521	77				

Table 9. ANOVA analysis comparing DHT11 sensor humidity data with weather station temperature data.

Humidity Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Humidity from Weather Station	39	1826	46.82051	243.4669		
Humidity from DHT11 Sensor	39	1802	46.20513	245.9568		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.384615	1	7.384615	0.030177	0.862552	3.96676
Within Groups	18598.1	76	244.7119			
Total	18605.49	77				

- Analysis

Observing the plots shown in Fig. 6 and Fig. 7, it can be confirmed that when compared with weather station observations, the temperature and humidity values that are obtained for the same region are similar. To further the research, a hypothesis that the two sets of readings are similar was conducted and analysis of variance test was done on both datasets to see how similar the sets were. Also, for the test, the null hypothesis was carried out

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

to establish that the sets are similar; the high p-value obtained gives high confidence that the null hypothesis is correct, and the value obtained is similar. The temperature readings had a p-value of 86.50% and the humidity readings had a p-value of 86.26%. This reference confirmation gives confidence that the DHT11 sensor was working as expected since it aligns with the weather bit results and the data provided to the system will therefore be accurate because of the high probability value.

iii. pH Sensor Test

Buffer solutions of known pH were used to provide a control setup for the pH test, other chemicals such as vinegar and distilled water were also used to ensure that the sensor was working and accurately responding to the pH levels as expected. Fig. 9 shows how the buffer solution was used to get the reading of the sensor at a neutral point. The buffer solution was known to be 7.00 as illustrated:

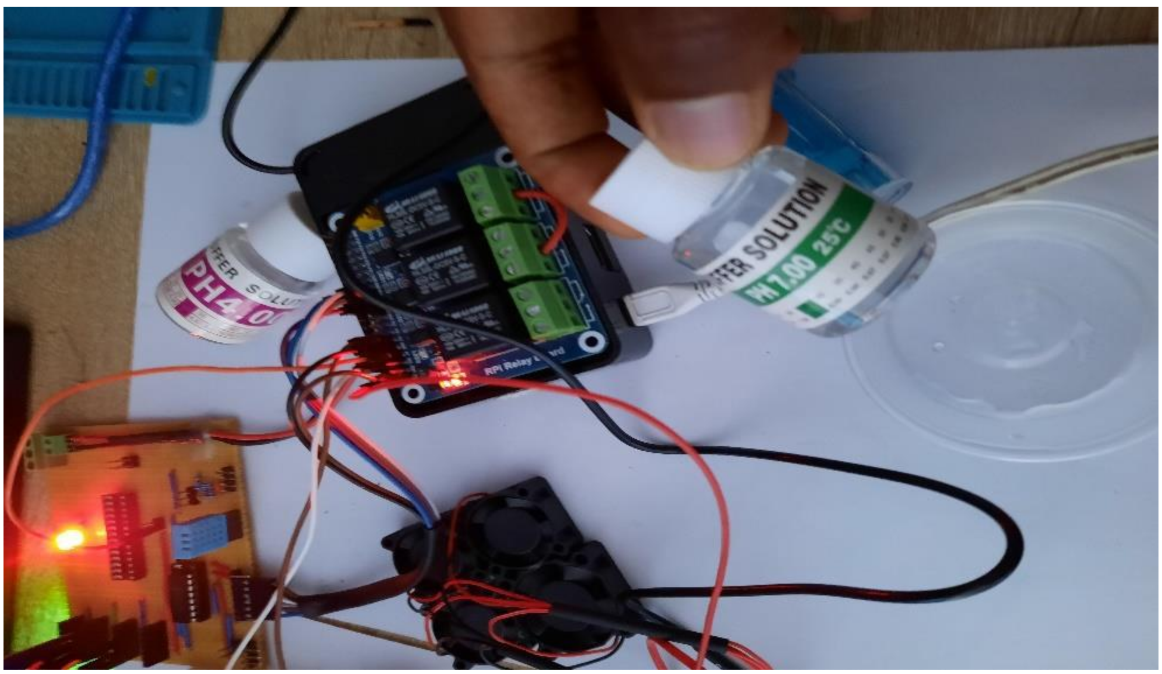


Fig. 9. pH sensor setup buffer solution of 7 pH.

The pH probe was inserted into the buffer solution and the sensor reading displayed on the terminal window and recorded.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

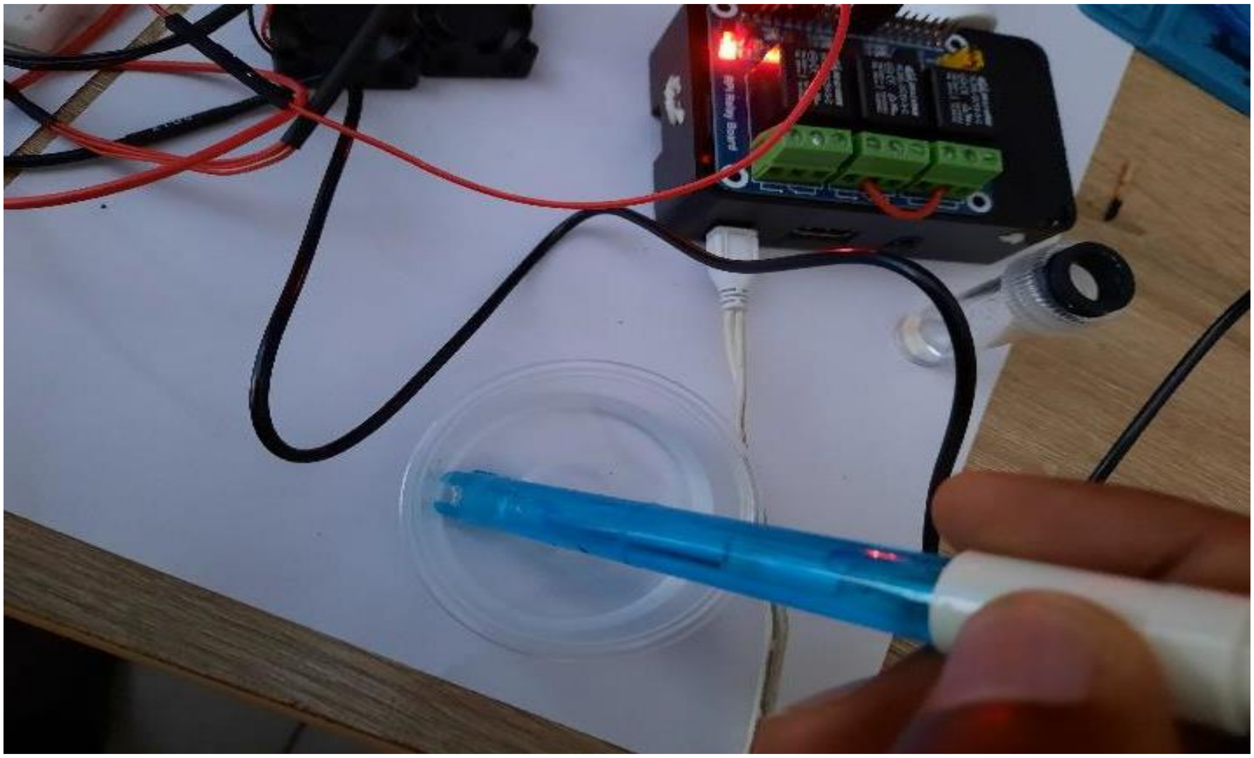


Fig. 10. pH sensor setup with testing probe

The second buffer solution that was used to record the pH recording off the sensor was calibrated at a pH level of 4.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

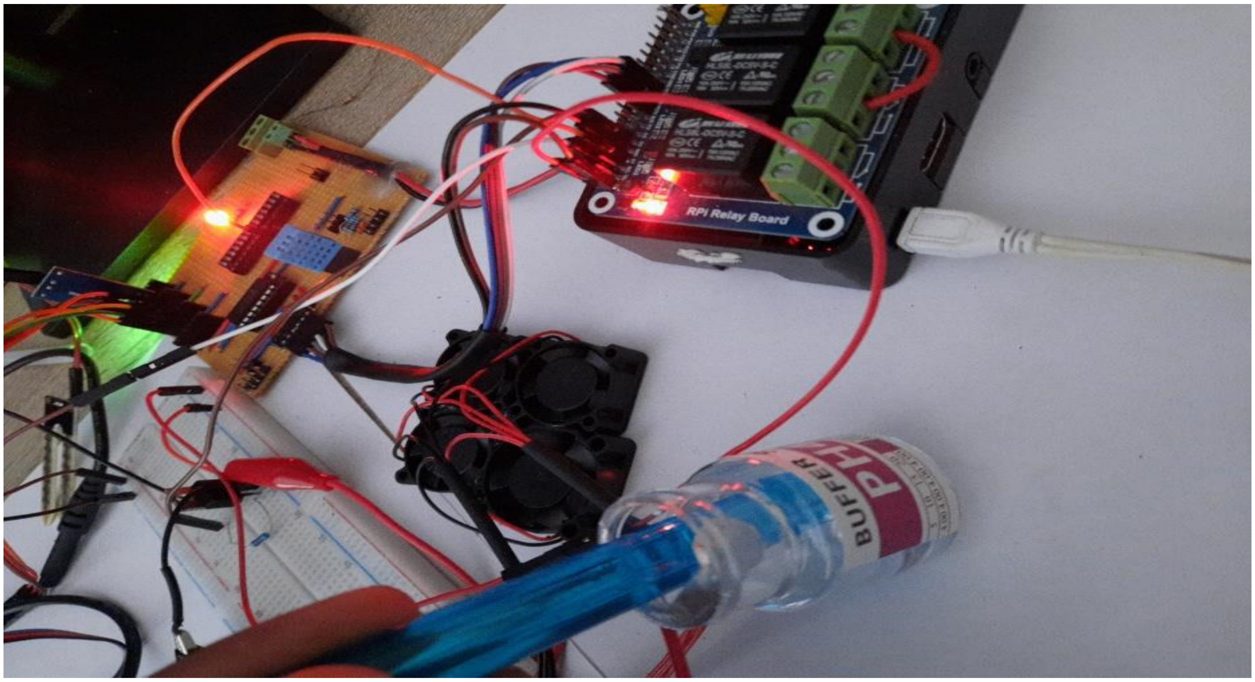


Fig. 11. pH sensor setup with a buffer solution of 4 pH.

- Results

The following results depicted in Table 10 were obtained from the pH sensor tests.

Table 10. Results for pH sensors tests

pH Values	pH Sensor Readings
White Vinegar (~2.5pH)	168
Buffer Solution A (4.00 pH)	292
Buffer Solution B (7.00 pH)	501
Oven Cleaner (~13.00 pH)	989

Fig. 12 shows the relationship between the pH sensor scale and the pH values obtained from the raspberry Pi.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

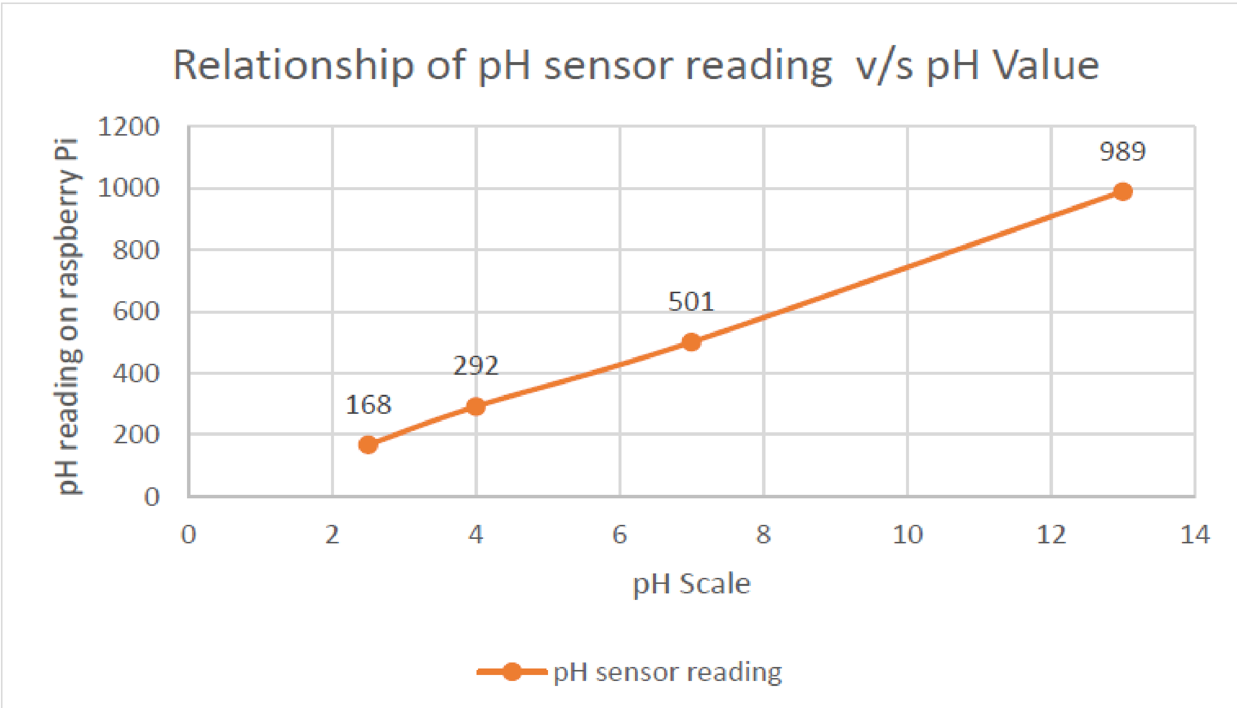


Fig. 12. Relationship between pH scale and obtained sensor readings.

- Analysis

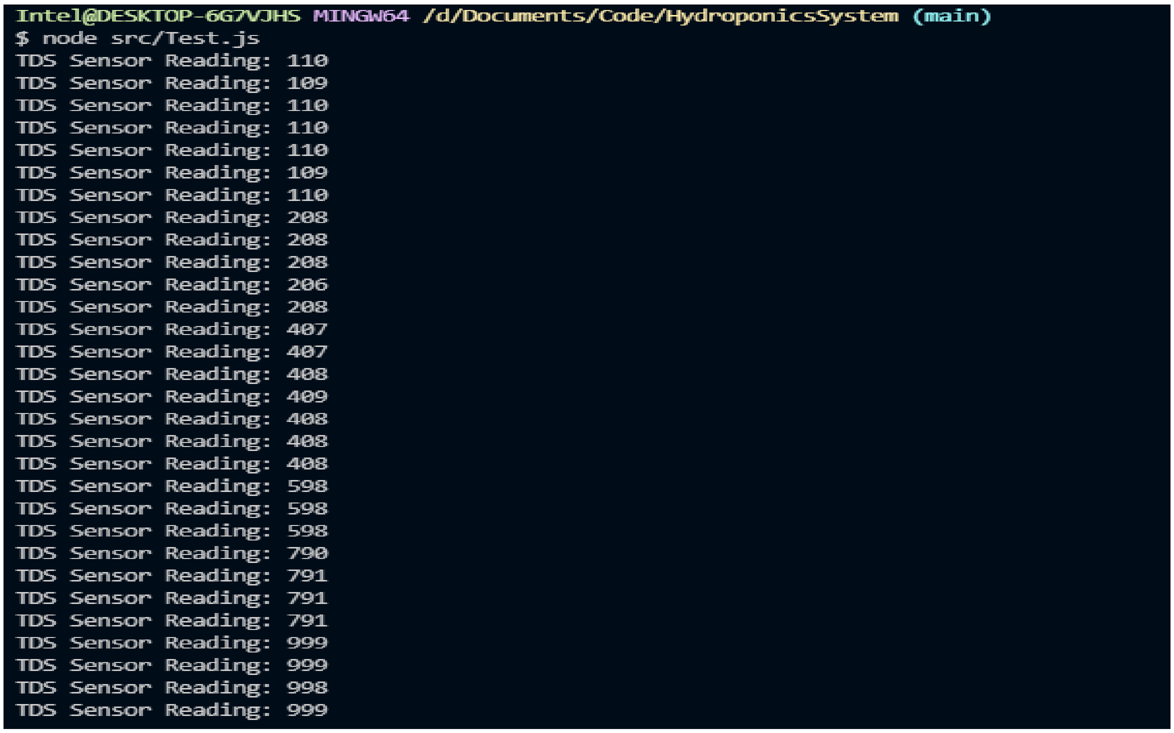
Fig. 12 illustrates a linear relationship between sensor values and known pH values. The consistency of the relationship for the known pH values made it possible to conclude that the pH sensor was producing accurate and expected results as it has been deduced from the experiment.

iv. Total Dissolved Solids (TDS) sensor Test

Sodium Chloride was used to measure the amount of Total Dissolved Solids that were added to distilled water. The sensors were used to show the relationship of the dissolved sodium chloride to that of the TDS Sensor reading.

- Results

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529



```
Intel@DESKTOP-6G7VJHS MINGW64 /d/Documents/Code/HydroponicsSystem (main)
$ node src/Test.js
TDS Sensor Reading: 110
TDS Sensor Reading: 109
TDS Sensor Reading: 110
TDS Sensor Reading: 110
TDS Sensor Reading: 110
TDS Sensor Reading: 109
TDS Sensor Reading: 110
TDS Sensor Reading: 208
TDS Sensor Reading: 208
TDS Sensor Reading: 208
TDS Sensor Reading: 206
TDS Sensor Reading: 208
TDS Sensor Reading: 407
TDS Sensor Reading: 407
TDS Sensor Reading: 408
TDS Sensor Reading: 409
TDS Sensor Reading: 408
TDS Sensor Reading: 408
TDS Sensor Reading: 408
TDS Sensor Reading: 598
TDS Sensor Reading: 598
TDS Sensor Reading: 598
TDS Sensor Reading: 790
TDS Sensor Reading: 791
TDS Sensor Reading: 791
TDS Sensor Reading: 791
TDS Sensor Reading: 999
TDS Sensor Reading: 999
TDS Sensor Reading: 998
TDS Sensor Reading: 999
```

Fig. 13. Real-time TDS sensor readings taken every second during salt addition.

Table 11. Salt measurements and TDS sensor readings.

Salt Measurement	TDS Sensor Reading
0g/L (Distilled water)	0
0.1 g/L	110
0.2 g/L	208
0.4 g/L	408
0.6 g/L	598
0.8 g/L	791
1 g/L	999

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

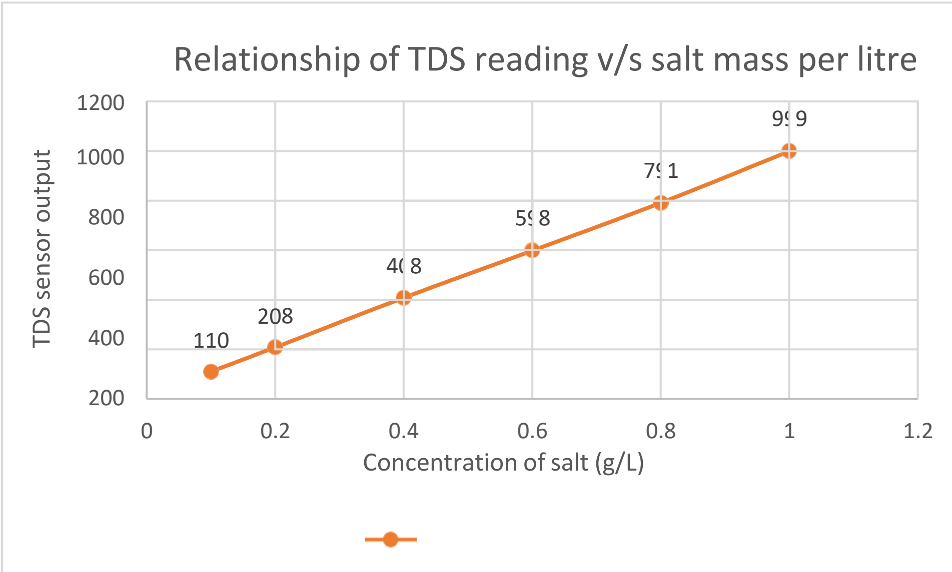


Fig. 14. Relationship of salt concentration in water and TDS sensor output.

- Analysis

The linear relationship between the salt concentration and the TDS sensor made it possible to deduce the amount dissolved of solids in the water. With the information, a threshold could be defined to allow the system to respond based on the obtained threshold. The perfect relationship obtained verified that the sensor was indeed and producing expected results.

AWS Services Integration

Water Level Sensor Readings

To verify that data was being successfully sent over to the cloud and consumed bythe AWS service successfully, the values that were read from the water level sensor were displayed on both terminal windows i.e. The raspberry pi's terminal and the AWS console.

- Results

The result in Fig. 15 shows the water level data sent to the AWS cloud using the WI-FI module connected to the raspberry pi.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

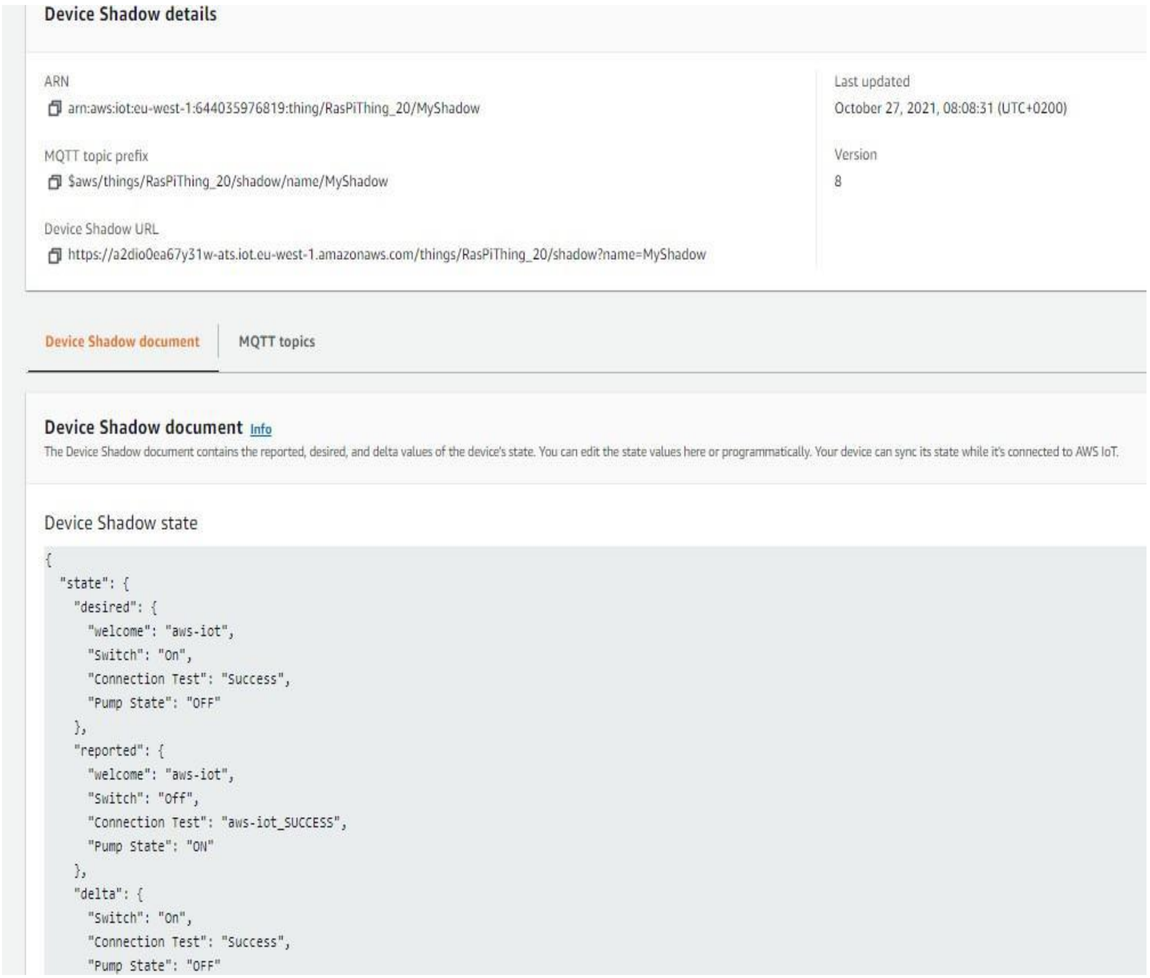


Fig. 15.AWS MQTT Connection verification.

Fig. 16 shows the sensor readings on the AWS cloud to show that the raspberry pi was able to send through the data readings to the cloud.

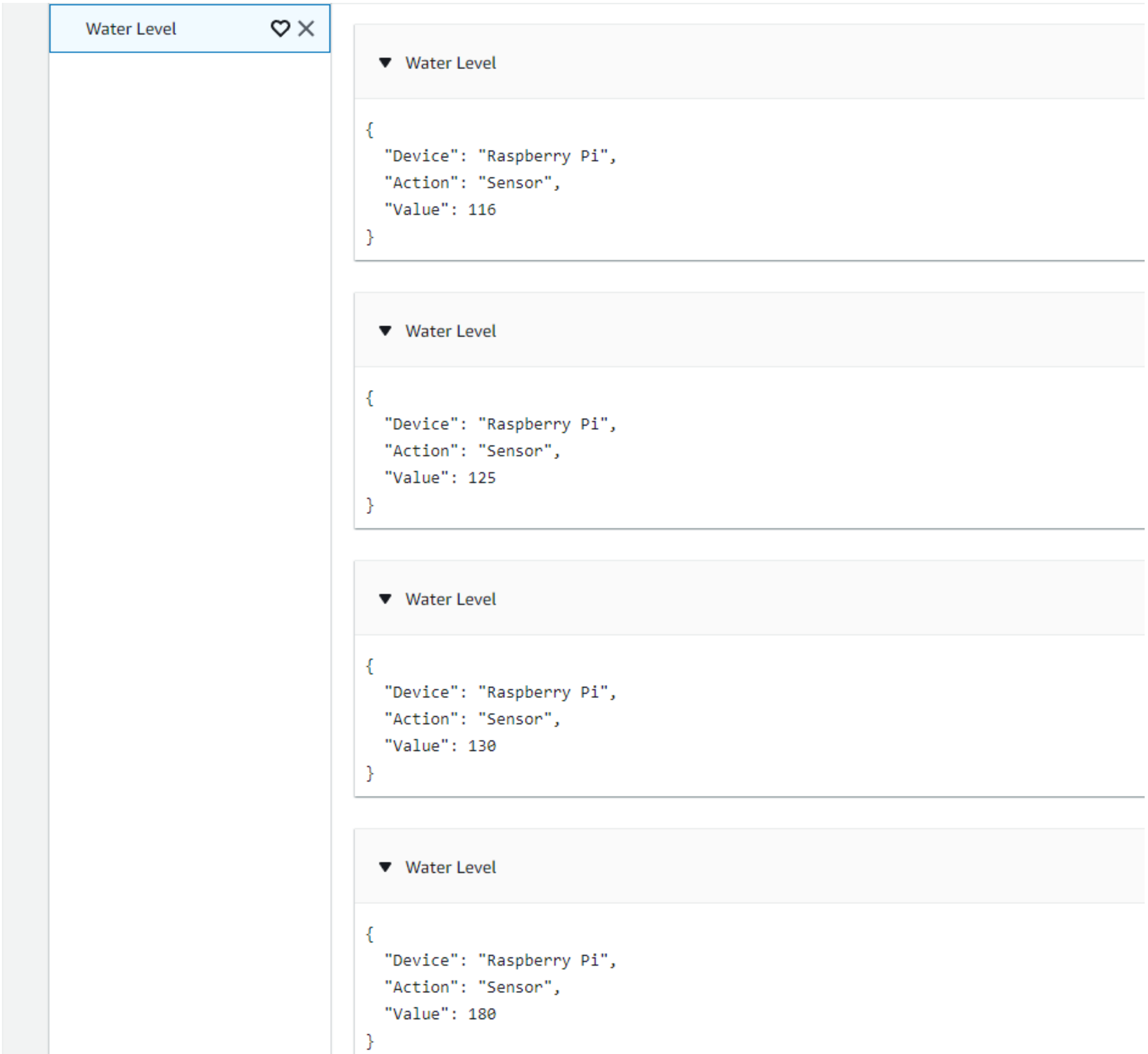


Fig. 16. AWS dashboard showing received sensor data.

- Analysis

The results obtained indicate that the sensor data was successfully pushed on the AWS servers and all the subscribing topics could get a copy of the sensor data. This allows many clients including the application interface to subscribe to the topics so they can get a copy of the data. The connection between AWS services and the raspberry pi was confirmed as the data from the sensor was published successfully.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

B. Notification and Control Test

- Water Valve Test

To guarantee that water flow is managed, a water flow valve must be capable of restricting and allowing water flow when specific criteria are satisfied. The water level (soil moisture) sensor was used to illustrate the functionality of the water valve to verify its operation and ensure that it was functioning properly.

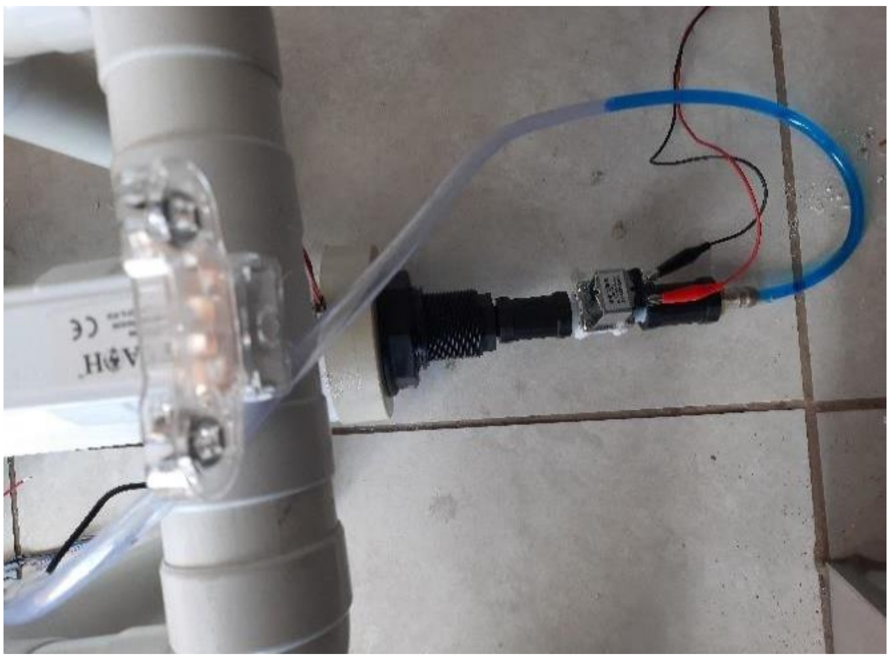


Fig. 17. Water valve setup.

Table 12 shows the water level sensor readings and the state of the water valve compared between the water valve's expected state and the water valve's observed state.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Table 12. Water level sensor readings with the expected state of the water valve and observed state.

Water level Sensor Reading	**Water valve expected state**	**Water valve observed state**
255	ON	ON
240	ON	ON
225	ON	ON
200	ON	ON
195	ON	ON
175	ON	ON
160	ON	ON
145	ON	ON
130	ON	OFF
115	OFF	OFF
100	OFF	OFF
85	OFF	OFF
60	OFF	OFF
50	OFF	OFF

- Results

Water Pump Test

The water pump test was performed to demonstrate that water was pumped properly throughout the system. A colorant was used to indicate the water flow. Fig. 18 shows the water being pumped from the tub to the growing medium. The blue colorant is used as a test to show the visibility of this test since water is clear and it was not going to be clear if the water is indeed being pumped from the tub to the growing medium.

Fig. 18. Water flow setup

Fig. 19 shows the blue water being fully pumped.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Fig. 19. Water flow stopped at the valve.

We compared the pump state and the expected water level state to ensure that the pump worked as expected. Table 13 illustrates how the water pump behaved at different levels.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Table 13. Water level sensor readings with expected water valve state and observed state.

Water level sensor reading	**Water valve expected results**	**Water valve observed state**
255	ON	ON
245	ON	ON
220	ON	ON
205	ON	ON
190	ON	ON
170	ON	ON
165	ON	ON
140	ON	ON
135	ON	ON
110	ON	ON
105	OFF	OFF
85	OFF	OFF
60	OFF	OFF
50	OFF	OFF

- Analysis

So far, a good number of sensors mentioned in this research have been tested in the laboratory based on the requirements and their specifications to ascertain their workability and accuracy when compared with the existing devices. Other sensors were also tested using the same approach and they were found functional, and their performances followed standard rules.

Notification Test

The notification test was performed to demonstrate that a notification was received by the user when critical conditions and significant changes had occurred in the system.

- Results

Fig. 20 shows a test of the notification systems when temperature was at 4°C

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

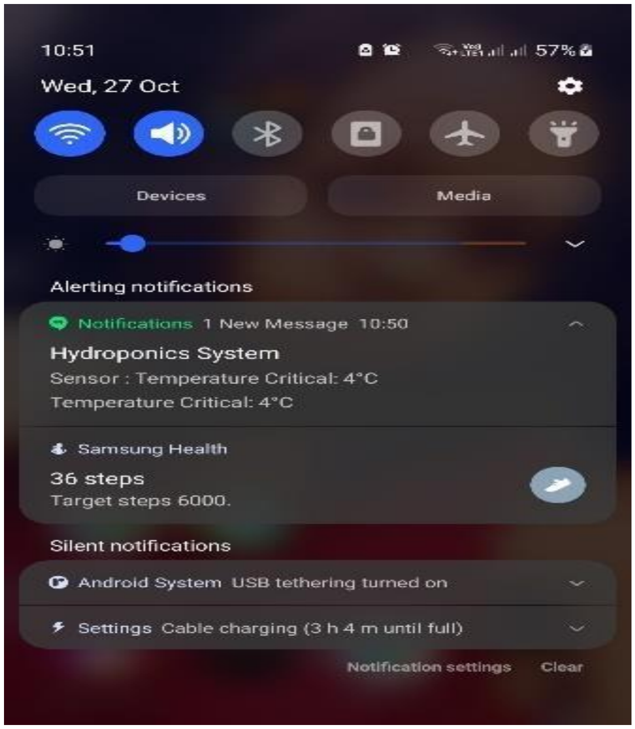


Fig. 20. Testing temperature notification display.

- Analysis

The notification received indicated that the system could deliver mobile notifications when an adverse effect has been detected, for this instance it was atthe temperature of 4°C.

Application Interface control test

This test was carried out to show if the system controls could be monitored accurately on the smartphone application and if the physical control devices weresynchronized on the app interface.

- Results

Fig. 21 shows the display of the temperature, humidity, water level, and the state of the pump.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

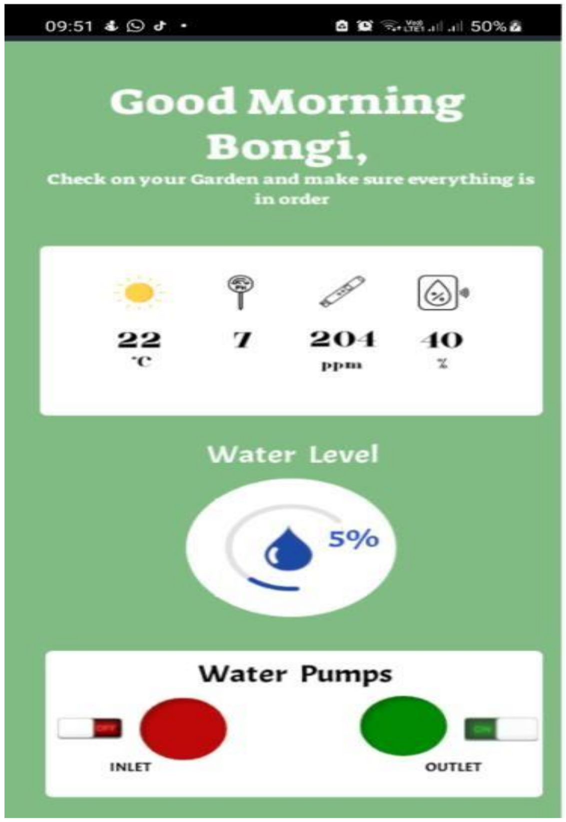


Fig. 21. Application interface to control system.

- Analysis

  The application successfully displayed the conditions of the system, and the pumpcontrol could be overridden by using the application control buttons. The application interface can also be used to monitor the environmental conditions and control the light of the system.

Integration system test (Control measures)

Pump control

To demonstrate that the pump was fully operational as a control measure, an integration test was conducted from detection using the data from the sensor tothe notification on the Android mobile application, a typical process was recorded, and results are given in Fig. 22.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

- Results

WATER LEVEL BELOW 22MM

The Fig. 22 shows the sensor readings detecting low water level height onthe water level sensor.

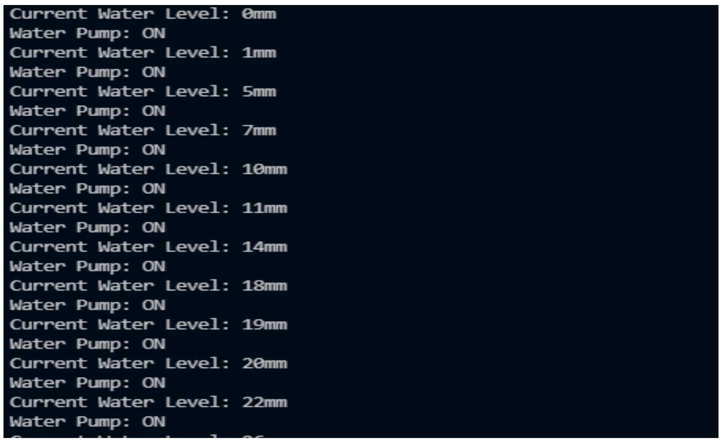


Fig. 22. Water level readings.

For water levels below 25mm, the inlet of the water pump was turned on automatically and the sensor information was published on to the AWS dashboardwhich had subscribed to receive all the sensor values. The illustrations in Fig. 23 show the sensor and pump state that was being published onto the AWS dashboard.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

Water Level

▼ Water Level


```
{
  "Device": "Raspberry Pi",
  "Sensor": "Water Level",
  "Value": 10
}
```


▼ Water Level


```
{
  "Device": "Raspberry Pi",
  "Sensor": "Water Level",
  "Value": 7
}
```


▼ Water Level


```
{
  "Device": "Raspberry Pi",
  "Sensor": "Water Level",
  "Value": 5
}
```


Fig. 23. Water level readings on AWS.

Light Control

The grow lights are controlled depending on the luminous intensity that is detected by the light sensor. The following are the results that were obtainedduring the day on a clear day and night where the luminous intensities both required the required thresholds.

- Results

FOR LUX ≤ 100

To obtain a Lux reading that was below 100, the experiment was conducted atnight with very minimal light. The Fig. 24 indicates the light sensor readings that were obtained by thesensor.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

```
Current Illuminance: 0.9LUX
Grow Lights: ON
Current Illuminance: 1LUX
Grow Lights: OFF
Current Illuminance: 0.8LUX
Grow Lights: ON
Current Illuminance: 0.7LUX
Grow Lights: ON
Current Illuminance: 0.8LUX
Grow Lights: ON
Current Illuminance: 0.6LUX
Grow Lights: ON
Current Illuminance: 0.6LUX
Grow Lights: ON
Current Illuminance: 0.6LUX
Grow Lights: ON
Current Illuminance: 0.7LUX
Grow Lights: ON
```

Fig. 24. Illuminance readings and Grow lights state.

During the night low levels of illuminance are detected so they grow lights wouldautomatically switch on as expected. To verify that this action, the results are displayed on the mobile application interface as shown in Fig 25.

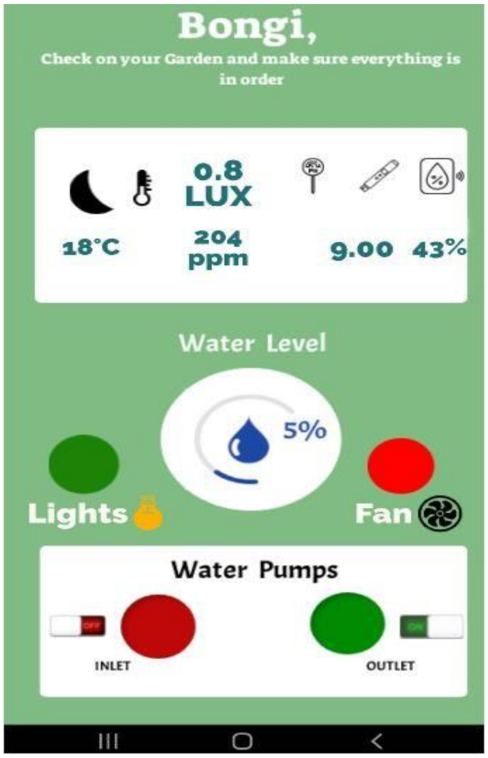


Fig. 25. Light switched for 0.8 LUX.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

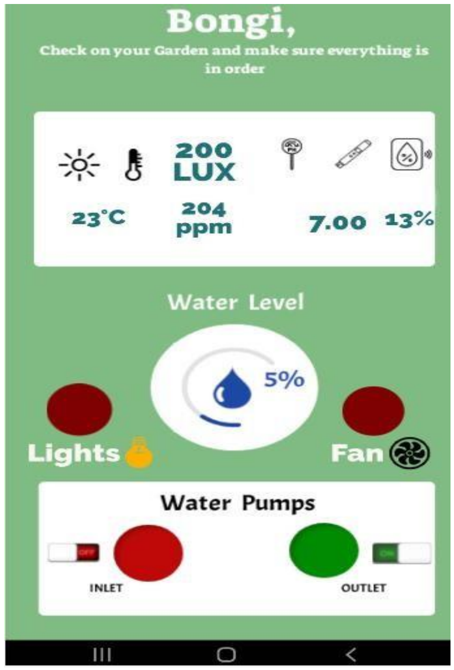


Fig. 26. During the day 200 LUX results for lights being off.

- Analysis

  The ambient illuminance controlled how they grow lights operated. The light sensor records the light intensity data and depending on the value if the LUX value was less than 100, it was considered too dark for the plants so the light would switch on, when the environment LUX was high, i.e., during the day thegrow lights would be automatically switched off.

Fan Control

The fans are adjusted in response to the temperature and humidity of the surrounding environment as sensed by the DHT11 sensor. Climatic tests were conducted on several days to achieve a range of temperature and humidity values. Since temperature changes were minimal, the experiments were conducted duringthe day and night, which supplied the necessary temperature gradients.

- Results

FOR TEMPERATURE $\geq 25\,°C$ AND HUMIDITY $\leq 70\%$

For temperatures that were above 25 $°C$ the atmosphere was considered too hot and considered low humidity, the fans would be switched on to cool the environment.

The Fig. 27 shows the mobile application interface that shows the user, the environment temperature, and humidity when fans were switched on.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

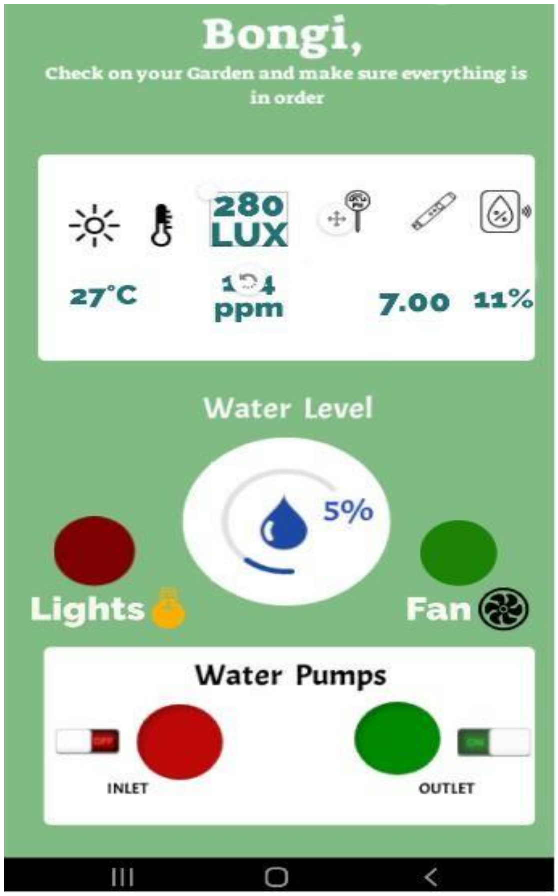


Fig. 27. Fan state for temperature > 25°C and humidity < 70%

IV Conclusion and recommendation for future work

The research conducted extensively explores the application of IoT in hydroponics smart farming, focusing on monitoring and controlling the system. Through meticulous experimentation, the study thoroughly comprehends and effectively applies the operational principles of various sensors to fulfill specific purposes within the hydroponics system. The conducted experiment demonstrates that hydroponics presents a superior alternative to traditional soil-dependent farming, particularly considering the prevailing level of degradation in recent times. Despite the comprehensive nature of this research, there is always room for enhancement. Consequently, it is recommended to incorporate an additional sensor, such as a carbon dioxide (CO_2) sensor, into the system to enable real-time monitoring of plant growth and development.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

References

[1] O. A. Ogbolumani and N. I. Nwulu, "A Food-Energy-Water Nexus Meta-Model for Food and Energy Security," *Sustain. Prod. Consum.*, vol. 30, pp. 438–453, 2021.

[2] O. A. Ogbolumani and N. Nwulu, "Integrated Appliance Scheduling and Optimal Sizing of an Autonomous Hybrid Renewable Energy System for Agricultural Food Production," *Lect. Notes Mech. Eng.*, pp. 651–660, 2020.

[3] M. Majid, J. N. Khan, Q. M. Ahmad Shah, K. Z. Masoodi, B. Afroza, and S. Parvaze, "Evaluation of hydroponic systems for the cultivation of Lettuce (Lactuca sativa L., var. Longifolia) and comparison with protected soil-based cultivation," *Agric. Water Manag.*, vol. 245, p. 106572, Feb. 2021.

[4] O. A. Ogbolumani and N. I. Nwulu, "Multi-objective optimisation of constrained food-energy-water-nexus systems for sustainable resource allocation," *Sustain. Energy Technol. Assessments*, vol. 44, p. 100967, 2021.

[5] L. O. David, N. I. Nwulu, C. O. Aigbavboa, and O. O. Adepoju, "Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis," *J. Clean. Prod.*, vol. 363, p. 132522, Aug. 2022.

[6] O. F. Ogunrewo and N. I. Nwulu, "Optimisation framework of biomass supply chain in southwest Nigeria," *Clean. Eng. Technol.*, p. 100711, Dec. 2023.

[7] O. A. Ogbolumani and N. I. Nwulu, "Environmental impact assessment for a meta-model-based food-energy-water-nexus system," *Energy Reports*, vol. 11, pp. 218–232, 2024.

[8] L. Jafta, N. Nwulu, and E. Dogo, "Development of a solar-powered greenhouse integrated with SMS and web notification systems," in *Artificial Intelligence and IoT-Based Technologies for Sustainable Farming and Smart Agriculture*, IGI Global, 2021, pp. 346–353.

[9] K. Tatas, A. Al-Zoubi, A. Antoniou, and D. Zolotareva, "IPONICS: IoT Monitoring and Control for Hydroponics," *2021 10th Int. Conf. Mod. Circuits Syst. Technol. MOCAST 2021*, no. July, 2021.

[10] V. Lagomarsino, "Hydroponics: The power of water to grow food - Science in the News," *Harvard Univ.*, pp. 1–22, 2019.

[11] K. Kularbphettong, U. Ampant, and N. Kongrodj, "An Automated Hydroponics System Based on Mobile Application," *Int. J. Inf. Educ. Technol.*, vol. 9, no. 8, pp. 548–552, 2019.

[12] A. Abu Sneineh and A. A. A. Shabaneh, "Design of a smart hydroponics monitoring system using an ESP32 microcontroller and the Internet of Things," *MethodsX*, vol. 11, no. June, p. 102401, 2023.

[13] I. A. Adeleke, N. I. Nwulu, and O. A. Ogbolumani, "A hybrid machine learning and embedded IoT-based water quality monitoring system," *Internet of Things (Netherlands)*, vol. 22, p. 100774, Jul. 2023.

[14] Y. Liu, X. Ma, L. Shu, G. P. Hancke, and A. M. Abu-Mahfouz, "From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges," *IEEE Trans. Ind. Informatics*, vol. 17, no. 6, pp. 4322–4334, Jun. 2021.

[15] M. Griffiths, "The Design and Implementation of a Hydroponics Control System.," *Int. J. Eng. Sci.*, p. 74, 2014.

[16] Helmy, M. G. Mahaidayu, A. Nursyahid, T. A. Setyawan, and A. Hasan, "Nutrient film technique (NFT) hydroponic monitoring system based on wireless sensor network," *2017 IEEE Int. Conf. Commun. Networks Satell. COMNETSAT 2017 - Proc.*, vol. 2018-Janua, pp. 81–84, 2017.

[17] D. Eridani, O. Wardhani, and E. D. Widianto, "Designing and implementing the arduino-based nutrition feeding automation system of a prototype scaled nutrient film technique (NFT) hydroponics using total dissolved solids (TDS) sensor," *Proc. - 2017 4th Int. Conf. Inf. Technol. Comput. Electr. Eng. ICITACEE 2017*, vol. 2018-Janua, pp. 170–175, 2017.

[18] C. J. G. Aliac and E. Maravillas, "IOT hydroponics management system," *2018 IEEE 10th Int. Conf. Humanoid, Nanotechnology, Inf. Technol. Commun. Control. Environ. Manag. HNICEM 2018*, pp. 1–5, 2018.

[19] N. K. Goyal, "Hydrobase: an iot gardening application," 2016.

[20] C. Peuchpanngarm, P. Srinitiworawong, W. Samerjai, and T. Sunetnanta, "DIY sensor-based automatic control mobile application for hydroponics," *Proc. 2016 5th ICT Int. Student Proj. Conf. ICT-ISPC 2016*, pp. 57–60, 2016.

[21] M. Yusuf Mazlan and S. Amely Jumaat, "Smart Internet of Things System for Hydroponic," *Evol. Electr. Electron. Eng.*, vol. 4, no. 1, pp. 615–624, 2023.

JDFEWS 4 (2): 106 - 140, 2023
ISSN 2709-4529

[22] TimeandDate, "Johannesburg CBD, South Africa 14 day weather forecast," 2023. [Online]. Available: https://www.timeanddate.com/weather/@11429001/ext. [Accessed: 18-Dec-2023].

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

Design and construction of an Arduino-based load-shedding management system for improving electricity consumption in a medium-sized creative office building

Olumuyiwa AMUSAN
Department of Electrical and Electronics Engineering Science, University of Johannesburg, South Africa
Department of Electrical and Computer Engineering, University of Lagos, Akoka, Nigeria

Benjamin Oluwamuyiwa OLORUNFEMI
Department of Electrical and Electronics Engineering Science, University of Johannesburg, South Africa
ben93olorunfemi@gmail.com

Ayomide FAGBOYO
Department of Electrical and Computer Engineering, University of Lagos, Akoka, Nigeria

Received: 08 December 2023

Review: 18 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract— Standalone energy generation is revolutionizing electricity production and consumption by offering decentralized and sustainable options, benefiting communities, enhancing resilience, and reducing dependence on traditional power grids. Nevertheless, standalone electricity systems can face overloading issues when demand varies or exceeds capacity, necessitating careful control and adaptable solutions. The scalability of standalone electricity systems is limited by infrastructure, technology, and cost, hindering easy capacity expansion to accommodate higher loads. This paper explores the feasibility of managing load shedding in an office building with a standalone energy source, assessing its impact on optimizing electricity consumption and contributing to operational efficiency, sustainability, and resilience. A hardware prototype has been developed for a programmable interface designed to manage various loads from the distribution board automatically and in a controlled manner. This includes controlling lighting, heating, cooling, security devices, and essential office gadgets. The system is implemented and validated through experiments utilizing the Arduino Mega control board. Operators can input load-shedding times flexibly using a 4x4 matrix keypad synchronized with the real-time clock (RTC). The microcontroller then instructs the relay to shed the specified load, displaying the shedding time on the LCD. The results indicate that the programmable interface exhibits a high dynamic response speed, highlighting its effectiveness and flexibility in load-shedding management. Comparing the cost of building the device with the long-term cost of overloading a standalone electricity generator, considering accelerated wear and tear, increased maintenance expenses, reduced operational lifespan, potential premature equipment failure, and overall decreased reliability, underscores the high-cost efficiency of adopting this device in office buildings. Additionally, implementing the system in an office building with an energy consumption of 23 MWh per annum resulted in a discernible annual energy saving of 9.86MWh by shedding off unnecessary loads at estimated timings.

Keywords— *Electricity demand, load shedding, office management, and programmable interface*

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

1 Introduction

In contemporary office environments, the energy demand is dynamic and influenced by factors such as workforce activities, technology usage, and the diverse functions within the workspace [1]. As the necessity for sustainability gains prominence, organizations increasingly recognize the significance of optimizing energy consumption to reduce operational costs [2], [3]. This research addresses the challenges of medium-sized creative office buildings, whose energy needs are often intricate due to integrating various equipment and technologies essential for creative workflow [4]. Traditional approaches to energy management, like static scheduling, manual control systems, rule-based systems, and non-integrated systems, may fall short of accommodating the variable requirements of such dynamic settings, leading to suboptimal energy utilization [5].

Furthermore, the utilization of independent energy generation, sourced either from renewable (for instance, solar panels, wind turbines) or non-renewable (for instance, diesel generators, batteries) means, within office buildings presents decentralized and environmentally friendly alternatives to traditional grid-dependent systems. [6]–[8]. However, effective load-shedding management becomes paramount to fully realizing the benefits of standalone energy [9], [10]. The rationale for this study is to develop and implement a load-shedding system based on Arduino technology, specifically customized to meet the distinctive requirements of a medium-sized creative office. Such a system holds the potential to enhance energy efficiency and contribute to the overall sustainability and resilience of the office environment. The landscape of energy generation and consumption is transforming, with standalone energy generation emerging as a pivotal player in reshaping the traditional paradigms of electricity production [11], [12]. The conventional reliance on centralized power grids is being complemented by standalone systems and, in some cases, supplanted.

While standalone energy generation systems bring many benefits, the challenge of effectively managing these systems to prevent overloading becomes paramount [10]. Variability in demand and unforeseen peaks can strain the capacity of standalone electricity systems, necessitating the development of sophisticated load management solutions [13], [14]. Addressing this challenge is crucial for ensuring the reliability and longevity of these systems, as well as for unlocking their full potential in diverse settings.

This research delves into the critical aspect of load-shedding management within a medium-sized creative office building powered by a standalone energy source. As organizations increasingly recognize the importance of sustainable practices, the need for efficient energy utilization becomes imperative. The proposed solution involves designing and implementing a programmable interface utilizing the Arduino Mega control board to shed loads at strategic times systematically. The loads encompass various components crucial to the office environment, including lighting, cooling and heating systems, security devices, essentials, and office gadgets. Through this study, we aim to assess the feasibility and effectiveness of the implemented load-shedding management system. The hardware prototype, incorporating a 4x4 matrix keypad for flexible input, real-time clock synchronization, and a relay-controlled shedding mechanism, is subjected to rigorous experimental validation. The research examines the technical aspects of the programmable interface and explores its impact on optimizing electricity consumption,

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

contributing to operational efficiency, sustainability, and resilience within the office building setting. Furthermore, the study extends its evaluation to the economic realm by comparing the upfront cost of building and implementing the load-shedding system with the potential long-term costs associated with overloading a standalone electricity generator. Considerations include accelerated wear and tear on equipment, increased maintenance expenses, reduced operational lifespan, the risk of premature equipment failure, and a decline in overall system reliability.

This manuscript is structured as follows: Section 2 provides an overview of the relevant literature related to the study. Section 3 outlines our methodology for office load management, control, and circuit design. Section 4 delves into the outcomes of our experimental endeavors. Finally, in Section 5, we offer conclusions based on our research findings and propose potential avenues for future exploration.

2 Related work

The research on load shedding management of standalone energy in buildings is driven by the essential need to optimize performance, enhance efficiency, and ensure the reliability of standalone energy sources with a focus on extending component lifespan, preventing overloading, improving electricity supply quality, and minimizing environmental impact. Therefore, using the programmable interface to manage load switching is an important strategy for dealing with building energy management difficulties. Numerous investigations have proposed and examined diverse load-shedding management systems for standalone generators based on Arduino technology. In a study by [15], a conceptual model for an Android application was introduced, serving a smart microgrid power pool monitoring and control scheme. The Arduino IDE was employed to develop, monitor, and control the operational algorithm of the system. The findings demonstrated that Android facilitates remote soft-touch human-machine interfaces, enhancing optimal energy operation. According to the findings, future research endeavors could focus on extending a similar scheme to encompass up to 10 communities. Furthermore, a revolutionary algorithm was developed to incorporate current solar photovoltaic and utility supply charging systems [16]. An Arduino microcontroller is equipped with an algorithm that detects the voltage of the battery and then uses that information to manage the availability of the utility grid supply by connecting or disconnecting a relay. This allows the battery to be charged continuously. The design was customized to tackle the issues of irregular power supply that commonly arise in Indian circumstances, leading to planned and unplanned load shedding. In another study [17], an Arduino microcontroller, coupled with a switching circuit, was employed to implement a load-shedding plan in four settlements of a laboratory-scale urban setting designed for teaching and research purposes. The power distribution Company approved the switching plan, ensuring optimal usage of the available 7.5MW against a 10MW power demand. [18] introduced an intelligent meter capable of monitoring usage patterns, reducing load during peak hours, and cutting electricity costs by 25-30%. Linked to a GSM module, the meter receives updated energy consumption units via Arduino Uno and controls appliances on/off using the Internet of Things (IoT) through switching mechanisms. Furthermore, [19] recommended a residential load-shedding method for demand-side load management in a real system under a time-of-use tariff. Demand-side load management is

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

achieved without changing the electricity meter using an Arduino microcontroller system, incorporating the developed load-shedding algorithm. The microcontroller also generates signals the relay system uses to control the lines at the output of the electricity meter. [20] conducted an intelligent wiring design for domestic house layouts, utilizing solar panels for load shedding. An intelligent Arduino system controlled the loads, resulting in a prototype with high safety, reliability, and automation performance. Additionally, [21] designed a model providing a stable and efficient real-time load-shedding technique. Interfacing with Arduino Uno, the real-time clock DS1302 replaces manual ON/OFF operations, overcoming associated challenges.

With its ATmega2560 microcontroller, the Arduino Mega has been effectively utilized in various load-shedding management systems due to its robust processing power and extensive I/O capabilities. The Arduino Mega's many digital and analog pins have proven crucial in energy management. [22] proposed a lightweight smart demand response management scheme for direct load control in a residential grid. Verified through simulation and deployed on a test bed, this algorithm assumes static priorities for every house and its appliances, with Arduino Mega as the decision-making unit.

Furthermore, the Arduino Mega's large memory capacity allows for storing and processing substantial amounts of data, a feature essential in load-shedding systems. This was exemplified in a project by [23], where an infrared radiation sensor and light-dependent resistors (LDR) were used to signal the Arduino Mega to control energy usage. The Arduino Mega's multiple UART interfaces enable it to communicate with various devices, such as energy meters and GSM modules. This was demonstrated in a study by [24], where the Arduino Mega was used to send SMS alerts during load-shedding events. These practical implementations underscore the suitability of the Arduino Mega in designing and constructing an efficient load-shedding management system for improving electricity consumption in medium-sized creative office buildings. The Arduino Mega's capabilities align well with the requirements of such a system, making it a preferred choice over other Arduino boards.

These studies demonstrate the feasibility and effectiveness of using Arduino-based load-shedding management systems for standalone or microgrids and provide useful insights and references for designing and constructing a similar system for a standalone office building. However, some challenges and limitations need to be addressed, such as the scalability, robustness, and user-friendliness of the Arduino-based load-shedding management system. Therefore, further research and development are needed to improve the performance and functionality of the Arduino-based load-shedding management system for a standalone office building and to evaluate its impact on its electricity consumption and energy efficiency.

3 Methodology

The design procedure followed in implementing the load-shedding management system with a programmable interface was segmented into two integral parts: hardware design and software design. The automatic load shedding system is designed for a single phase four load distribution box. The design allows for expansion to multiple loads up to ten, depending on the building's power distribution system. In this project, four loads are connected,

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

operating through a microcontroller using an AC contactor switch and 4x4 relay module board. Since power system relays are used to trip the circuit at any fault or disturbance, power relays are used to shed a particular load at any time as set. The load-shedding management system incorporates a 5V relay with a coil draw of 30mA, demonstrating an energy-efficient design. The relay's switching capacity of 230V ensures it can effectively control electrical loads within the medium-sized creative office building. In conjunction with the relay, the MCCB (Molded Case Circuit Breaker) has a rated voltage of 230V, 30A unit with short circuit breaking capacity to ensure safe and efficient load management in the designed system. The relay receives the command from the microcontroller.

Input load shedding time is provided through input 4x4 matrix keypad. Upon synchronizing the real-time clock (RTC) with the specified load-shedding time, the microcontroller issues a command to the relay, removing the designated load from the system. Subsequently, the shed time is presented on the LCD (16x2 character LCD module with an HD44780-compatible controller). The DS3231 RTC module selected for load-shedding management research with Arduino Mega features exceptional accuracy with a deviation of only a few seconds per month. Its low power consumption is within the range of 2.0μA, contributing to energy efficiency. The integrated temperature compensation ensures reliable timekeeping, and the module incorporates a temperature sensor with a measurement range of -40 °C to +85°C. These specifications justify its selection, offering precise timekeeping, energy efficiency, and additional temperature-sensing capabilities to enhance the overall effectiveness of the load-shedding management system.

The internal program runs at power up. After initial startup, the controller will revert the relay module to the load shedding state, turning connected loads OFF for a set delay period. After the delay times out, the program will look at the default scheduling algorithm developed and shown in Tables 1 and 2. The program will then repeat the process of restoring and removing load based on the schedule.

Table 1. Load shedding schedule between 00:00 to 11:00

Load	**00:00**	**01:00**	**02:00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**	**08:00**	**09:00**	**10:00**	**11:00**
Load 1	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On
Load 2	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	On
Load 3	On	On	On	On	On	On	On	On	On	On	On	On
Load 4	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

Table 2. Load shedding schedule between 12:00 to 23:00

Load	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Load 1	On	On	On	On	On	On	On	Off	Off	Off	Off	Off
Load 2	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off
Load 3	On	On	On	On	On	On	On	On	On	On	On	On
Load 4	On	On	On	On	On	On	On	Off	Off	Off	Off	Off

Load 1 – lighting, load 2- cooling and heating, load 3- security devices and essentials, load 4 – office gadgets.

The proposed system was simulated to validate its functionality through testing, while the simulation model was implemented using Proteus simulation software. The simulation was conducted to verify the efficacy of the proposed system.

3.1 Design approach

The initial design approach involved researching and assessing the feasibility of the load-shedding controller. Another crucial step was understanding the fundamental principles governing the distribution box and comprehending the intricacies of the building's wiring. Determining the load capacity of the device that would be controlled and classifying these loads into different categories was undertaken and presented in section 4. Figure 1 presents the flow diagram of the hardware design. The subsequent steps included selecting appropriate components and parts for constructing the load-shedding distribution box and exploring datasheets to understand the interactions between various components.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

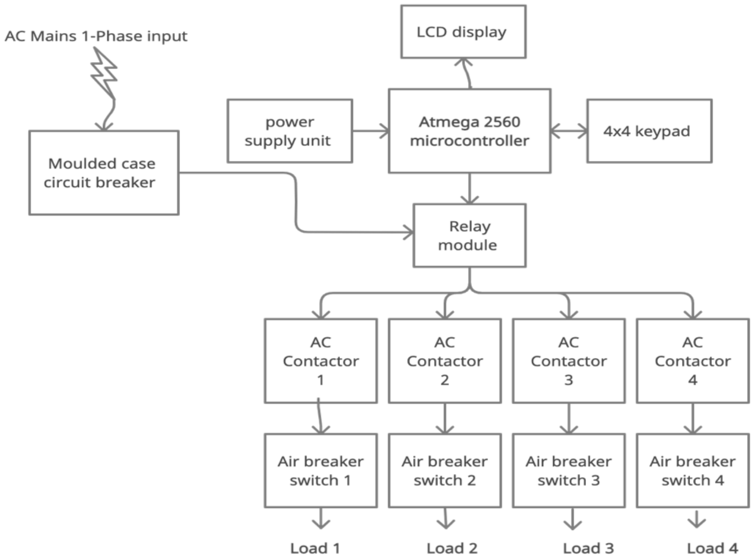


Fig. 1. Flow diagram of the hardware design

The power supply connection for the system was meticulously designed to ensure reliability and stability. It comprises a series of components: a 220V/12V step-down transformer, a full-wave bridge rectifier, a 1000uF electrolytic capacitor filter, a 7805 voltage regulator, and a 1A fast-blow fuse. The transformer reduces mains voltage to 12V AC, subsequently converted to 12V DC by the rectifier. The filter minimizes ripples and noise, while the regulator maintains a constant 5V DC output, protecting against input voltage variations. A fast-blow fuse safeguards the system from overcurrent or short-circuit incidents. This regulated power is channeled to the Arduino Mega and the relay through suitable connectors and wires. The Arduino Mega interfaces with a 2N2222 NPN transistor, amplifying a low-current signal from an Arduino pin to control the Single Pole Single Throw (SPST) relay efficiently. To protect the transistor from back-EMF generated during relay deactivation, a 1N4148 diode is integrated with the relay coil, ensuring the overall reliability and longevity of the load-shedding management system's switching mechanism.

3.2 System process

The Arduino Mega development board incorporates ATmega2560 microcontrollers, which were programmed using C++. The Arduino Mega's ATmega2560 microcontroller, with its high number of I/O pins and large memory, is ideal for managing complex systems [25]. Its robust processing power will ensure efficient electricity

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

consumption management in medium-sized creative office buildings. The Arduino project offers an integrated development environment (IDE) for compiling and uploading programs to the microcontroller via the Arduino development board. The step-by-step processes of the system are illustrated in Figure 2 through a flow chart. The project's code is included in the appendix of this article.

The hardware construction phase entailed building and connecting the components using the circuit diagram in Figure 3. The firmware code for the microcontroller responsible for load shedding was written, and the developed algorithm was implemented for load shedding management.

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

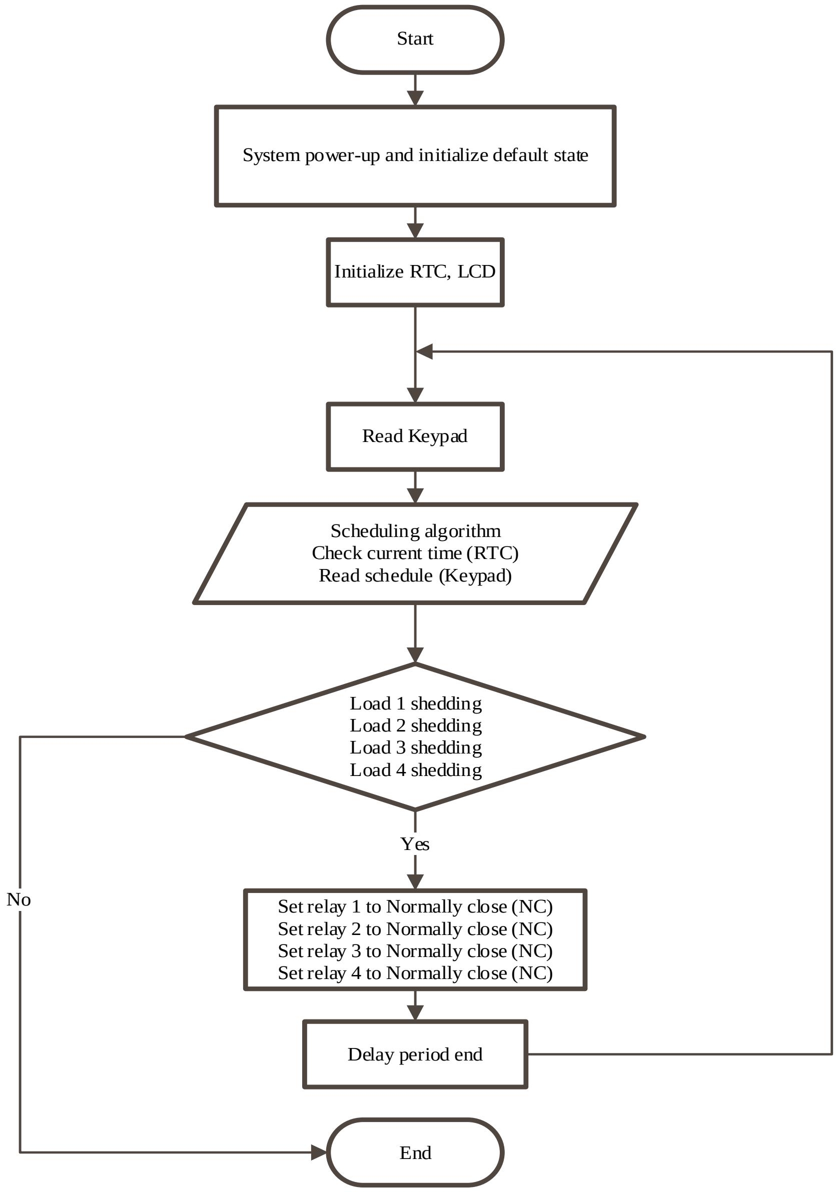


Fig. 2. Flow chart of the step-by-step processes of the system

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

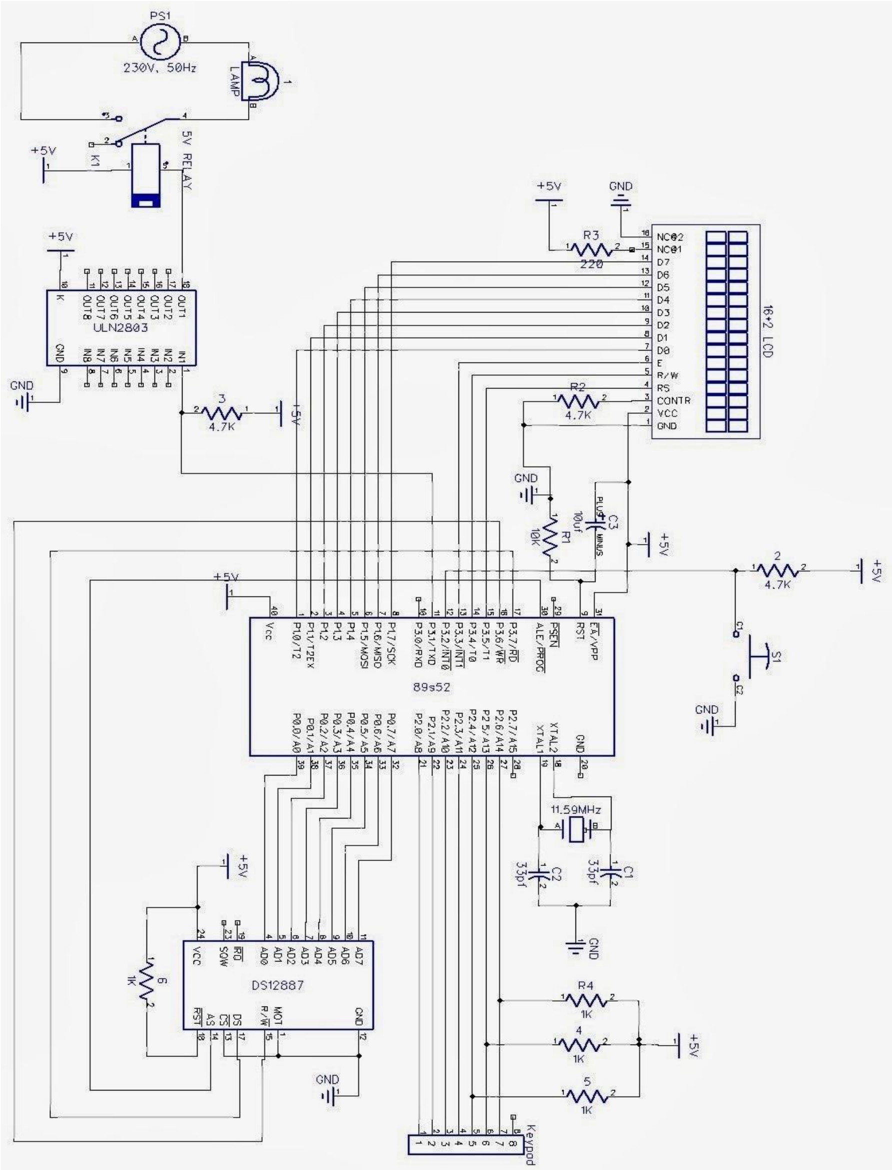


Fig. 3. Circuit diagram of the programmable interface in proteus software

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

4 Results and Discussion

4.1 Project prototype

The connection process was initialized by identifying the necessary components and the connection points. The components were verified for integrity through resistance checks, utilizing a multimeter before connection. The testing phase was conducted to validate the functionality of the designed system. The initial testing of the project design was implemented on a breadboard. The soldering procedure was carried out to attach the components to a vero board.

A case was then designed to house the entire circuit, encompassing the core components and external peripherals such as indicators, LCD, keypad, and switch. This comprehensive encapsulation ensured the protection of the internal circuitry and facilitated efficient operational interplay between the integrated components. The casing design considered the spatial arrangement and optimal positioning of each element, promoting seamless functionality within the confined space and contributing to the overall robustness of the constructed system.

Following the construction of the circuit and the casing, the assembly focused on the precise arrangement and integration of the various sections within the designated casing. This process involved the interconnection of peripheral devices, strategically linking each element to optimize operational efficiency. The assembly configurations depicted in Figure 4 are designed to optimize interconnectivity and operational efficiency within the assembled system.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

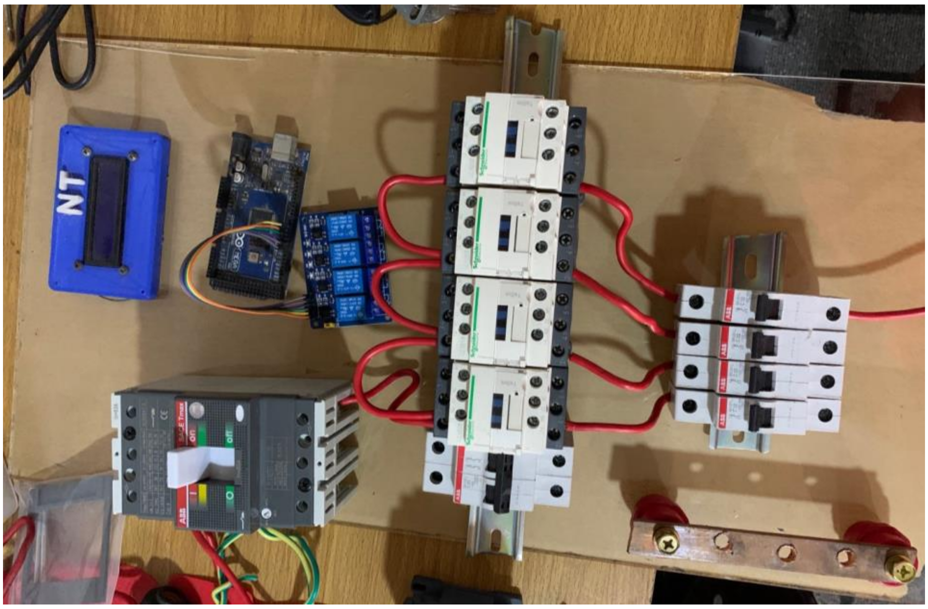


Fig. 4. Proposed configurations of parts

4.2 Prototype test

The post-construction results analysis was done following comprehensive troubleshooting to indicate a commendable system performance, showcasing its proficient responsiveness to operational demands. An energy consumption assessment was conducted to quantify the consequential impact of the project on a creative office building with a load of 23 MW. To find the energy consumption per hour of the medium-sized creative office building, we can use the equation (1).

$$Energy\ Consumption\ per\ Hour\ = \frac{Total\ Energy\ Consumption}{Total\ Number\ of\ Hours} \tag{1}$$

Given the total energy consumption as 23MWh per annum, and the total number of hours is 10 hours daily for 365 days.

$$Energy\ Consumption\ per\ Hour\ = \frac{23MWh}{10\ hours\ per\ day\ \times 365\ days} \tag{2}$$

$$= \frac{23}{3650} MWh/h$$

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

$$= 0.0063MWh/h$$

Therefore, the energy consumption per hour is approximately 0.0063 MWh/h.

Equation (3) was used to calculate the new total annual energy consumption when the usage hours were reduced from 10 to 6 hours per day.

$$New\ Total\ Annual\ Energy\ Consumption = Energy\ Consumption\ per\ Hour \times New\ Total\ Number\ of\ Hours \times Days\ per\ Year \quad (3)$$

$$New\ Total\ Annual\ Energy\ Consumption\ (6\ hours\ per\ day) = 0.0063MWh \times 6 \times 365 \quad (4)$$

$$= 13.14MWh$$

Therefore, when the energy usage was reduced from 10 hours to 6 hours per day, the new total annual energy consumption was approximately 13.14MWh.

The shift in daily energy usage from 10 to 6 hours notably influences the overall annual energy consumption. Initially, with a daily usage of 10 hours, the yearly energy consumption amounted to 23 MWh, indicating a substantial demand for power. However, by reducing usage duration to 6 hours per day, the annual energy consumption experienced a significant decrease, reaching approximately 13.14MWh. This considerable disparity underscores the efficiency gains resulting from a more mindful and restrained approach to energy consumption. The adjustment reduces energy costs and aligns with sustainable practices, emphasizing the importance of optimizing energy use for economic and environmental considerations. The reduction in annual energy consumption, achieved by implementing the proposed construction in an office building, amounts to approximately 9.86MWh.

Following Nigeria's National Electric Power Policy, the tariff established by distribution companies for customers was assessed at 51.11 Naira per kWh [26].

To calculate the cost for 9.86 MWh at a rate of 51.11 Naira per kWh, equation (5) was used.

$$Cost = Energy\ Consumption \times Rate \quad (5)$$

Where:
Energy Consumption = 9.86 MWh
Rate = 51.11 Naira per kWh

$$Cost = 9.86MWh \times 51.11\ Naira\ per\ kWh \quad (6)$$

$$Energy\ Consumption\ in\ kWh = 9.86MWh \times 1000kWh/MWh \quad (7)$$

$$Energy\ Consumption\ in\ kWh = 9860kWh$$

$$Cost = 9860kWh \times 51.11Naira\ per\ kWh$$

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

$$Cost = 504{,}004.60\ Naira$$

Therefore, the cost saved for 9.86 MWh at a rate of 51.11 Naira per kWh amounts to approximately 504,004.60 Naira. This analysis underscores the system's efficacy in optimizing electricity consumption. The findings contribute to the broader discourse on sustainable energy management strategies in office environments.

4.3 Cost analysis

Furthermore, the complete analysis of the financial cost associated with procuring components and materials for the project's construction is systematically detailed in Table 3, showcasing the comprehensive breakdown of costs in Nigeria Naira.

Table 3. Cost expenditure for building the device

S/no.	Items	Description	Cost (Naira #)
1	Arduino Mega board	MEGA R3 Board ATmega 2560	#34,587.74
2	Keypad	4 x 4 Matrix Array 16 Key Membrane Switch Keypad Keyboard Compatible	#8,721.74
3	LCD Display	LCD Display Module DC 5V 16x2 Character	#10,303.46
4	Wires	Multicolored Dupont Wire 40pin Male to Female, 40pin Male to Male, 40pin	#5,542.64
5	Earthing rod	Brass Grounding Rod with 40ft Wire, Earthing Rod Great to Use with Grounding	#21,057.86
6	AC Contactors	40 Amp contactor 240V coil HVAC Contactor	#13,721.06
7	Air Breaker Switch	Low-Voltage Miniature Air Circuit Breaker Circuit Breaker	#12,139.29
8	Real-Time Clock Module	RTC Breakout Module DS3231 Board 3.3V 5V	#10,303.46

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

9	Relay Module	4 Channel 5V Relay Module OPTO-Isolated Support High and Low Level Trigger	#5,868.52
10	Power supply kit	Component Power Supply Module Assorted Kit for Arduino Power Supply Kit	#7,935.54
11	Miscellaneous		#11,917.95
		Total	#142,099.26

This detailed breakdown reflects a total expenditure of #142,099.26 to procure essential components. The presentation of a comprehensive cost breakdown in this research is essential to transparently delineate the allocation of resources, ensure reproducibility, and facilitate informed decision-making for future endeavors within the field. Also, the presented cost analysis serves as a valuable reference for researchers and practitioners in the field, contributing to the broader discourse on the economic considerations associated with implementing advanced technological systems.

4.4 Limitations of the research and future works

This research has some limitations that need to be acknowledged and addressed in future studies. The hardware prototype was tested in a simulated office environment, not in a real office building with a standalone energy source. Therefore, the actual performance and reliability of the device may vary depending on the environmental conditions, the quality of the energy source, and the user behavior. The operators input the load-shedding times manually using a keypad, which may introduce human errors and inconsistencies. A more automated and intelligent method of determining the optimal load-shedding times based on the energy demand and supply could improve the accuracy and efficiency of the system. The energy saving of 9.86MWh per year was calculated based on the average energy consumption of an office building in Ikeja, Lagos, Nigeria, which may not be representative of other regions or countries.

Moreover, the energy saving may change depending on the season, the weather, and the occupancy of the office building. The cost-benefit analysis of the device was based on some assumptions and estimates, which may not reflect the actual costs and benefits of adopting the device in different scenarios. A more comprehensive and realistic analysis of the economic and environmental impacts of the device is needed to justify its feasibility and attractiveness.

Considering the limitations identified in this research and the corresponding findings, several promising directions exist for future investigations. Conducting field experiments in genuine office buildings equipped with standalone energy sources would allow the results to be compared with those obtained from simulated experiments. This approach not only ensures more valid and reliable data on the performance and reliability of the device

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

but also sheds light on potential challenges and opportunities in its practical implementation. Developing a more advanced and adaptive algorithm for determining optimal load-shedding times is crucial. This should consider energy demand, supply, and user preferences and feedback. Such advancements aim to enhance the overall functionality and usability of the device while concurrently reducing the need for human intervention and minimizing errors. Expanding the research scope to include various types of buildings and sectors, such as residential, commercial, industrial, and agricultural, would be instrumental. This broader perspective seeks to increase the applicability and impact of the device, catering to the diverse needs and specific characteristics of users in different contexts. A detailed and realistic cost-benefit analysis is imperative to understand the device's feasibility and attractiveness comprehensively. This analysis should consider various factors and parameters, including the initial investment, operational and maintenance costs, energy prices, carbon emissions, and social and environmental benefits. Such a comprehensive examination aims to provide a convincing justification for the viability and appeal of the device.

5 Conclusion

The developed load-shedding system, equipped with a programmable interface and time management capabilities, has demonstrated noteworthy achievements. Its functionalities include the strategic deactivation of loads during low usage periods as specified by the device, user input customization for work hours, and a consequential reduction in overall energy consumption within the building. The potential expansion of this concept envisages a centralized monitoring system for distribution points, wherein relays and circuit breakers manage the supply to designated geographical regions. This system lets users control the distribution point in response to load demands and requirements. Upon relay tripping, operators receive crucial electrical parameters, including active power, reactive power, current, voltage, frequency, and other relevant data displayed on the LCD. Utilizing a 4 X 4 keypad to interact with the microcontroller offers a practical and efficient solution for obtaining input data in a user-friendly manner. The system's ability to control load-shedding intervals based on management commands contributes to its efficiency in varying load demand and considerations in a creative office building. The prospect of implementing this system in a medium-sized creative office building, particularly at the main distribution point, underscores its potential as a sophisticated solution for optimizing energy management. This innovative approach addresses current energy challenges and opens avenues for broader applications in diverse settings, establishing its significance in advanced power systems.

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

6 References

[1] G. P. Hodgkinson and J. K. Ford, "International Review of Industrial and Organizational Psychology 2011," Int. Rev. Ind. Organ. Psychol. 2011, vol. 26, pp. 1–347, Mar. 2011, doi: 10.1002/9781119992592.

[2] X. Zhou, S. Xue, H. Du, and Z. Ma, "Optimization of building demand flexibility using reinforcement learning and rule-based expert systems," Appl. Energy, vol. 350, 2023, doi: 10.1016/j.apenergy.2023.121792.

[3] H. Chen, L. Gao, Y. Zhang, and C. Zhao, "Optimal scheduling strategy of a regional integrated energy system considering renewable energy uncertainty and heat network transmission characteristics," Energy Reports, vol. 8, pp. 7691 – 7703, 2022, doi: 10.1016/j.egyr.2022.05.235.

[4] J. L. Torres-Moreno, A. Gimenez-Fernandez, M. Perez-Garcia, and F. Rodriguez, "Energy management strategy for micro-grids with PV-battery systems and electric vehicles," Energies, vol. 11, no. 3, 2018, doi: 10.3390/en11030522.

[5] L. A. Hurtado, E. Mocanu, P. H. Nguyen, M. Gibescu, and R. I. G. Kamphuis, "Enabling Cooperative Behavior for Building Demand Response Based on Extended Joint Action Learning," IEEE Trans. Ind. Informatics, vol. 14, no. 1, pp. 127 – 136, 2018, doi: 10.1109/TII.2017.2753408.

[6] M. Pichan and H. Rastegar, "A New Hybrid Controller for Standalone Photovoltaic Power System with Unbalanced Loads," Int. J. Photoenergy, vol. 2020, 2020, doi: 10.1155/2020/5373914.

[7] A. Alzahrani, "Energy Management and Optimization of a Standalone Renewable Energy System in Rural Areas of the Najran Province," Sustain., vol. 15, no. 10, 2023, doi: 10.3390/su15108020.

[8] R. Syahputra, K. Purwanto, and I. Soesanti, "Performance investigation of standalone wind power system equipped with sinusoidal PWM power inverter for household consumer in rural areas of Indonesia," Energy Reports, vol. 8, pp. 4553 – 4569, 2022, doi: 10.1016/j.egyr.2022.03.145.

[9] O. V. G. Swathika and K. T. M. U. Hemapala, "IOT Based Energy Management System for Standalone PV Systems," J. Electr. Eng. Technol., vol. 14, no. 5, pp. 1811–1821, 2019, doi: 10.1007/s42835-019-00193-y.

[10] S. M. Ferdous, G. M. Shafiullah, F. Shahnia, R. M. Elavarasan, and U. Subramaniam, "Dynamic Frequency and Overload Management in Autonomous Coupled Microgrids for Self-Healing and Resiliency Improvement," IEEE Access, vol. 8, pp. 116796–116811, 2020, doi: 10.1109/access.2020.3004185.

[11] F. Asghar, M. Talha, and S. Kim, "Robust Frequency and Voltage Stability Control Strategy for Standalone AC/DC Hybrid Microgrid," Energies, vol. 10, no. 6, p. 760, 2017, doi: 10.3390/en10060760.

[12] L. Olatomiwa, R. Blanchard, S. Mekhilef, and D. Akinyele, "Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery," Sustain. Energy Technol. Assessments, vol. 30, pp. 121 – 138, 2018, doi: 10.1016/j.seta.2018.09.007.

[13] Q. Yuan, K. Zhou, and J. Yao, "A new measure of wind power variability with implications for the optimal sizing of standalone wind power systems," Renew. Energy, vol. 150, pp. 538 – 549, 2020, doi: 10.1016/j.renene.2019.12.121.

[14] L. K. Gan, J. K. H. Shek, and M. A. Mueller, "Hybrid wind-photovoltaic-diesel-battery system sizing tool development using an empirical approach, life-cycle cost, and performance analysis: A case study in Scotland," Energy Convers. Manag., vol. 106, pp. 479 – 494, 2015, doi: 10.1016/j.enconman.2015.09.029.

[15] K. E. Jack, D. O. Dike, J.-K. C. Obichere, and M. Olubiwe, "The development of an Android Applications Model for the Smart Micro-Grid Power Pool System Monitoring and Control," Int. J. Eng. Adv. Technol., vol. 9, no. 3, pp. 3474–3479, 2020, doi: 10.35940/ijeat.c5620.029320.

JDFEWS 4 (2): 141 - 158, 2023
ISSN 2709-4529

[16] S. R. R. D. Purusothaman, R. Rajesh, K. K. Bajaj, V. Vijayaraghavan, and M. Venkatesan, "Hybrid Battery Charging System Using Solar PV and Utility Grid," in 2014 POWER AND ENERGY SYSTEMS: TOWARDS SUSTAINABLE ENERGY, 2014, pp. 1–5. doi: 10.1109/pestse.2014.6805275.

[17] O. K. Ogidar, K. O. Temikotan, and K. C. Chike, "Development of an Arduino Microcontroller-Based Automatic Load Shedding Module for Teaching and Research," in 2017 IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON), 2017, pp. 1130–1134. doi: 10.1109/nigercon.2017.8281976.

[18] R. T. Mathew, S. Thattat, K. V Anirudh, V. P. K. Adithya, and G. Prasad, "Intelligent Energy Meter with Home Automation," in 2018 3rd International Conference for Convergence in Technology (I2CT), 2018, pp. 1–4. doi: 10.1109/i2ct.2018.8529702.

[19] C. Keles and Y. Yigit, "Implementation of Demand Side Load Management by Domestic Load Shedding Algorithm for Conventional Electricity Meters," in 2019 International Artificial Intelligence and Data Processing Symposium (IDAP), 2019, pp. 1–4. doi: 10.1109/idap.2019.8875941.

[20] M. Mulyono and H. J. Berchmans, "DESIGN AND SIMULATION OF WATER LEVEL MONITORING AND CONTROL SYSTEM IN MINI HYDRO POWER PLANT," Proc. Conf. Manag. Eng. Ind., vol. 1, no. 1, pp. 13–16, 2019, doi: 10.33555/cmei.v1i1.14.

[21] P. Kharade, P. P. Padhi, M. G. Vivek, P. S. Reddy, and B. Prajwal, "Automatic Load shedding Time management using Arduino," in 2021 Sixth International Conference on Image Information Processing (ICIIP), 2021, pp. 47–51. doi: 10.1109/iciip53038.2021.9702633.

[22] S. Dash, R. Sodhi, and B. Sodhi, "A Smart Demand Response Management Scheme for Direct Load Control in Residential Grid," in 2018 20th National Power Systems Conference (NPSC), 2018, pp. 1–6. doi: 10.1109/npsc.2018.8771746.

[23] M. Niaz and M. Haque, "WIRELESS SENSED INTELLIGENCE POWER SWITCHING MECHANISM FOR RESIDENTIAL LOAD," irjmets.comMNM Haqueirjmets.com, 1266, Accessed: Dec. 15, 2023. [Online]. Available: https://www.irjmets.com/uploadedfiles/paper/issue_2_february_2022/19271/final/fin_irjmets1645772061.pdf

[24] M. Nallasivam, S. R., V. A., and N. S., "Design of Smart Energy Meter with IOT Using Arduino Mega," ECS Trans., vol. 107, no. 1, pp. 19435–19442, Apr. 2022, doi: 10.1149/10701.19435ECST/XML.

[25] R. Butuner, Y. U.-S. Kocer, O. Dundar, and undefined 2021, "Arduino microcontroller card," isres.org, Accessed: Dec. 18, 2023. [Online]. Available: https://www.isres.org/books/chapters/bolum_1_16-12-2021.pdf

[26] "Distribution/End User Tariff." Accessed: Dec. 18, 2023. [Online]. Available: https://nerc.gov.ng/index.php/home/myto/408-distribution-end-user-tariff

7 Authors

Amusan Olumuyiwa
Department of Electrical and Electronics Engineering Science, University of Johannesburg, South Africa.
Department of Electrical and Computer Engineering, University of Lagos, Akoka, Nigeria.

Benjamin Oluwamuyiwa Olorunfemi
Department of Electrical and Electronics Engineering Science, University of Johannesburg, South Africa.

Ayomide Fagboyo
Department of Electrical and Computer Engineering, University of Lagos, Akoka, Nigeria.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Evaluating Prospective Energy Services Demand for Residential Solar Photovoltaic (RSPV) Generated Electricity in Lagos State, Nigeria

Aquila JESULEYE
Department of Project Management Technology, The Federal University of Technology, Akure, Nigeria; oajesuleye@futa.edu.ng

Olatubosun ORIOLA
Federal Ministry of Science and Technology, National Centre for Technology Management, Nigeria; aoriola@ymail.com

Adeyemi ADEPOJU
Department of Project Management Technology, The Federal University of Technology, Akure, Nigeria; aoadepoju@futa.edu.ng

Received: 08 December 2023

Review: 21 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: The ongoing energy and climate crisis demand transition to sustainable energy resources aided by accurate estimation of energy demand to guide policies for adequate planning of renewable fueled electricity generation technology in urban areas. This study evaluated the electricity demand for standalone residential solar photovoltaic (RSPV) technology by potential household adopters of the technology in the metropolitan area of Lagos state, Nigeria plagued with endemic epileptic grid electricity supply. The study adopted quantitative research design with structured questionnaire to solicit information from the respondents. Three hundred and twenty-six (326) responses from the potential adopters were analysed with a model for analysis of demand for energy (MADE-II) and Pareto tool. The results show that space cooling services has the highest energy intensity of 7.59 kWh/hh/day while the entertainment services have the lowest energy intensity of 0.84kWh/hh/day. The study concluded that the household energy services demand for electricity by the potential RSPV technology adopters from the solar module panel is 31.59kWh/hh/day. The study further conclude that the respondents guided by their consciousness of the quantity of energy demand carefully select appliances base on the energy requirements of the appliances. The study recommends effective planning, monitoring, and controlling of operation and performance of the household appliances vis-a-viz the operation and performance of the stand-alone RSPV system to minimise the energy demand and optimize the energy services output. Further study could investigate the smart integration and interaction of the household appliances with the stand alone RSPV system to minimise the energy demand and optimise the performance of both the supply and demand system.

Keywords: *Energy demand; MADE II; Residential Solar Photovoltaic; Energy Services; Adopters; Energy intensity*

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

1.0 Introduction

Urbanisation and energy demand has been identified to be consequentially related to Climate change and global warming [1]. The progress of urbanisation, population growth, economic development, and living standards iscorrespondingly increasing the demandfor energy services in urban areas resulting to large carbon footprint. About 55% (4.2 billion) of the world population projected to reach about 6.5 billion (two third) by 2050 live in cities and significantly responsible for more than 80% of global gross domestic product [2]. The urban areas generate an estimated 75% of human caused global emission of carbon dioxide (CO_2) as a result of about two thirds of global final energy use and significant indirect consumption of energy embodied in products and other material goods [2], hence improving environmental performance of the energy system in the urban area is an indispensable necessity to attain green growth. Green growth entails economic advancement that promotes development characterized by environmental sustainability, reduced carbon emissions, social inclusivity and in other words operates on the pedestal of sustainable socio-economic systems driven by transition from non-renewable (fossil) energy to renewable resources [1].

Solar energy, based on its large technological potential and being amongst the cleanest energy sources, is used to generate electricity directly with solar photovoltaic technology [3, 4]. The solar photovoltaic (PV)electricity generation technology is considered to be the most sustainable and environmentally friendly technology among the available renewable electricity generation technologies [5, 6]. Therefore, accelerating the deployment of solar PV Technology is crucial to fill the energy gap, mitigate climate change and realise green growth.

Recent studies [7, 8, 9] shows that residential sector is the largest electricity consumer in Nigeria and account for about 59% of the country's electricity consumption, hence the sector can speed up the progress of tackling energy deficit and reduction of greenhouse gas (GHG) emission to mitigate climate change by rapid deployment of residential photovoltaic (RSPV) technology.The appropriate deployment of residential solar PV (RSPV) technology demandsintegrated planning involving dedicated policies, regulations and creation of energy demand profile for households [10]. A better understanding of residential energy demand is vital to transition of the energy system towards renewable sources from fossil energy sources. To adequately evaluate the household electricity demand for residential solar PV technology, it is vital to identify the energy services need of the households [6, 11]. Electrical power audit is paramount to ascertain the energy use of the households in order to plan for the suitable capacity of PV system that would meet the households' energy services demand [12, 6].

Past studies [13, 7, 4]) on estimation of energy demand for solar PV system are based on retrospective survey of the technology users which may not be suitable for accurate energy demand forecasts to aid policy makers in development of energy supply and provision of valuable suggestions for energy supply system operations planning. This study uses prospective surveys to evaluate the electricity demand of potential household users of RSPV technology to fill this methodology gap in literature. Furthermore, studies on application of solar off grid electricity generation had focused more on rural dwellers that does not have the financial capability to pay for the solar PV services, most especially in the sub-Saharan Africa [14, 15, 17] while there is dearth of studies on the application of the system in urban areas that contribute large amount of greenhouse gases to the environment and also has the financial buoyancy to pay for the services are lacking.

2.0 Literature Review

The concept of energy service is commonly used in very diverse fields and activities. Though there are notable differences in how energy services are conceptualised, it has been commonly argued that what people demand are the benefits provided by energy for human well-being and the society not energy or its carrier [18,19,20]. According to

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

[21] energy services are "energy forms and processes from where consumers ultimately derive and realise the value of energy carriers like electricity and gas" (p 3). Energy services are also described as the functions performed by the use of energy thus energy services drive energy consumption and energy demand [20].

In the residential sector, [22] identified the most common form of energy service as refrigeration, lighting, cooking, heating, water heating and space heating while [21] observe the common forms of energy services to include illumination, space conditioning, water heating, communications, and information processing. [23] describe what energy produces as lighting, cooling, cooking, space, and water heating, etc. and [18] categorised the urban household energy services for the low-income households as Cooking, Lighting, space heating and cooling, refrigeration, television, telephony, radio, mobile phone charging and hot water. According to the study, the middle-income households have all the low-income services plus entertainment, refrigeration and freezing, clothes washing and drying, computing, and surfing of the internet, advanced telecommunication while the high-income households have all the middle-income services plus luxury practices such as swimming in a heated pool, going to the bathroom with a heated toilet to the sound of music, and watching television while cooking. [7] considered lighting, Computing/internet, entertainment, process heating, cooking, water pumping, space cooling, ventilation, and refrigeration services as the forms of energy services in their study on Solar photovoltaic contribution to energy mix in selected Nigerian estates. These forms of energy services were adopted to guide this study.

When electricity is used as the energy carrier, provision of electricity to the consumers for the derived demand while ensuring the security of the power system is the conventional approach of providing energy services [21]. Much of the investment and operational decision making associated with this approach is focused on the supply side of the power system, while the potential contributions of the demand side are less regarded. This approach is increasingly becoming unfavourable due to growing electricity demand, deteriorating load factors and the evolving environmental concerns. Hence, [22] posited that there is a continuing increase in recognition of the significance of the demand-side of energy. According to [21] evaluation of the demand for energy can be approached in two ways. The first approach is by the actual energy consumption of the conversion technology used to deliver the service. The second approach is by specifying the required temporal changes to a variable directly related to the service, such as the volume of hourly consumption of hot water and the hourly temperature in a room. The accuracy of the first method relies on the immediate conversion of electricity to the corresponding energy service by the appliance. In contrast, the second method faces a challenge in assessing the hourly consumption of hot water through the electricity consumption of water heaters, as certain households utilize storage-type heaters. For energy services involving the instantaneous conversion of electricity to services, like lighting, or scenarios where the benefit stems not from the converted energy form but from the resulting process, such as information processing, the actual electricity consumption can be considered synonymous with the energy equivalent or demand [21]. This approach was adopted for this study because all the energy conversion technologies (appliances) studied instantly converts energy to services such as lighting, water pumping and ventilation services.

There are various literatures with different perspective and methods to analyse the household energy demand. According to [24] the theoretical frameworks are categorise based on discipline and integrated perspectives. The dominating disciplines in the disciplinary frameworks are economics, engineering, sociology and anthropology, and psychology. The engineering frameworks considers the physical laws to analyses the technology aspect of household energy demand [25]. The economic frameworks analyse the effects of income levels, energy prices, taxes and other economic and some behavioural factors [26]. The psychology frameworks consider the human behavioural aspect of household energy demand [27], while the sociology and anthropology frameworks analyse the social and cultural context of the household energy demand. The study of [28] suggest that the disciplinary frameworks which are developed on specific discipline such as economics, engineering, sociology and anthropology, and psychology

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

approach that has been used to guide energy policies over the years may be limited in the analysis of today's complex problems in the energy sector. This is because the disciplinary frameworks have some inadequacies and could not analyse the interactions between the various disciplines, and similarly are not able to properly explain the disjunction between the actual and predicted household energy demand [29]. The integrated perspective combines different discipline to form a robust framework for analysis of energy demand and adequately proffer energy demand solutions. [30] conceptualise a framework of household energy demand combining economics, engineering, sociology and anthropology, and psychology approaches but the idea did not translate to simulation models. Similarly, the study of [31] conceptualise an integrated framework based on socio-technical systems concepts that did not transform to modelling method. These theoretical frameworks serve as bases for all the studies on household energy demand modelling techniques [24].

Several models are developed for forecasting and estimating household energy demand and the associated carbon emission over the years. Principally two main epistemic approaches are used to model household energy demand and the consequential emissions of carbon dioxide namely top-down and bottom-up approaches with ongoing progress in development of the robust hybrid of the two approaches [32,33]. The top-down techniques which is mainly econometric method uses existing interaction between the energy sector and the general economy to predict and forecast the behaviour of household energy demand and carbon emissions at aggregate level when the policy parameters are changed within the models. The bottom-up techniques comprising of building physics and statistical method concentrates only on the energy sector, models household energy demand and carbon emissions by disaggregating the statistical or building physics method that contains high level of details. According to [24] there are significant variations in these models on the bases of disaggregation levels, complexity, output resolution, aggregation of output levels, performed scenario analysis, validation of model, and how they are made available for the public to scrutinize. The scholars further assert that there is a need to find more robust and sophisticated modelling techniques that take into account the associated complexity and burden of household energy demand and carbon emissions problems due to the chaotic nonlinearity, high interdependence and qualitative nature of some of the variables involved.

According to [4,7] the Model for Analysis of Demand for Energy (MADE-II) which appropriately combines the application of engineering process, econometric and statistical techniques to analyse demand for energy in various economic sectors is flexible and applicable for projection of energy demand over short and long period of time is suitably developed for developing countries such as Nigeria. These characteristics make the model suitable for this study.

3.0 Methodology

Lagos state, the most populous and fastest growing megacity in Africa and the former capital of the federal republic of Nigeria with an estimated population of about 24 million [34] people and population density of about 5,000 persons/km^2 was selected for the study. The study area located in the southwest geopolitical zone of Nigeria lies approximately between longitude 2º42'E and 3º22'E and between latitude 6º22'N and 6º42' Nhas solar radiation intensity of between 3.54 and 5.43 kWh/m^{2}day [12] suitable for generating electricity with solar PV technology. The metropolitan area span over sixteen (16) of the twenty (20) local government areas of Lagos State and accounts for over 85% of the total population of the State. The study area is the economic centre of Nigeria hence energy consumption and GHG emission rate seems to be high in Lagos state compared to other states in Nigeria because of its high level of urbanisation and industrialisation. The state receives just about 1GW of electricity for an average of no more than 12 hours daily average i.e. 12 gigawatt-hours (GWh) per day (6.25% of the demand) from the national grid according to [35]. Estimate is pointing at the use of about 15 GW back-up capacity fossil fuel-based self-generated off-grid electricity (diesel and petrol back-up generators) in Lagos area which produces a very significant amount of

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

greenhouse gases emission and pollution that damages the environment. It appears to be an increasing interest in alternative and more sustainable electricity in Lagos state [12] and the willingness to pay for standalone photovoltaic electricity by businesses in Lagos is high [36].

The study used quantitative research design with structured questionnaire to seek information from the potential users of RSPV technology. Multi-stage sampling method was used for the study. Multi-stage sampling is common in green power uptake studies [37, 38, 39,40, 12] and is effective where there are many local government areas or municipalities that present logistic challenge [41]. At the first stage, purposive sampling technique was used to select the metropolitan area comprising a total of sixteen local government areas categorised as densely populated urban area out of the total 20 Local government areas, which is more than 50% of the local government areas in Lagos state [42]. [43] justified the choice of 50% when the study population is large in his paper on sampling a population in educational research. The second stage involved the use of proportionate sampling technique to select the potential adopter household population in each of the sixteen local government areas that make up the metropolitan area according to the population size of each local government areas. Simple random sampling technique was used to select the potential adopter households in each of the local government area at the third stage.

The study used [44] formula for sample size to calculate the appropriate sample size.

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

n = sample size

N = population size

e = level of precision (probability error)

A total number of 400 questionnaires were administered to the respondents. Three hundred and fifty-five (355) completed questionnaires were returned; three hundred and twenty-six (326) were correctly completed and found suitable for analysis giving a response rate of 88.75%.

Model for Analysis of Energy Demand II (MADE-II) was adapted for the analysis. The model which suitably uses the combination of engineering process, econometric and statistical methods for the analysis of different economic sectors was developed at the Institute for Energy Economics and Rational use of Energy, University of Stuttgart, Germany in 1989. The model works on the perception that energy is a means to an end that functions with other factors of production to produce goods and provide services to the society. MADE-II is a flexible model used to project energy demand for short- and long-term period and suitable for solar energy demand analysis in developing countries (Jesuleye et al., 2010) which made it appropriate for this study.

The model as shown in Figure 1. Operates on 7 blocks of data inflow to analyse energy demand. Block 1 treats the general information about energy levels, the base year and future time periods, Block 2works on population development information while block 3 analyse the household sector useful energy demand data. The Households, Cottage Industries and Community Services are handled in blocks 4 and 5. Block 6 deals with energy intensity while efficiencies, penetration factors and sectoral demand for Solar electricity such as lighting, Water Pumping, Powering of TV, Video, Radio, Refrigeration, Ventilation, Cooking and Personal computers are treated in block 7. For the study, block 6 (energy intensities) of the MADE-II data inflow as shown in figure 1. was adapted to analyse the energy intensity of the selected household energy services. Nine categories of household energy services were selected and the total energy demand computed in block 7 (Solar electricity demand for energy services) with the appropriate selection of the energy conversion technologies - end use appliances (Diemuodeke et al., 2017; Somefun et al., 2020;

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Jesuleye et al., 2020b). The end use appliances rates were based on the ratings of the public utility company (Ikeja Electricity Company) that service the study area.

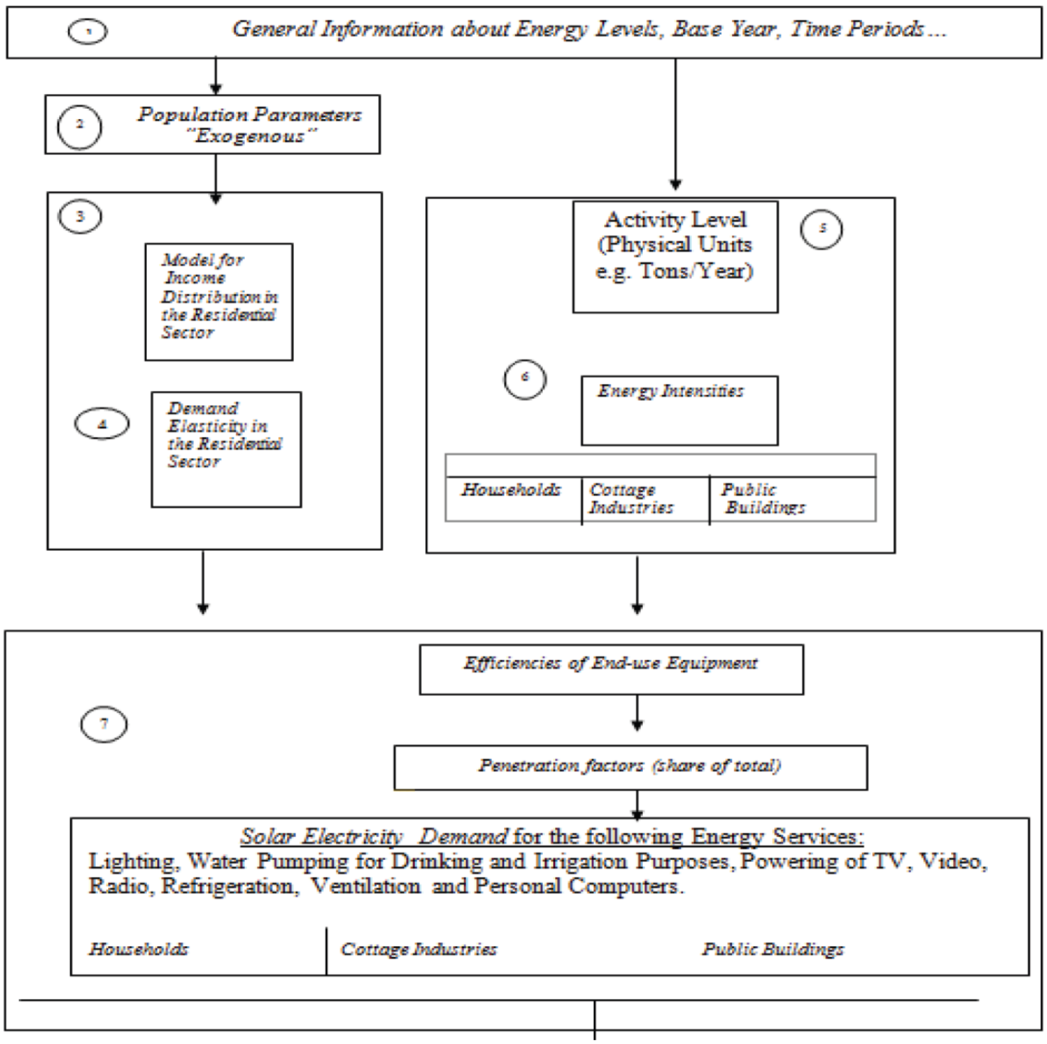


Figure 1. Adapted data flow in model for analysis of demand for energy (MADE –II) From Jesuleye (2020b)

Measurement of Variables for Household Energy Services in the study area

The energy services demand for RSPV was categorised as:

a) Electricity for refrigeration services (Freezers, Fridges)

b) Electricity for entertainment services (Television, Radio, VCD/DVD player)

c) Electricity for Computing services (Computers, Printers, Phones)

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

d) Electricity for Space cooling services (Air conditioner)

e) Electricity for ventilation services (Ceiling fans, Standing fans)

f) Electricity for lighting services (Energy saving bulbs, yellow-Incandescence) bulb.

g) Electricity for cooking services (Electric stove)

h) Electricity for process heat (Shaving kits, pressing iron, microwave oven, blender)

i) Electricity services for water pumping

The total demand for the various energy services was calculated using the data for energy demand collected from the study area with the following formula:

Total Final energy demand from energy mix

$TF_e = EI_{rf} + EI_{et} + EI_{cp} + EI_{sc} + EI_{vt} + EI_{lt} + EI_{ck} + EI_{ph} + EI_{wp}$

Where:

EI_{rf} : Energy Intensity for Refrigeration services

EI_{et} : Energy Intensity for entertainment services

EI_{cp} : Energy Intensity for Computing services

EI_{sc}: Energy Intensity for Space cooling services

EI_{vt} : Energy Intensity for ventilation services

EI_{lt} : Energy Intensity for lighting services

EI_{ck} : Energy Intensity for cooking services

EI_{ph} : Energy Intensity for process heating services

EI_{wp} : Energy Intensity for water pumping services

Variables for Energy Intensity Calculation

Variables used for the calculations include various conversion technologies (end-use appliances) power ratings in watts (technical efficiency), stock and duration of use of the conversion technologies (Household appliances). Essentially energy intensities for the various services were calculated to determine their energy demand with the following equation adapted from Jesuleye et al. (2020b).Energy Intensity ($EI_{j,t}$)= $\frac{(HDSES_{jt})\ Energy\ Input\ (Wp)}{(AL_{jt})populationShare(million)}$

Where,

$HDES_{j,t} = AL_{j,t} * EI_{j,t}$

And,

$EI_{j,t}$: Per Household's Energy Intensity (EI) for Energy Service j (e.g. Lighting) in time period t.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

$HDES_{j,t}$: Per Household's Demand D for Energy Service j (e.g. Lighting) in time period t.

Wp: Watt

$AL_{j,t}$**:** Per Household's Activity Level (AL) (Population Share) for Energy Service j (e.g. Lighting)in time period t.

4.0 Results and Discussion

Sociodemographic Characteristics of the Respondents

Table 1. revealed that more than half (58%) of the respondents were male, large percentage (41%) were between age range 31- 40 years, more than two third (68%) were married with about two third (64%) educated to undergraduate level which indicate that the respondents were mature, educated, knowledgeable to understand and interpret the questionnaire and could take decision concerning their households in response to the questionnaire.

Regarding the dwellings, largest percentage (28%) of the households had four (4) members, more than half (54%) own their homes while the largest (27%) live in three (3) bedrooms homes and more than half (56%) dwell in flats (Apartments) and majority (93%) of the homes were connected to the national grid showing that the respondents were households with suitable dwelling place for the study.

The largest percentage (39%) of the household earn within the band of one (1) and three (3) million-naira income per year and the largest percentage (41%) pay between five thousand and ten thousand naira (N5,000 - N10,000) as monthly electricity bill suggesting that the respondents have sources of income and are presently paying for their electricity consumption.

The result shows that (37%) and (39%) of the respondents earn below one million naira (N1,000,000) and between one million and three million naira (N1,000,000 – N3,000,000) respectively annually, with 31% and 41% of the respondents paying below five thousand naira (N5000) and between five thousand and ten thousand naira (N5,000 – N10,000) monthly bills respectively for the poor quality electricity supply from the national grid. The result further revealed that almost all the respondents' dwellings (93%) are connected to the national grid and prospectively intend to shift to the alternative standalone RSPV system for consistent good quality (uninterrupted supply) and quantity (sufficient supply all the time) electricity supply suggesting that consistent good quality electricity supply is indispensable to their daily household activities and one can deduce that the respondents seems to be ready to pay for the services.

Table 1. Sociodemographic Characteristics of the Respondents

Parameters	Classification	F (%
Gender	Male	190 (58)
	Female	136 (42)
Total		**326 (100)**
Age	21-30yrs	71 (22)
	31-40yrs	135 (41)
	41-50yrs	66 (20)
	Above 50yrs	54 (17)
Total		**326 (100)**
Marital Status	single	73 (22)

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

	married	223 (68)
	Divorced	19 (6)
	Widowed	11 (3)
Total		**326 (100)**
Education	Primary	4 (1)
	Secondary	24 (7)
	Undergraduate	209 (64)
	Postgraduate	89 (27)
Total		**326 (100)**
How many people, including yourself live in your home?	2	32 (10)
	3	53 (16)
	4	91 (28)
	5	74 (23)
	6 and above	76 (23)
Total		**326 (100)**
Do you own your home?	yes	151 (46)
	No	175 (54)
Total		**326 (100)**
How many bedrooms are there in your home?	1	32 (10)
	2	70 (21)
	3	119 (37)
	4	62 (19)
	5	29 (9)
	6 and above	14 (4)
Total		**326 (100)**
Which of these best describes your type of dwelling?	Duplex	40 (12)
	Bungalow	57 (17)
	Detached house	14 (4)
	Semi-detached	8 (2)
	Terraced house	5 (2)
	Flat (Apartments)	184 (56)
	Tenement(face to face)	18 (6)
Total		**326 (100)**
Is your dwelling connected to national grid?	Yes	303 (93)
	No	23 (7)
Total		**326 (100)**
Which of the following bands best represent your approximate total household income per year (N)?	Less than 1m	122 (37)
	1m - 3m	123 (39)
	3m - 5m	51 (16)
	5m - 10m	24 (7)

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

	10m - 20m	5 (2)
	Over 20m	1 (0)
Total		**326 (100)**
What is your average monthly electricity bill (N)?	Below 5,000	102 (31)
	5000 – 10,000	135 (41)
	10000 – 15,000	29 (9)
	15000 - 20000	24 (7)
	Above 20000	36 (11)
Total		**326 (100)**

Table 2. shows the household energy intensity for nine categories of household energy services namely refrigeration services, entertainment services, computing services, space cooling services, ventilation services, lighting services, cooking services, process heating services, and water pumping services demanding RSPV technology generation electricity by potential adopters in the study area. The table indicates that Refrigeration services, has a total appliance wattage of 280watts, total average number of end use appliances in use per household/day is 1.1 and average appliance usage hours per household per day is 8.9 while the energy intensity is 1.06kWh/hh/day.

The entertainment services have a total appliance wattage of 190watts, total average numbers of appliances in use/household/day of 2.1, total average appliance usage of 10.7 Hours/Household/Day and energy intensity of 0.84kWh/hh/day. The Computing services have a total appliance wattage of 665 watts, 23.3 as average numbers of appliances in use/household/day, 38.8 Hours/Household/day average appliance usage with a total of 0.97kWh/hh/day as the energy intensity. The appliance wattage for space cooling services is 1492 watts, number of appliances in use/household/day is 0.6, Hours/Household/day average appliance usage is 2.9 with 7.59 as the energy intensity. Ventilation services have a total of 155 watts as end use appliance wattage, 2.6 as number of appliance in use/household/day, 9.5 Hours/Household/Day as average appliance usage and energy intensity of 1.46kWh/hh/day. The Lighting services have a total average end use appliance wattage of 75 watts, 5.5 as average numbers of appliances in use/household/day, 9.5 Hours/Household/day average appliance usage with a total of 1.42kWh/hh/day as the energy intensity.

The table further reveals that for cooking services, electric stoves have wattage of 2500 Watts, the average number of the appliance per household is 0.5 while the average appliance usage hours per household per day is 1.7 and the appliance energy usage is 2.77kWh/hh/day in the study area. For process heating services, the total average end use appliance wattage is4670 watts, 2.7is average numbers of appliances in use/household/day, 6.6 Hours/Household/day is average appliance usage with a total of 6.43kWh/hh/day as the energy intensity. For water pumping services, Water pump wattage is 1119 watts, average number of appliance in use/household/day is 0.5, average appliance usage is 1.7 Hours/Household/day, and the energy intensity is 1.89kWh/hh/day.

Furthermore, the result indicates that the numbers of energy consuming appliances namely, washing machine (2,100w), electric stove (2,500w), water pump (1,119w) and Air-conditioner (1492w) are relatively few compared to other appliances with lower wattages. It can be deduced that the respondents are conscious of the quantity of the energy to be consumed by these appliances therefore intend not to use higher energy consuming appliances and seems to seek alternative means as the services of these household appliances are essential.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Table 2 **Household Energy Intensity for RSPV Technology**

Energy Services	End use Appliances	End use Appliance wattage	Average no. of end use Appliances in use/Household/day	Average Appliance usage Hours/ Household/Day	Total end use appliance energy usage (kWh/hh/day)
Refrigeration services	Refrigerators	100	0.6	4.6	0.46
	Freezers	180	0.4	4.3	0.60
Total		**280**	**1.1**	**8.9**	**1.06**
Entertainment services	Flat screen TV	100	0.9	5.2	0.64
	Radio	70	0.6	2.7	0.15
	VCD/DVD player	20	0.6	2.8	0.05
Total		**190**	**2.1**	**10.7**	**0.84**
Computing services	charging of Phone	5	2.5	5.7	0.38
	Computer	60	0.7	2.4	0.17
	Printer	600	0.2	0.7	0.42
Total		**665**	**3.3**	**8.8**	**0.97**
Space Cooling services	Air conditioner	1492	0.6	2.9	7.59
Total		**1492**	**0.6**	**2.9**	**7.59**
Ventilation Services	Ceiling fan	85	1.6	5.0	0.98
	Standing fan	70	1.0	4.5	0.48
Total		**155**	**2.6**	**9.5**	**1.46**
Lighting services	Incandescent bulbs	60	1.7	3.5	0.92
	Energy saving bulbs	15	3.8	5.9	0.50
Total		**75**	**5.5**	**9.5**	**1.42**
Cooking services	Electric stove	2500	0.5	1.7	2.77
Total		**2500**	**0.5**	**1.7**	**2.77**
Process heating services	Shaving kits	20	0.5	1.1	0.02
	Pressing iron	1200	0.8	1.5	1.63
	Microwave oven	900	0.4	0.9	0.80
	Blender	450	0.6	1.6	0.60
	Washing machine	2100	0.5	1.6	3.38
Total		**4670**	**2.7**	**6.6**	**6.43**

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Water pumping services	Water pump	1119	0.5	1.7	1.89
Total		**1119**	**0.5**	**1.7**	**1.89**

Table 3. revealed that the total household energy services electricity demand for RSPV technology by the potential adopters is 24.43 kWh/day. Consistent with the report of [45] that cooling services consumes the bulk of household energy demand in hotter climates, the result indicates that space cooling services have the highest energy intensity, 7.59kWh/hh/day (31.1%) as shown in figure 2.

Table 3. Household Energy Services Electricity Demand for RSPV Technology

Energy Services	**Household Energy Intensity (kWh/hh/day)**	**(%)**
Refrigeration services	1.06	4.3
Entertainment services	0.84	3.4
Computing services	0.97	4.0
Space Cooling services	7.59	31.1
Ventilation services	1.46	6.0
Lighting services	1.42	5.8
Cooking services	2.77	11.3
Process heating services	6.43	26.3
Water pumping services	1.89	7.7
Total	**24.43**	**100.0**

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

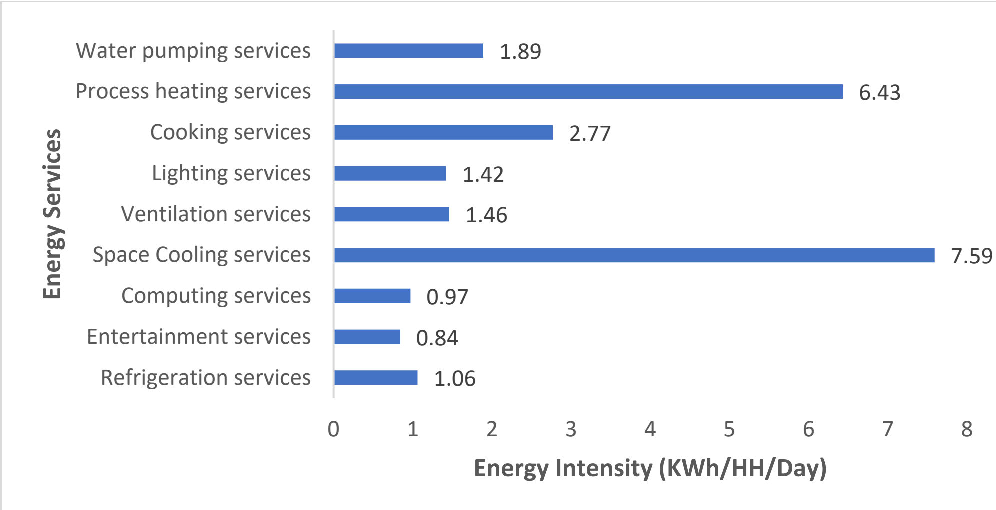


Figure 2 Household energy intensity for RSVP Technology

The total electricity demand from the solar modules is calculated thus:

The total household electricity demand from the PV modules = Total household electricity demand x 1.3

The total household electricity demand from the PV modules = 24.43 x 1.3 = 31.59kWh/day

And the total PV panel capacity per household is:

$$\text{Total wattage of PV panel capacity required} = \frac{\text{Total household electricity demand from the PV modules}}{\text{Panel Generation Factor for Nigeria}}$$

$$= \frac{31.59\text{kWh/day}}{3.41} = 9.2639 \text{ kW}$$

***Note**: 1.3 is the multiplying factor to cater for the energy lost from the solar modules and Panel generator factor (PGF), 3.41 for Nigeria is the varying factor used to calculate the size of the solar PV cells (modules) which depend upon the global geographic location, specifically the climate of the solar PV system, site location. [46,47]*

This aligns with the findings of [42] who simulate the size of PV system in three local government areas in the metropolitan area of Lagos state. The base case scenario in their study indicates that the PV panel capacity ranges from 0.3 to 76 kW for different building types in the study area.
In addition, the rooftop area needed for the capacity required is calculated as follows:

PV power rating per module = 400 W

The number of solar panels required for the capacity required = 9.2639 kW/400 W

= 23.16 ≈ 24 panels

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

The rooftop area needed for the capacity required = number of solar panels x area of one solar panel.

= 24 x 2.32 =55.68 m^2

The study of [48] and [42] in the Southwest geopolitical zone of Nigeriaindicated that the rooftop area of typical buildings is: Tenement(Face-me-I-face-you) -156.78 m^2;traditional court - 282.24 m^2; flat apartment - 280.72 m^2; single family bungalow - 332.12 m^2 and duplex - 218.3 m^2.The result indicates that the required solar panel sizes can be accommodated by the rooftop areas of buildings in south west Nigeria according to literature.For dwellings such as flat (apartments) and Tenement(Face-me-I-face-you)occupied by 56% and 6% of the respondents respectively which are multi-occupancy in nature, there may be roof space limitation to accommodate the solar module panels for all the occupant households. Hence the energy intensities can be improved in order to reduce the capacity and the number of PV panels per household in order to accommodate all the occupant households while simultaneously maintaining or increasing the output level of the energy services [42].

The Pareto analysis in figure 3. shows that the energy intensities for space cooling services (31.1%), process heating services (26.3%) and cooking services (11.3%) constitute more than two third (68.7%) of the total household energy demand suggesting the potential for improvement and concentration of improvement efforts and resources on the energy intensities of these services in descending order.

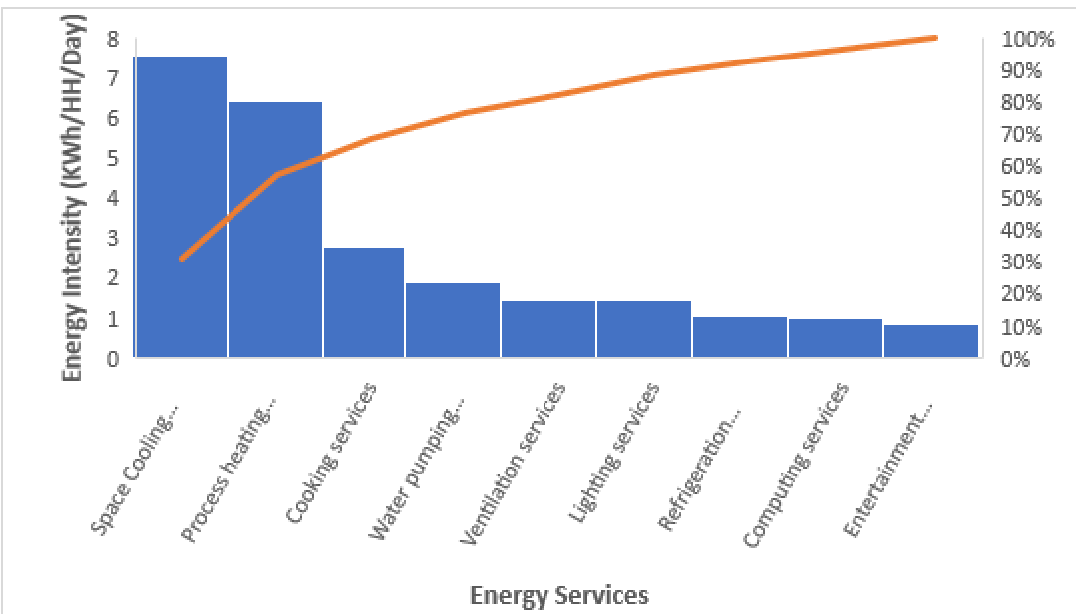


Figure 3. Pareto Analysis of Household Energy Intensity for RSPV Technology

Figure 4. shows the analysis of the household energy conversion technologies (Household appliances) with air conditioner in the space cooling services having the highest energy consumption value of 7.59 kWh/hh/day and shaving kits having the lowest energy consumption value of 0.02 kWh/hh/day. The Pareto analysis in Figure 5. indicates that the most important few energy conversion technologies (household appliances) that needs urgent improvement attention are four items namely, air conditioner (7.59kWh/hh/day) in space cooling services, washing

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

machine (3.38kWh/hh/day) in process heating services, electric stove(2.77kWh/hh/day) in cooking services and water pump (1.89kWh/hh/day) in water pumping services demanding 15.63kWh/hh/day out of the twenty appliances that demands a total of 24.43kWh/hh/day from RSPV.

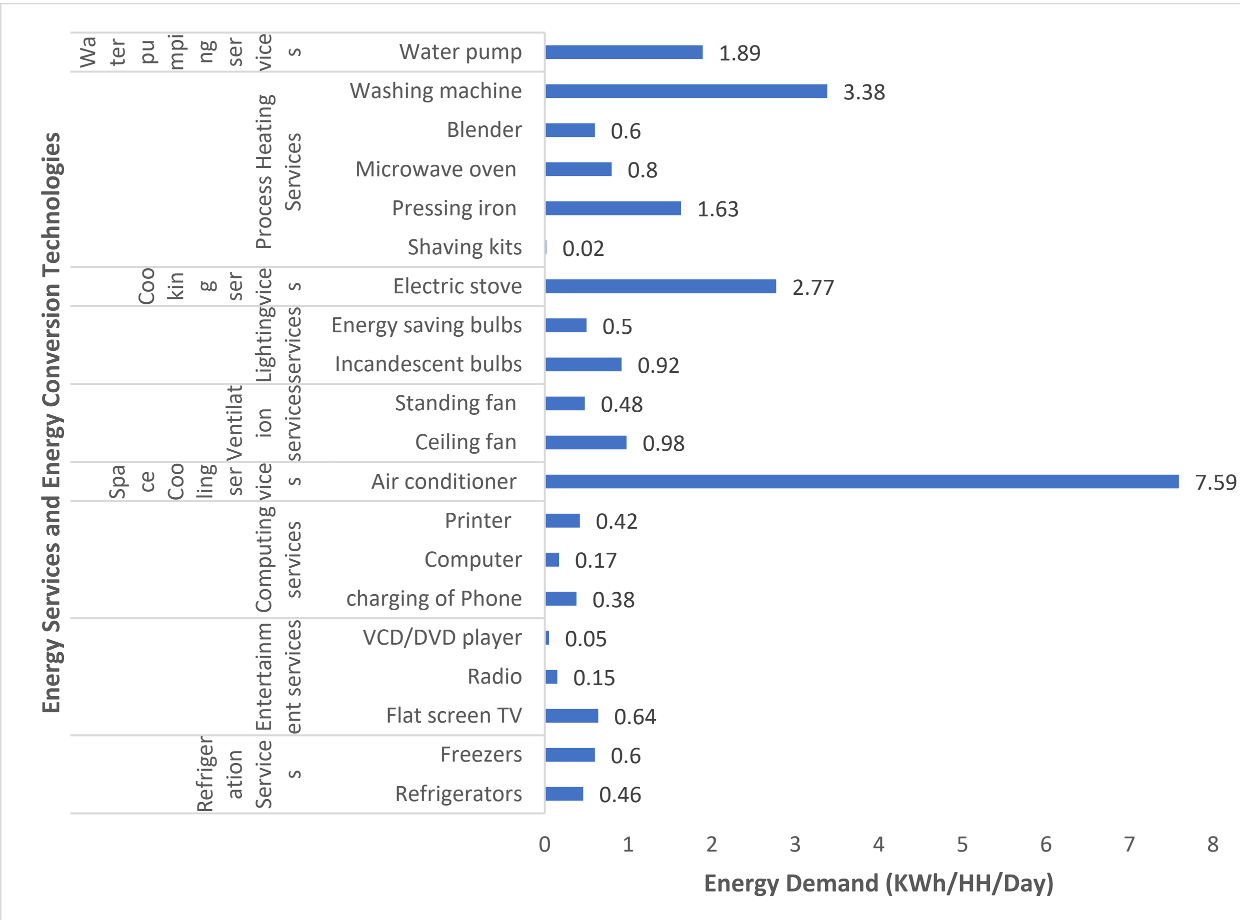


Figure 4. Household Energy Conversion Technologies Electricity Demand

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

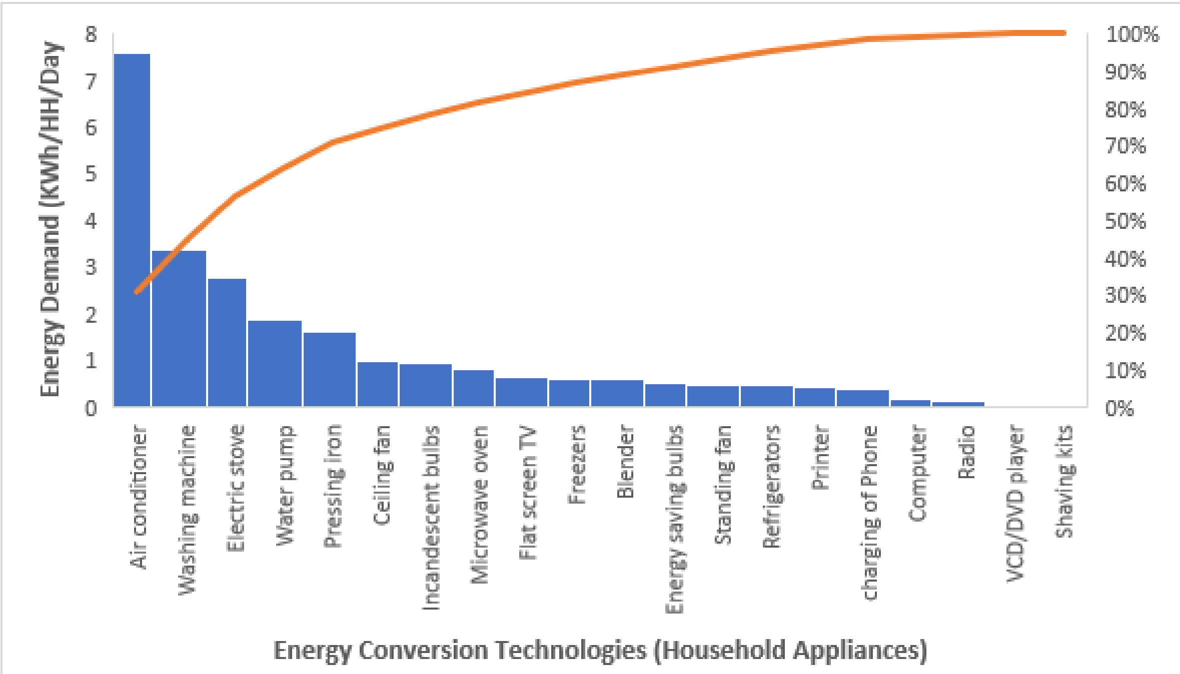


Figure 5 Pareto Analysis of Electricity Demand of Energy Conversion Technologies

The implication is that replacing these conversion technologies (Air conditioner, washing machine, electric stove and water pump) in descending order with higher energy efficient conversion technologies will significantly reduce the energy intensity of the energy services (electric load), the capacity and numbers of the PV panels while the system delivers the same or increase output level of energy services.

5.0 Conclusion and Recommendations

The study evaluates the prospective energy services demand for RSPV technology generated electricity by potential household RSPV adopters to effectively plan the deployment of RSPV technology in Lagos state, Nigeria plagued with endemic epileptic supply of grid electricity. The study provided information on the proposed electricity consumption by household appliances for energy services and concludes that each household demands 24.43kWh/hh/day of electricity to meet their energy services with the total demand of 31.59kWh/hh/day from the solar module panel. However, the result shows that the respondents seems to be conscious of the energy consumption and carefully select household appliances based on the energy requirements of the appliances suggesting that the daily energy demand should be planned, monitored and controlled to minimize the demand.The study recommend that the energy intensity for the energy services could be improved by increasing the efficiency and effectively monitor the performance of the household appliances vis-a-viz the operation and performance of the stand-alone RSPV system to minimise the energy demand and optimize the energy services output. The study further recommends government intervention with dedicated policy to guide adoption of high efficiency standard for household appliances and appropriate financial schemes to support replacement of inefficient household appliances with highly efficient ones.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Further study could investigate the integration and interaction of the household appliances with the stand alone RSPV system to measure and track the real time household energy consumption, schedule and balance the operation time of the appliances, identify and isolate high energy consuming appliances to minimise the energy consumption and optimise the performance of both the supply and demand system The study could be conducted in other regions of Nigeria for comparism and to have a national understanding of energy services demand for electricity from RSPV technology. Additionally, economic feasibility and behavioural acceptability of RSPV technology could be investigated for effective planning of the energy system transformation.

References

[1] F. Arroyo, L. Miguel, the trends of the energy intensity and CO_2 emissions related to final energy consumption in Ecuador: Scenarios of national and worldwide strategies, Sustainability, December (2019) DOI: 10.3390/su12010020.

[2] REN21 Renewables 2023 global Status report collection, global overview (Paris: REN21 Secretariat) (2023) ISBN 978-3-948393-11-3

[3] E. Amoako, J. T. Wilson, Environmental behavior factors influencing the outlook of Chinese college students on the domestic adoption of solar photovoltaic technology, Undergraduate Review 13 (2017) 7-30. Available at: http://vc.bridgew.edu

[4] O. A. Jesuleye, A. O. Adepoju, O. F. Arigbede, Status of solar PV utilization for energy services in the Nigerian housing estate, International Journal of Engineering, Applied Sciences and Technology 4(10) (2020) 386-394

[5] S. Ahmad, R. Tahar, M. Bin, J. K. Cheng, & L. Yao, Public acceptance of residential solar photovoltaic technology in Malaysia, Environment Behaviour. 34 (2017) 740–756

[6] O. A. Jesuleye, O. F. Arigbede, A. O. Adepoju, Factors influencing solar photovoltaic utilization for energy services among residential in Akure, Nigeria Journal of Energy Research and Reviews 4(3) (2020) 14-28. /undergrad_rev/vol13/iss1/5

[7] A. Adepoju, O. Jesuleye, O. Arigbede, Solar photovoltaics contribution to energy mix in selected Nigerian estates, Archives of Business Research 8(3) (2020) 131-164

[8] O. Olabisi, Forecasting Nigeria's electricity demand and energy efficiency potential under climate uncertainty. PhD dissertation, University of Tennessee. (2021) https://trace.tennessee.edu/utk_graddiss/7012

[9] A. Adepoju, K. J. Ekundayo, A. K. Oladiipo, Household energy conservation behaviour: A Socio-economic perspective, Journal of Digital Food Energy & Water Systems 4(1) (2023) 1-24, ISSN 2709-4529

[10] E. O. Diemuodeke, A. Addo, I. Dabipi-Kalio, C. O. C. Oko, Y. Mulugetta, Domestic energy demand assessment of coastline rural communities with solar electrification, Energy and Policy Research, 4:1(2017) 1-9, DOI: 10.1080/23815639.2017.1280431

[11] K. Muchiri, J. N. Kamau, D. W. Wekesa, C. O. Saoke, J. N. Mutuku, J. K. Gathua, Energy demand and its implication on wind/pv system sizing in Machakos, Kenya. International Journal of Sustainable and Green Energy. 10(3) (2021) 92-98. doi: 10.11648/j.ijrse.20211003.12

[12] A. I. Ugulu, C. Aigbavboa, Assessing Urban Households' Willingness to Pay for Standalone Solar Photovoltaic Systems: A Case Study of Lagos, Nigeria, Journal of sustainable development Energy Water Environmental System, 7(3) (2019) 553-56.

[13] K. Olaniyan, B. C McLellan, S. Ogata, T. Tezuka, Estimating residential electricity consumption in Nigeria to support energy transitions, Sustainability 10, (2018)1440 doi:10.3390 /su10051440

[14] C. L. Azimoh, P. Klintenberg, C. Mbohwa, F. Wallin, Replicability and scalability of mini-grid solution to rural electrification programs in sub-Saharan Africa, Renew. Energy, (June 2017) 222e231, https://doi.org/10.1016/j.

[15] O. A. Jesuleye, Solar PV demand for lighting in nigerian remote villages International Journal of Management and Applied Science 3 (2017) 10ISSN: 2394-7926

[17] A. J. Njoh, S. Etta, I. B. Ngyah-Etchutambe, L.E.D. Enomah, H. T. Tabrey, U. Essia, Opportunities and challenges to rural renewable energy projects in Africa: Lessons from the Esaghem Village, Cameroon solar electrification project, Renew. Energy 131 (Feb 2019) 1013e1021, https://doi.org/10.1016/ j.renene.

[18] B. K. Sovacool, Conceptualising urban household energy use: climbing the "Energy Services Ladder", Energy Policy 39 (2011).1659–1668.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

[19] J. Cravioto, E. Yamasue, H. Okumura, K. N. Ishihara, Energy service satisfaction in two Mexican communities: a study on demographic, household, equipment and energy related predictors, Energy Policy 73 (2014) 110–126, https://doi.org/10. 016/j.enpol.

[20] G. Kalt, D. Wiedenhofer, C. Görg, H. Haberl, Conceptualizing energy services: A review of energy and well-being along the Energy Service Cascade. Energy Research & Social Science 53 (2019) 47-58. 10.1016/j.erss

[21] M. A. Pedrasa, T. Spooner, I. MacGill, An energy service decision-support tool for optimal energy services acquisition Centre for Energy and Environmental Markets University of New South wales (2010).

[22] M. J. Fell, Energy services: a conceptual review. Energy Research and Social. Science. 27 (2017) 129–140 https://doi.org/10.1016/j.erss.

[23] L. C. Hunt, D. L. Ryan, Economic modelling of energy services: Rectifying mis specified energy demand functions, surrey energy Economics Centre, University of Surrey, Guildford, UK (2014) Available at http://www.seec.surrey.ac.uk/research/SEEDS/SEEDS147.pdf

[24] M. G. Oladokun I. A. Odesola, Household energy consumption and carbon emissions for sustainable cities – A critical review of modelling approaches, International Journal of Sustainable Built Environment 4 (2015) 231–247

[25] M. Hart, R. de Dear, Weather sensitivity in household appliance energy end-use. Energy Build. 36 (2004)161–174.

[26] Ruffell, An econometric analysis of the household demand for electricity in Great Britain by R.J., Ruffell. Scottish Academic Press (1977).

[27] I. Ajzen, The theory of planned behaviour. Organ. Behav. Human Decis. Processes 50 (2) (1991) 179–211.

[28] J. Keirstead, Evaluating the applicability of integrated domestic energy consumption frameworks in the UK. Energy Policy 34 (17) (2006)3065–3077.

[29] S. Natarajan, J. Padget, L. Elliott, Modelling UK domestic energy and carbon emissions: an agent-based approach. Energy Build. 43 (2011) 2602–2612.

[30] L. Lutzenhiser, A cultural model of household energy consumption. Energy 17 (1) (1992) 47–60.

[31] G. Hitchcock, An integrated framework for energy use and behaviour in the domestic sector. Energy Build. 20 (1993) 151–157.

[32] M. Kavgic, A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, M. Djurovic-Petrovic, A review of bottom-up building stock models for energy consumption in the residential sector. Build. Environ. 45 (2010) 1683–1697.

[33] S. Kelly, Do homes that are more energy efficient consume less energy? a structural equation model for England's residential sector, EPRG Working Paper, Electricity Policy Research Group, University of Cambridge (2011).

[34] Lagos state government official website, www.lagosstate.gov.ng/aboutlagos, Accessed 14/07/2023.

[35] Lagos State Government, Lagos state electricity policy (2021).

[36] Y. O. Akinwale, A. O. Adepoju, Factors influencing willingness to adopt renewable energy technologies among micro and small enterprises in Lagos State Nigeria. International Journal of Sustainable Energy Planning and Management 19 (2019) 69–82

[37] N. Nomura, M. Akai, Willingness to pay for green electricity in Japan as estimated through contingent valuation method, Applied Energy 78(4) (2004) 453-463.

[38] S. Komatsu, S. Kaneko, P. Ghosh, A. Morinaga, Determinants of user satisfaction with solar home systems in rural Bangladesh, Energy 61 (2013) 52-58.

[39] X. Guo, H. Liu, X. Mao, J. Jin, D. Chen, S. Cheng, Willingness to pay for renewable electricity: A contingent valuation study in Beijing, China, Energy Policy, 68 (2014) 340-347.

[40] T. Arega, T. Tadesse, Household willingness to pay for green electricity inassessment and evaluation in higher education 33 (2017) 301–14.

[41] S. Abdullah, P. Mariel, Choice experiment study on the willingness to pay to improve electricity services, Energy Policy 38(8) (2010) 4570-4581.

[42] K. E. Enongene, F. H. Abanda, I. J. J. Otene, S. I. Obi, C. Okafor, The potential of solar photovoltaic systems for residential homes in Lagos city of Nigeria. Journal of environmental management, 244 (2019) 247–256. ttps://doi.org/10.1016/j.jenvman.2019.04. 039

[43] R. Jacobs, Sampling a population in educational research. Villanova University: Department of Public Administration (2016).

[44] T. Yamane, Statistics: An Introductory analysis, 2nd Edition, New York: Harper and Row (1967).

[45] IEA, Market report series: Energy Efficiency (2018) – Analysis [WWW Document]. URL. IEA, 1.4.21. https://www.iea.org/reports/energy-efficiency-2018.

[46] A. A. Adewale, A. I. Adekitan, O. J. Idoko, F. I. Agbetuyi, I. A. Samuel, Energy audit and optimal power supply for a commercial building in Nigeria, Cogent Engineering, 5:1 (2018) 1546658.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

[47] T. Somefun, C. Awosope, A. Abdulkareem, J. Ojo, E. Amuta, T. Sanni, Cost implications analysis of grid supplied electricity and solar source of electricity in Nigeria, TELKOMNIKA Telecommunication, Computing, Electronics and Control 18(6) (2020) 3258~3265 .DOI: 10.12928/.v18i6.13558

[48] A. O. Eruola, G. C. Ufoegbune, A. O. Eruola, J. A. Awomeso, C. O. Adeofun, O. A. Idowu, A. Sowunmi, Qualitative and quantitative assessment of rainwater harvesting from rooftop catchments: case study of oke-lantoro community in Abeokuta, Southwest Nigeria Journal of Agricultural Science and Environment 10(2) (2010).

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

Integrating Human-Computer Interactions in Nigerian Energy System: A Skills Requirement Analysis

Omoseni Oyindamola ADEPOJU
Department of Management and Accounting, School of Social Sciences and Management, Lead City, University Ibadan, Nigeria. adepoju.omoseni@lcu.edu.ng
Oluwarotimi Edmund AKINYOMI
Centre for Cyber-Physical Food Water and Energy Systems, Faculty of Engineering and Built Environment University of Johannesburg, Auckland Park, Johannesburg, South Africa; edmundrotimi@gmail.com
Oluwadamilola Abidemi ESAN
Centre for Cyber-Physical Food Water and Energy Systems, Faculty of Engineering and Built Environment University of Johannesburg, Auckland Park, Johannesburg, South Africa; esanoluwadamilola2@gmail.com

Received: 18 December 2023

Review: 21 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: The energy sector constitutes an important contributor to the growth and development of the Nigerian economy. Despite Nigeria's abundant energy resources, the sector faces multiple challenges, such as infrastructural deficits, policy inconsistencies, regulatory uncertainties, and overreliance on non-renewable energy sources. Industry 4.0 technologies and Human-Computer Interaction (HCI) present opportunities that address the challenges of the energy sector in Nigeria. This research explores the impact of HCI in the adoption of technologies of 4IR (Artificial Intelligence, the Internet of Things, Big Data, and Cloud Computing), in Nigeria's energy sector. The research assesses the current level of implementation of Industry 4.0, requirements for the implementation of Industry 4.0 technology, demand, and skills for HCI in the implementation of 4IR technology in Nigeria's energy generation sub-sector. This study adopted a comprehensive and critical systematic review of existing literature on the subject matter. The findings reveal the level of 4IR implementation in its infancy, with some energy companies and start-ups beginning to integrate digital technologies to enhance their operations and services. The study further revealed the potential of HCI in facilitating the integration and social acceptance of 4IR technologies and identified significant skills demand for HCI, such as digital literacy, data analysis, critical thinking, problem-solving, and system thinking to facilitate the adoption of 4IR. The research concludes that the development of HCI skills in the adoption of 4IR presents a great opportunity to transform the energy sector in Nigeria. The research recommends policy formulation, to embrace Industry 4.0 and multifaceted process development of HCI skills for the application of 4IR in the energy sector.

Keywords: *Human-Computer Interaction, Fourth Industrial Revolution, Energy System, Skills Requirements*

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

1.0 Introduction

The economic fabric of Nigeria is strongly interwoven with its energy generation subsector, particularly oil and gas, which play a crucial role in propelling the country's gross domestic product (GDP). The energy subsector does not significantly influence the nation's economic landscape alone, but also fuels the operations of other industries, thereby paving the way for direct and indirect employment opportunities. Given Nigeria's wealth of resources ranging from oil, gas, and coal, to hydroelectric power and an increasing focus on renewables such as solar and wind, the energy generation sub-sector holds significant potential to support the country's economy further. The energy generation landscape in Nigeria is dotted with numerous players, which include state-owned corporations and private entities. In terms of energy generation within Nigeria, key organizations include entities like Egbin Power Plc and Kanji Hydroelectric Plc which are privately and state-owned organizations respectively. These companies contribute significantly to Nigeria's energy landscape, focusing on hydroelectric power generation to fuel the national grid. Additional key contributors to the energy generation sector would be solar energy companies such as Solar Century and Energy- a privately owned company, which is pioneering the use of solar energy to supplement the national grid and provide off-grid solutions [1]. These companies and their respective energy generation methods represent crucial subsystems of Nigeria's energy system.

However, while this sector is ripe with potential, it is equally beset with many challenges. Among these challenges are infrastructural deficits. Nigeria's energy infrastructure remains significantly underdeveloped, restricting its capacity to produce and distribute energy effectively. Existing facilities are obsolete and in dire need of modernization, while the growth of new infrastructure is stunted by limited investments and inefficient planning [2]. This infrastructural decay manifests itself in recurrent power outages and inadequate electricity supply that stifles economic activities, leaving a significant proportion of the population without reliable access to electricity. These challenges significantly undermine the sector's growth trajectory and its capacity to utilize the nation's abundant energy resources optimally.

The previous industrial revolutions have resulted in the initiation and development of the consumption of energy sources, such as oil, natural gas, coal, and nuclear energy, and recognized an energy consumption pattern subjugated by fossil fuels. Nigeria's energy infrastructure, especially the power transmission system, need to be updated and efficiently handle the generated energy, leading to substantial energy losses. Additionally, the prevalence of regulatory uncertainties and issues of corruption deters potential investment, thereby restricting the sector's growth [3]. However, the advent of Industry 4.0 provides a glimmer of hope to mitigating these challenges and propelling the energy sector toward efficiency and growth. This latest industrial revolution, also known as the Fourth Industrial Revolution (4IR), is characterized by a strategic integration of traditional manufacturing with digital technology, creating a new paradigm in industrial development [4]. The bedrock of Industry 4.0 lies in advances such as artificial intelligence (AI), the Internet of Things (IoT), robotics, and advanced human-computer interaction (HCI).

Human-Computer Interaction, a burgeoning interdisciplinary field, emphasizes the interaction between users (humans) and computers, focusing on the design and use of computer technology. As digital transformation sweeps across various industries under the umbrella of Industry 4.0, HCI gains prominence. It enables the seamless integration between human and digital systems, thus facilitating productivity and efficiency. The existing literature indicates a positive correlation between the advent of Industry 4.0 and energy generation. Technological breakthroughs integral to Industry 4.0, such as IoT, AI, and big data analytics, can improve efficiency, productivity, and sustainability within the energy sector [5]. For example, implementing smart grids and predictive maintenance enabled by AI and IoT can drastically improve the reliability and efficiency of power generation.

Research focusing on the nexus between Industry 4.0 and energy generation within the Nigerian context appears to be scarce and nascent. There needs to be more in-depth investigations assessing the level of implementation of Industry 4.0 technology in Nigeria's energy sector and the role of HCI in the integration of 4IR technologies. This

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

research gap underscores the need for this study, with the aim of assessing the level of implementation of Industry 4.0 technology in the energy generation sector in Nigeria, with a specific focus on the role of HCI in the integration process. This research will perform a comprehensive assessment of the skill requisites for HCI within the domain of energy generation [6]. This, in turn, could set the stage for the evolution of a technology-centric energy sector in Nigeria.

The role of Human-Computer Interaction (HCI) becomes pivotal. HCI provides the means through which humans and computers can interact seamlessly, enabling better control and optimization of energy systems. At the heart of Industry 4.0 in the energy sector lies the concept of smart grids. Smart grids, powered by IoT and big data analytics, can potentially improve the efficiency and reliability of power generation. They provide real-time data on consumption patterns, enabling energy companies to adjust their operations according to demand, thus optimizing energy use and reducing waste [7]. Furthermore, predictive maintenance, another critical aspect of Industry 4.0, can significantly improve the lifespan and efficiency of energy infrastructure [7]. Through AI and machine learning, predictive maintenance systems can predict potential failures in the system, allowing proactive measures to be taken before a complete breakdown occurs.

Despite the promising prospects of Industry 4.0 in the energy sector, its implementation in Nigeria's energy generation sub-sector has yet to be fully explored. There is a pressing need to investigate the current implementation of Industry 4.0 technology within Nigeria's energy sector and to identify the barriers that may be hindering its full adoption. Moreover, the role of HCI in the context of Industry 4.0 in Nigeria's energy sector deserves attention. The interaction between humans and computers is a crucial aspect of implementing Industry 4.0 technologies. As such, it is necessary to determine the level of HCI in the implementation of these technologies in the energy generation sector [8]. This assessment will provide information on the current state of HCI in Nigeria's energy sector. It will offer clues on the necessary steps that need to be taken to improve HCI and fully realize the potential of Industry 4.0.

In addition, the skill requirements for HCI in energy generation in Nigeria need to be thoroughly examined. The advent of Industry 4.0 will inevitably require new skills and competencies. The workforce must be adept at using new technologies, interpreting data, and making decisions based on the insights derived from these data. Therefore, assessing the existing skills landscape and identifying the existing skills landscape and identifying skill gaps can guide future training and education initiatives, ensuring that Nigeria has a workforce ready to take advantage of Industry 4.0 in the energy sector. Implementing Industry 4.0 in Nigeria's energy sector presents an opportunity for the country to overcome challenges plaguing the industry and improve its efficiency and sustainability. However, a comprehensive understanding of the current level of industry 4.0 technology implementation, the role of HCI, and the required skills for HCI is critical to navigate this digital transformation. This study seeks to contribute to this understanding and to provide information that can guide Nigeria's journey toward a digitally transformed energy sector. Consequently, the study aims to achieve the following objectives:

(i) Assess the level of implementation of Industry 4.0 technology in energy generation in Nigeria.
(ii) Examine the requirements for the implementation of Industry 4.0 technology in energy generation in Nigeria.
(iii) Examine the skills required for Human-Computer Interaction in energy generation in Nigeria; and
(iv) Determine the development of Human-Computer Interaction skills in the application of 4IR in energy generation.

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

2.0 Review of Literatures

2.1 The Energy Generation System and the Integration of Industry 4.0 in Nigeria

As Nigeria remains one of the most populous nations in Africa, its energy sector is crucial to driving its economic growth and development. Indeed, the energy sector in Nigeria is highly characterised by its considerable potential and the abundance of resources available. The importance and role of the energy sector cannot be overstated.

In addition, the sector needs to improve at different levels of the value chain, from production and distribution to end-user application. Operational inefficiencies in power stations, distribution losses due to outdated or poor-quality infrastructure, and inefficient consumer energy use collectively contribute to a poorly performing energy sector. Policy inconsistencies and regulatory uncertainties further complicate the situation. The energy policies in Nigeria have been described as inconsistent and ambiguous, causing uncertainty for investors and other stakeholders[9]. Regulatory challenges include the need for enforcement of existing regulations, corruption, and the absence of comprehensive and coherent energy policies and planning [9].

There is also the issue of overreliance on non-renewable energy sources. Despite Nigeria's enormous renewable energy resources, such as solar, wind, biomass, and hydropower, the energy sector remains heavily dependent on nonrenewable sources, mainly oil and gas. This overreliance is unsustainable and exposes the country to economic volatility linked to fluctuating global oil prices and environmental issues associated with fossil fuel-based energy generation [10]. Collectively, these issues hamper the realization of their full potential, leading to negative impacts on the economy, social development, and environmental sustainability.

However, the advent of the Fourth Industrial Revolution, or Industry 4.0, offers the possibility of a new era for the Nigerian energy sector. Defined by a fusion of technologies blurring the lines between the physical, digital, and biological spheres, Industry 4.0 represents a potential turning point to address issues of the Nigerian energy sector. Industry 4.0 introduces various innovative technologies, such as cyber-physical systems (CPS), the Internet of Things (IoT), artificial intelligence (AI), Big Data, Cloud Computing, and others [11]. These technologies could be instrumental in resolving numerous problems currently impeding the growth and efficiency of Nigeria's energy sector.

For example, CPS can provide enhanced control and coordination of distributed energy resources, leading to improved reliability and efficiency in energy generation and distribution. IoT can enable real-time monitoring of energy infrastructure, improving operational efficiency, and enabling predictive maintenance to reduce downtime and lower operational costs. AI can help forecast energy demand more accurately, optimize energy distribution, and enable more intelligent and efficient energy management. Big data can provide valuable insights for energy planning and policy formulation, while cloud computing can facilitate the integration and sharing of energy data, promoting transparency and efficiency in the sector. However, the transition to Industry 4.0 in Nigeria's energy sector has been considerably slow. Multiple factors have contributed to this slow pace [12]. Lack of a conducive policy environment, inadequate infrastructure, high implementation costs, lack of technical expertise, and cybersecurity concerns are some of the primary impediments.

The absence of a supportive policy environment inhibits the integration of Industry 4.0 technologies into the Nigerian energy sector. Effective policy frameworks are crucial in setting clear directions, creating incentives for innovation and investment, and establishing the necessary regulatory controls. Similarly, inadequate infrastructure, both in terms of energy and ICT infrastructure, presents a significant barrier. Implementing Industry 4.0 technologies requires a robust and reliable ICT infrastructure in many parts of Nigeria [13]. Furthermore, existing energy infrastructure may not be compatible with these new technologies, which requires substantial investments in upgrading or replacing existing infrastructure.

The high costs of implementing Industry 4.0 technologies also pose a significant challenge. These costs include the acquisition of the technology itself and the associated costs of training personnel, maintaining the technology, and upgrading the infrastructure, among others. The lack of technical expertise is another hurdle. Industry

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

4.0 technologies are complex and require a high level of expertise to implement and manage effectively [14]. However, Nigeria currently faces a skill gap in this area, with a shortage of trained professionals capable of handling these technologies.

Lastly, cybersecurity concerns cannot be ignored. The increased digitization and connectivity inherent in Industry 4.0 technologies raises the potential for cyberattacks, which could disrupt energy services and compromise sensitive data. Therefore, robust cybersecurity measures are critical to ensure the secure adoption of these technologies. Addressing these challenges to enter an era of Industry 4.0 in the Nigerian energy sector requires a holistic approach [15]. A combination of policy reform, infrastructure investment, capacity building, and public-private partnerships is needed to facilitate the transition.

Policy reform should aim to create a conducive environment for the adoption of Industry 4.0 technologies. This could involve introducing incentives for technology adoption, establishing clear regulatory frameworks for the operation of these technologies in the energy sector, and incorporating the goals of Industry 4.0 into national energy policies. Investment in infrastructure is also necessary, both in terms of upgrading the existing energy infrastructure and developing the ICT infrastructure needed to support Industry 4.0 technologies [16]. These investments could be facilitated through public-private partnerships, with the government providing the necessary policy and regulatory support, and private entities bringing in investment and technological expertise.

Capacity building initiatives are required to develop the technical expertise needed to handle Industry 4.0 technologies. This could involve collaborations with educational institutions to introduce relevant training programmes, as well as on-the-job training and reskilling initiatives within energy sector organizations. In summary, while the road to Industry 4.0 in the Nigerian energy sector is fraught with challenges, it also holds significant promise [17]. If properly harnessed, Industry 4.0 technologies could revolutionize the sector, leading to improved efficiency, cost reductions, and improved service delivery, ultimately contributing to Nigeria's economic growth and development.

2.2 Overview of Human-Computer Interaction

Human-Computer Interaction (HCI) represents a dynamic and multidisciplinary domain dedicated to understanding and optimizing the interplay between humans and computers. At its core, HCI investigates the design and use of computer technology, with a particular emphasis on the interfaces between people (users) and computers [18]. Being an intersection of several other fields of study, HCI is critical to the design of technological systems that are not only useful and usable but also offer gratifying and pleasant interaction experiences.

2.2.1 The Human Factor

The "human" facet of HCI fundamentally underscores the importance of understanding user needs, capabilities, and behaviours in the context of their interaction with computer systems. It delves into human factors such as cognition, perception, anthropometry, physiology, and various social aspects that are instrumental in molding a human's ability to interact with a computer system. Understanding human cognition, including memory, attention, and decision-making processes, is crucial, as these elements shape how humans process information and interact with technology [19]. Understanding these cognitive aspects helps to design systems that align with human mental capacities, thus improving usability and performance.

In addition, physical abilities, such as motor skills and sensory perception, also play a crucial role in HCI. For instance, a system's design should consider the user's capability to use input devices such as a mouse or keyboard and their ability to perceive output such as text or graphics. Moreover, the user's emotional state can significantly impact their interaction with a system [20]. Therefore, creating emotionally intelligent systems that can recognize and respond to a user's emotional state can enhance the overall user experience.

Furthermore, cultural contexts and socioeconomic conditions can significantly influence user needs and preferences. HCI, thus, must consider these factors to ensure that technology is accessible, inclusive, and equitable

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

across diverse user groups. User-centered design (UCD) represents a pivotal approach in HCI that emphasizes involving users throughout the design process [21]. By integrating user input at all stages of design and development, UCD ensures that the final product aligns with user expectations and abilities.

2.2.2 The Computer Factor

In HCI, the "computer" aspect relates to the technological components of the interaction, which include the hardware, software, and interfaces that facilitate the user-computer interaction. This requires a thorough understanding of computer technology, its capabilities, and its limitations. Hardware considerations include the physical elements of a computer system that a user interacts with, such as the display screen, keyboard, mouse, and touch interface [22]. These elements should be designed with usability and accessibility in mind to facilitate efficient and comfortable user interaction.

Software considerations, on the other hand, involve the capabilities of the software to perform tasks, respond to user input, and present output in a user-friendly manner. Software should be designed to align with user needs, offering a seamless, intuitive, and enjoyable user experience. Interfaces, which serve as the link between the user and the computer, are another critical aspect. They should be designed to facilitate easy and efficient interaction [23]. This includes not just the graphical user interface (GUI), but also other interaction modes such as voice interfaces, haptic interfaces, and augmented/virtual reality interfaces.

2.2.3 The Interaction Factor

The interaction in HCI encapsulates the communication and participation between the user (human) and the computer system. This involves understanding how users interact with digital system, including their input methods (like typing, touching, or speaking) and how they perceive the system output (such as text, graphics, sound, or haptic feedback). Interaction design plays an important role in HCI. It focuses on creating engaging and efficient interfaces that enable users to understand how to use a system intuitively, predict the system's response, and accomplish their tasks efficiently [24]. The interaction should not only be functional but also enjoyable, leading to user satisfaction and a positive overall user experience.

In addition, the interactions must be adaptable and flexible, catering to different user styles and preferences. This can be achieved through personalization and adaptivity features that allow the system to learn from user interactions and adjust accordingly. The role of HCI is particularly significant in the context of Industry 4.0, the digital revolution characterised by advanced technologies such as AI, IoT, cyber-physical systems, and big data [25]. The complexity and sophistication of these technologies require an equally sophisticated approach to HCI.

This involves designing interfaces and interaction models that allow users to utilize these technologies, making technology more transparent and understandable to users. It also involves integrating AI into interfaces to personalize user experiences, making interaction more natural and intuitive. Moreover, given the extensive data collection and processing capabilities of Industry 4.0 technologies, ethical considerations become paramount. HCI must consider data privacy, consent, transparency, and fairness to ensure that technology respects user rights and societal norms [26]. In conclusion, HCI plays a critical role in shaping the interaction between users and computer systems, making it an essential field of study and practice in our increasingly digital world.

3.0 Methodology

A systematic literature review will help the research methodology to explore the use of Industry 4.0 technologies in Nigeria's energy sector and the skills required for effective Human-Computer Interaction (HCI). The approach encompassed a comprehensive search strategy, screening and selection, quality assessment, data extraction, critical analysis, and synthesis. In the search phase, databases such as Google Scholar, IEEE Xplore, ScienceDirect, JSTOR, Energy Information Administration (EIA), and World Energy Council were used to identify pertinent research papers, articles, and reports. The search leveraged on keywords like 'Industry 4.0', 'energy generation', 'Nigeria',

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

'Human-Computer Interaction', and 'digital skills'. The intention is to capture an exhaustive understanding of the evolution and current state of the topic, unrestricted by time constraints.

Screening involves carefully examining titles, abstracts, and keywords of the identified materials. Those that align closely with the research objectives were selected for a full-text review. Subsequently, a quality assessment of each selected study was performed, with the criteria for evaluation encompassing the research methodology, the validity and reproducibility of the results, the sample size, and the reputation of the publication source. The next phase entails data extraction, focusing on information such as the status of Industry 4.0 implementation in Nigeria's energy sector, the role and significance of HCI, and the required skills for effective HCI. A critical analysis was performed to identify trends, patterns, and knowledge gaps. The final stage involved synthesizing data and insights into a comprehensive report that elucidates the current state of Industry 4.0 adoption in Nigeria's energy sector and the role and skills of HCI. The systematic literature review methodology was chosen due to its rigorous design and comprehensive coverage. The potential limitations, such as the availability of research on the specific context and potential bias in published studies were mitigated through rigorous quality assessment and critical analysis.

4.0 Discussion of Findings

4.1 Level of Implementation of Industry 4.0 Technology in Energy Generation in Nigeria.

The transformative potential of Industry 4.0 to revolutionise Nigeria's energy sector is significant. Characterised by the integration of digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics and cloud computing, the fourth industrial revolution stands to enhance energy generation, distribution, and consumption. Through the advent of intelligent systems capable of monitoring, analysing and controlling energy flows, we can anticipate improvements in cost savings, energy efficiency and greenhouse gas emission reduction, thus progressing towards a more sustainable energy future. However, the implementation of these technologies in Nigeria's energy sector requires a detailed examination. While Nigeria has made commendable strides in adopting digital technologies across various sectors, its energy sector trails behind. Currently, the energy infrastructure is heavily reliant on manual controls, making it prone to inefficiencies, losses, and system failures [27]. Currently, Nigeria's policy framework catering to Industry 4.0 is still in its infancy, with a dearth of specific policies and regulations guiding the integration of these technologies in the energy sector.

Despite these challenges, there are promising developments in the integration of Industry 4.0 technologies within Nigeria's energy sector. Several energy companies and start-ups are beginning to integrate digital technologies to enhance their operations and services. For example, the Nigerian Electricity Regulatory Commission (NERC) has implemented smart metering initiatives, enhanced revenue collection and improving customer service. Furthermore, international development agencies are supporting efforts to integrate Industry 4.0 technologies into Nigeria's energy sector, as exemplified by the World Bank's Nigeria Electrification Project. However, the adoption of Industry 4.0 in Nigeria's energy sector is not just about keeping up with global trends. At its core, it is about addressing perennial sectoral challenges such as unstable power supply, inadequate infrastructure, and high costs [28]. The integration of Industry 4.0 technologies can be instrumental in this regard, enabling real-time monitoring and control of energy systems, predictive maintenance of infrastructure, and efficient management of energy resources.

Addressing these risks requires robust cybersecurity measures and regulations to protect energy systems and consumer privacy. Ultimately, the integration of Industry 4.0 technologies is not an end in itself, but a means to an end - ensuring reliable, affordable, and sustainable energy for all Nigerians. In summary, the incorporation of Industry 4.0 technologies into Nigeria's energy sector is an intricate undertaking, brimming with potential but fraught with challenges. Currently, the level of implementation of these cutting-edge technologies remains low due to several critical impediments [29]. These barriers include inadequate infrastructure, an inconsistent policy framework, limited investment, a significant skill gap, and challenges related to governance and cybersecurity.

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

Despite these obstacles, Industry 4.0 holds the promise of fundamentally transforming the energy sector and significantly contributing to the development and energy goals of Nigeria. However, to fully realise this potential, concerted efforts must be made to address these impediments. This involves developing robust policies that promote the adoption of Industry 4.0 technologies, making significant investments in the upgrading of infrastructure and training the workforce, fostering public-private collaborations and fortifying cybersecurity measures. Moreover, it is imperative that future research and initiatives concentrate on understanding how to effectively and ethically leverage these technologies within the context of Nigeria's specific needs and circumstances. This involves designing user-friendly interfaces, ensuring the ethical use of these technologies, and understanding the needs and preferences of the users [30]. Through a concerted and strategic approach, the energy sector in Nigeria can fully harness the benefits of the Fourth Industrial Revolution, leading to a more sustainable, efficient, and prosperous future.

4.2 Requirements for the Implementation of Industry 4.0 Technology in Energy Generation in Nigeria

The slow Industry 4.0 technologies implementation in Nigeria's energy sector can be traced back to a combination of interrelated factors. Primarily, inadequate infrastructure, characterized by unstable power supply and unreliable internet connectivity, presents a significant barrier to the adoption of these advanced technologies. Additionally, inconsistencies in the policy framework contribute to the sluggish pace of implementation. The absence of clear regulations and supportive policies for technological advancements often results in uncertainty, thus deterring potential investments in Industry 4.0 technologies. Governance challenges also play a critical role in slow implementation. Lack of transparency, inefficient regulatory practices, and corruption all serve to stifle progress and innovation in the sector. Finally, insufficient investment, public and private, in the energy sector and specifically in the technologies of Industry 4.0, hampers the pace of implementation. Without adequate financial support, the development, deployment, and maintenance of these technologies become challenging tasks. Thus, it is clear that the slow Industry 4.0 technologies implementation in Nigeria's energy sector is not due to a single isolated issue [31]. Rather, it is a complex issue rooted in a variety of infrastructural, policy-related, governance and financial constraints.

Furthermore, the transition to Industry 4.0 technologies is a profound change in energy generation and management methods, necessitating the introduction of new skills and business models and a shift in organizational culture, which can be resisted by both staff and management. The effective implementation of Industry 4.0 technologies also depends on a supportive policy environment that fosters innovation and addresses associated risks. This includes the creation of financial incentives, data privacy safeguards, cybersecurity policies, and fair competition norms[28].

An exploration of the realm of Human-Computer Interaction (HCI) within Nigeria's energy generation sector illustrates the urgent need for a diverse set of skills [27]. These competencies range from technical proficiency to cognitive aptitude and effective interpersonal communication, all of which contribute significantly to the successful integration of Industry 4.0 technologies within this sector.

Digital literacy, one of the core skills, goes beyond a basic understanding of how to operate digital devices such as smartphones or computers. This skill embodies an extensive comprehension of digital systems, requiring an individual to grasp the complexity of effective and secure interactions with these systems and fully leverage their potential [10] . Digital literacy is far-reaching, calling for an intricate understanding of the digital realm.

In the context of Nigeria's energy sector, digital literacy implies deep knowledge of advanced technologies such as Artificial Intelligence (AI), cloud computing, big data analytics, and the Internet of Things (IoT). Energy sector workers must understand how to incorporate these technologies into their daily operations, extending from energy generation to distribution and consumption[32]. This comprehensive understanding of digital technologies equips

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

them with the skills to effectively manage digital resources and optimize their use for the benefit of the sector and consumers.

Effective HCI in the energy sector also requires critical thinking abilities, which involve the capacity to analyze and interpret results from these advanced technologies. This skill is imperative to understand the implications and potential consequences of these technologies [33]. Critical thinking allows for the careful scrutiny and analysis of complex concepts and ideas, which are essential in a technical sector like energy production.

As we dive deeper into the information age, data literacy has gained prominence as a critical skill for HCI within Nigeria's energy sector. In an era where big data is increasingly becoming a cornerstone for operational efficiency, data literacy, the ability to understand, interpret and effectively use data—provides organizations with a competitive advantage in terms of efficiency, cost savings, and decision-making capabilities [34]. Within the energy sector, data literacy involves proficiency in statistical analysis, data mining, predictive modelling, and data visualisation techniques, all crucial in making sense of IoT devices generated data.

Another critical skill required for effective HCI in the energy sector is systems thinking, which refers to the ability to comprehend complex systems, including the interaction of various components and the overall behaviour of the system [35]. This skill is vital to understanding the interactions between different energy sources, technologies, and infrastructures, and for strategising ways to optimize these interactions to enhance energy efficiency and reliability.

The interdisciplinary nature of the energy sector requires collaboration across disciplines, emphasising the need for effective teamwork skills. This becomes particularly crucial when professionals from different fields join forces to problem-solve or innovate, creating comprehensive and effective solutions. This form of collaboration leads to more holistic and informed approaches to the challenges and opportunities within the energy sector. Cultural awareness is another indispensable skill in the complex tangle of HCI skills in the energy sector [36]. Understanding local customs, traditions, beliefs, and social dynamics helps ensure that new technologies and systems are implemented in a culturally sensitive and respectful manner, enhancing their acceptance and acceptance among end users.

Information Communication Technology (ICT) skills are integral to the successful implementation of HCI within the energy sector. In this context, these skills extend beyond basic computer literacy to include proficiency in working with specialized software and hardware related to energy generation and management, database management, cloud computing, and cybersecurity. Another cornerstone skill within HCI is problem-solving, often considered one of the most critical skills in this field. Within the energy sector, problem-solving involves the ability to identify, analyze and solve complex, often interdisciplinary, problems that arise in the design, implementation, and operation of energy generation systems.

Communication skills are fundamental to effective HCI, especially within a complex and interdisciplinary field such as energy production. Effective communication involves the ability to listen to, understand, and respond appropriately to the needs, concerns, and ideas of others, significantly affecting the success of energy generation projects. Additionally, the ability to work effectively in a team is paramount in the interdisciplinary domain of energy production. This includes the ability to collaborate, negotiate, manage conflicts, and understand team dynamics, along with the roles and responsibilities of team members.

In an industry that is constantly evolving due to technological advancements and changing market dynamics, adaptability is a crucial skill. The ability to adapt to new tools, technologies, procedures, and regulations is essential for professionals in the energy sector.

4.3 Adoption of HCI in 4IR Technology in Energy Generation.

In the landscape of Fourth Industrial Revolution (4IR) technologies, the domain of Human-Computer Interaction (HCI) has emerged as a significant player, especially within the sphere of energy production. HCI, a

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

discipline rooted in the design, evaluation, and implementation of interactive computer systems crafted for human use, has immense potential for enhancing communication between human operators and digital elements of the industry 4.0 infrastructure. The digital elements referred to here encompass advanced technologies such as big data analytics, Artificial Intelligence (AI), and the Internet of Things (IoT). These 4IR technologies are complex by nature, and it is within this complexity that the role of improving their accessibility, usability, and intuitiveness becomes paramount. This not only enhances the experience for users but also equips human operators with the means to manage these systems more effectively [37]. For example, the role of HCI is evident in designing interactive dashboards and visualization tools that simplify the process of monitoring and controlling energy generation systems, allowing early detection of potential issues, and facilitating informed decision-making.

Zooming into the context of Nigeria, the potential for HCI in facilitating the integration of 4IR technologies in energy production is significant. Nigeria's energy sector is plagued by numerous challenges, such as infrastructural limitations, operational inefficiencies, and issues of transparency. The introduction of HCI in this landscape can enhance the human-digital interface, making these systems more manageable, user-friendly, and ultimately more efficient. Despite the apparent advantages, the adoption of HCI in Nigeria's energy sector presents its own challenges. Among these, capacity building and skill development emerge as primary obstacles. The new wave of 4IR technologies demands a new set of skills, encompassing digital literacy, data analysis, and systems thinking, competencies that are not commonly found in Nigeria's energy sector[38]. Therefore, it becomes imperative to invest substantially in training and education at both the individual and organizational levels to bridge this skills gap.

Another considerable challenge is the need for a user-centric design, a cornerstone for successful HCI implementation. Achieving this necessitates an in-depth understanding of the users, their operating context, and constraints, which are vital for effective technology design. Unfortunately, the practice of user-centric design remains underutilized in Nigeria, primarily due to a lack of research and the required expertise in the field. Although these challenges are significant, it is encouraging to note that there are early signs of progress. Increasing recognition of the importance of Nigeria's energy sector is leading to the growth of research and development projects. Initiatives that promote digital skills and promote user-centric design are also beginning to emerge [39]. These initiatives, while still in the early stages, signal a paradigm shift towards a more human-centered approach in technology integration within the energy sector.

The potential to bridge the gap between human operators and digital technologies enables it to address the multitude of challenges in the energy sector, setting the stage for the sector to tap into the potential benefits of 4IR. However, this process necessitates significant investments in capacity building and user-centric design and a firm commitment to placing individuals at the heart of the technology adoption process. The importance of HCI becomes even more pronounced considering the diversity of the workforce in Nigeria's energy sector. The workforce ranges from highly skilled engineers to low-skilled workers, and from those already familiar with digital technologies to those just beginning to adapt to them. HCI has the potential to design interfaces and interactions that are inclusive, flexible, and intuitive for all users, regardless of their skill level or familiarity with technology.

Beyond the domain of energy generation, HCI has a pivotal role to play in driving the social acceptance of 4IR technologies. Social acceptance is a crucial factor when introducing new technologies that carry the potential to significantly alter work practices and social norms. By involving users in the design and implementation process, addressing their concerns through user-friendly designs, and clear communication, HCI can help foster social acceptance of these new technologies. Furthermore, the benefits of HCI are not confined to the energy sector. They have far-reaching implications for energy conservation and sustainability. They also contribute to the digital transformation of the Nigerian economy, creating a conducive environment for innovation and growth in various sectors.

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

Despite the potential, it must be acknowledged that the adoption of HCI in the context of 4IR technology in Nigeria's energy sector is still in its early stages. There are few, if any, successful examples of HCI applications and the field remains largely unexplored in Nigerian research and practice. This presents vast research and development opportunities, with the aim of understanding HCI's specific challenges and opportunities and devising effective strategies for its integration. In summary, the potential of HCI for the integration of 4IR technologies into Nigeria's energy sector is immense. By improving the human-digital interface, HCI can address the sector's challenges, enhance the efficiency and effectiveness of energy systems, and contribute to broader social and economic objectives. However, achieving this potential requires a deep understanding of Nigeria's energy sector, significant investments in capacity building, a commitment to user-centric design, and an unwavering focus on a human-centric approach [40]. As Nigeria embarks on its journey towards Industry 4.0 in the energy sector, HCI provides a valuable compass, promising inclusivity, sustainability, and benefits for all.

4.4 Skills Requirement for HCI in Energy Generation in Nigeria

The incorporation of human-computer interaction (HCI) into the heart of Industry 4.0 technology within Nigeria's energy sector necessitates a vast array of skills that extend beyond traditional technical competencies. These skills encapsulate a broad spectrum, including digital literacy, data analysis, systemic thinking, user-centered design, cross-disciplinary collaboration, and an in-depth understanding of societal and cultural implications. When we delve into the intricacies of digital literacy, we are not talking merely about proficiency in using digital tools and technologies. Digital literacy, in the context of Industry 4.0, involves the ability to understand, evaluate, and create digital content. It extends to the domain of digital ethics and safety, encapsulating an understanding of data privacy, intellectual property, and cybersecurity. The energy sector in Nigeria can greatly benefit from a workforce equipped with digital literacy skills [41]. It will enable workers to operate advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics, all of which are vital components of Industry 4.0.

Understanding and making sense of data is an indispensable skill in the age of HCI and Industry 4.0. The energy sector is inundated with data generated by ubiquitous IoT devices and sensors, which have enormous potential to optimize energy production, distribution, and consumption. However, harnessing this potential requires the ability to interpret this data and convert these data into actionable insights. This, in turn, requires a combination of statistical and computational skills, critical thinking, effective communication skills and problem-solving abilities to articulate complex data in an understandable manner. Another critical competency is systems thinking, the ability to understand how different elements within a system interact with each other, and the ripple effects that changes in one part can have on the entire system. Within the energy sector, systems thinking can help manage the complex interplay between various technologies, processes, and stakeholders. It equips workers with the ability to anticipate potential issues and devise strategies to address them.

The skill of user-centred design plays a fundamental role in HCI within Industry 4.0. This involves understanding the needs, preferences, and contexts of users and developing technologies and systems that are intuitive, accessible, and satisfactory. In the energy sector, this translates into creating user-friendly technologies that are adaptable to the specific needs and conditions of various users. Interdisciplinary collaboration is another important skill for HCI within Industry 4.0. It involves the ability to effectively collaborate with individuals from various disciplines and backgrounds [42]. In the energy sector, interdisciplinary collaboration can bring together expertise from fields as diverse as engineering, computer science, psychology, sociology, and design. This melding of different expertise can lead to comprehensive and innovative solutions to tackle the challenges posed by Industry 4.0.

Finally, a deep understanding of social and cultural factors is crucial for a successful HCI within Industry 4.0. This involves understanding how technology is ingrained in social and cultural contexts and how it influences and is influenced by social norms, values, and practices. In the energy sector, such understanding can pave the way

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

for broader social acceptance of advanced technologies and ensure that they are designed and implemented in a manner that respects and responds to the cultural diversity and social needs of different stakeholders. The diverse and complex skills required for HCI within Industry 4.0 in the Nigerian energy sector require significant investments in education and training. Additionally, a paradigm shift towards a more human-centric approach to technology is required. Despite the daunting nature of this task, these skills should not be viewed simply as a means to an end. They are valuable assets that can improve the creativity, adaptability, and resilience of the workforce and contribute to Nigeria's overall social and economic development. As Nigeria embarks on its journey to Industry 4.0 in the energy sector, the need to invest in these skills is not merely a necessity, but an opportunity. An opportunity to lay the foundations for a more inclusive, sustainable, and prosperous future [43]. The path to Industry 4.0 is undeniably challenging, but with the right skills and a human-centric approach, Nigeria can not only navigate this path, but can do so in a way that ensures maximum benefit for all stakeholders involved.

4.5 The Development of HCI Skills in the Application of 4IR in the Energy Generation

The advent of the Fourth Industrial Revolution (4IR), characterised by its blending of physical, digital, and biological technologies, has brought about a paradigm shift in various industries, including the energy sector. As part of this transition, human-computer interaction (HCI) skills have emerged as an essential competency, given the increased dependence on technology and digital interfaces [44]. This discourse will focus on how these HCI skills can be developed for the effective application of 4IR in energy generation in Nigeria.

The development of HCI skills in the context of 4IR begins with education, which extends from the primary to the tertiary levels. It is widely acknowledged that today's digital era necessitates the integration of digital literacy into the core curriculum. This implies not only teaching students how to use technology but enabling them to understand how technology functions and how it can be harnessed to solve problems. In particular, students should be exposed to aspects of HCI, such as understanding user needs, creating intuitive interfaces, and testing usability [45]. In Nigeria, this could be facilitated by reviewing academic curricula, incorporating HCI principles and practices into relevant subjects like computer science, engineering, and design.

In higher education, specifically, universities could consider offering specialised courses and programs in HCI and related fields. These courses could go deeper into subjects such as interaction design, user experience design, and usability testing. They could also touch on emerging topics such as artificial intelligence, virtual reality, and data visualisation, given their relevance to 4IR technologies [40]. The goal should be to equip graduates with both theoretical knowledge and practical skills, preparing them for the demands of the evolving energy sector.

Beyond formal education, training programmes play a pivotal role in the development of HCI skills. Training can be particularly effective for professionals already working in the energy sector who need to update their skills in light of the integration of 4IR technologies. Employers can organise in-house training sessions, workshops, or seminars focused on HCI skills [46]. These programmes could cover topics such as how to design intuitive interfaces for energy management systems, how to implement user-centred design approaches in the development of new tools and technologies, and how to ensure the accessibility and inclusion of digital solutions.

In addition, online learning platforms offer a vast range of courses and tutorials covering various aspects of HCI. These platforms can be advantageous as they offer flexible learning options, allowing individuals to learn at their own pace and convenience. In Nigeria, where physical infrastructure and resources may be limited, leveraging online learning platforms could be a viable strategy to facilitate widespread and affordable access to HCI education and training.

Mentorship and apprenticeship programmes are another avenue to develop HCI skills. These programmes provide a platform for experienced professionals to pass on their knowledge and expertise to less experienced individuals. In the context of HCI, such programmes could involve tasks such as shadowing a user experience

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

designer, participating in usability testing sessions, or assisting in the development of an interactive system [47]. These hands-on experiences can offer invaluable insights into the real-world applications of HCI principles and practices.

Lastly, the role of continuous learning and professional development should be emphasised. The rapidly evolving nature of 4IR technologies means that HCI skills will need to be continuously updated and refined. Professionals should be encouraged to engage in lifelong learning, regularly participate in continuing education and training opportunities, attend industry conferences and seminars, and stay abreast of the latest trends and advances in HCI and 4IR technologies [48].

The development of HCI skills for applying 4IR in energy generation is a multifaceted process involving education, training, mentorship, and continuous learning. In Nigeria, this process requires concerted efforts from various stakeholders, including educational institutions, employers, government bodies, and the professionals themselves. Through these collective efforts, Nigeria's energy sector can be well-positioned to harness the transformative potential of 4IR technologies.

5.0 Conclusions

In drawing together, the conclusions from the extensive analysis that encompasses points, the transformation of Nigeria's energy sector through the application of HCI and Industry 4.0 technologies is a multifaceted and complex process, characterized by both challenges and opportunities.

The exploration of the current level of Industry 4.0 implementation in Nigeria's energy sector revealed significant constraints including infrastructural deficits and policy inconsistencies that hinder full utilization of the sector's potential. However, the inherent efficiency and predictive capabilities of Industry 4.0 technologies like Artificial Intelligence and the Internet of Things suggest substantial opportunities for revolutionizing Nigeria's energy sector. The detailed requirements for Industry 4.0 in the energy sector demonstrated a critical need for strategic planning, policy formulation, infrastructure investment, and substantial training of the workforce. These measures would be instrumental in accelerating the adoption of Industry 4.0 technologies and facilitating their transformative impact on the sector. Examining the role and status of human-computer interaction (HCI) in the application of 4IR technologies in energy generation revealed gaps in the effectiveness and ease of use of interfaces between human operators and digital technologies. This points to the importance of improving HCI by developing more user-friendly interfaces and gaining a deeper understanding of user needs and preferences. The study of the skills required for HCI within the energy sector in Nigeria highlighted a significant skill gap. The necessary skills range from digital literacy and problem-solving to systems thinking and adaptability. To meet the demands of Industry 4.0, it becomes imperative to upskill and reskill the Nigerian energy workforce. Lastly, exploring the development of HCI skills in the application of 4IR in energy generation underscored the need for a culture of continuous learning and adaptation. This would require active collaboration among stakeholders, including policymakers, industry players and academia, to foster workforce training, innovation, and alignment with national goals and strategies.

However, addressing these critical issues brings its own set of challenges, such as cybersecurity concerns, data privacy, and ethical issues. The transition to a more digitally connected system raises the potential for cyber-attacks and requires robust cybersecurity measures. Similarly, the increased data collection and processing demand not just technical but also legal and regulatory measures to ensure the privacy of individual and corporate data. As the energy sector in Nigeria navigates this complex journey towards Industry 4.0, it is vital to recognise the immense promise it holds. Using the potential of Industry 4.0 technologies, the sector can gain in terms of efficiency, reliability, and sustainability in energy generation. This offers opportunities to diversify energy sources and foster resilience in the face of global energy challenges. It is through concerted efforts and strategic planning, involving all stakeholders, that the energy sector in Nigeria can fully leverage the benefits of the Fourth Industrial Revolution and herald a more sustainable, efficient, and prosperous future.

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

References

[1] Makuochi Nkwo, Orji, R. and Ugah, J. (2021). Insider Perspectives of Human-Computer Interaction for Development Research: Opportunities and Challenges. doi:https://doi.org/10.1145/3448696.3448709.

[2] Muhammad Sadi Adamu (2021). Problematising Identity, Positionality, and Adequacy in HCI4D Fieldwork: A Reflection. Lancaster EPrints (Lancaster University). doi:https://doi.org/10.1145/3448696.3448703.

[3] Adoghe, A. U., Adeyemi-Kayode, T. M., Oguntosin, V., & Amahia, I. I. (2023). Performance evaluation of the prospects and challenges of effective power generation and distribution in Nigeria. Heliyon, 9(3), e14416. https://doi.org/10.1016/J.HELIYON.2023.E14416

[4] Ndukwe, I. and Obiorah, M. (2019). Design Insights from the Implementation of a Student Result Processing System in Nigeria. [online] Available at: https://core.ac.uk/download/pdf/234683528.pdf [Accessed 13 Dec. 2023].

[5] AL-Sayid, F. and Kirkil, G. (2022). Students' Web-Based Activities Moderate the Effect of Human-Computer-Interaction Factors on Their E-Learning Acceptance and Success During COVID-19 Pandemic. International Journal of Human–Computer Interaction, pp.1–24. doi:https://doi.org/10.1080/10447318.2022.2087013.

[6] Wang, J., Cheng, R., Liu, M. and Liao, P.-C. (2021). Research Trends of Human–Computer Interaction Studies in Construction Hazard Recognition: A Bibliometric Review. Sensors, [online] 21(18), p.6172. doi:https://doi.org/10.3390/s21186172.

[7] Nicholson, J., Opeyemi Dele-Ajayi, Kemi Fasae and Boniface Kayode Alese (2023). Friendly Folk Advice: Exploring Cybersecurity Information Sharing in Nigeria. Lecture Notes in Computer Science, pp.369–378. doi:https://doi.org/10.1007/978-3-031-42280-5_23.

[8] Thakur, N. and Parameshachari, B.D. (2022). Human-Computer Interaction and Beyond: Advances Towards Smart and Interconnected Environments (Part II). [online] Google Books. Bentham Science Publishers. Available at: https://books.google.com/books?hl=en&lr=&id=rS5eEAAAQBAJ&oi=fnd&pg=PP1&dq=HUMAN-COMPUTER+INTERACTION+IN+ENERGY+SYSTEM+IN+NIGERIA&ots=qfyu9TXVSW&sig=2BTayfgB92n-jolFAqz1NP3fP_Y [Accessed 13 Dec. 2023].

[9] Li, X. and Xu, Y. (2022). Role of Human-Computer Interaction Healthcare System in the Teaching of Physiology and Medicine. Computational Intelligence and Neuroscience, 2022, pp.1–12. doi:https://doi.org/10.1155/2022/5849736.

[10] Li, L. (2022). Reskilling and upskilling the future-ready workforce for industry 4.0 and beyond. Information Systems Frontiers, 24(3). doi:https://doi.org/10.1007/s10796-022-10308-y.

[11] Zhou, H., Wang, D., Yu, Y. and Zhang, Z. (2023). Research Progress of Human–Computer Interaction Technology Based on Gesture Recognition. Electronics, 12(13), pp.2805–2805. doi:https://doi.org/10.3390/electronics12132805.

[12] Muhammad Sadi Adamu (2020). Software Project Work in an African Context: Myths, Maps and Messes. Lancaster EPrints (Lancaster University). doi:https://doi.org/10.1145/3441000.3441071.

[13] Chinyere Onyemauche, U., Makuochi Nkwo, S., Elochukwu Mbanusi, C. and Queeneth Nwosu, N. (2021). Towards the Use of Eye Gaze Tracking Technology: Human Computer Interaction (HCI) Research. 3rd African Human-Computer Interaction Conference. doi:https://doi.org/10.1145/3448696.3448710.

[14] Aich, N., Kordas, K., Ahmed, S.I. and Sabo-Attwood, T. (2020). The Hidden Risks of E-Waste: Perspectives from Environmental Engineering, Epidemiology, Environmental Health, and Human–Computer Interaction. Transforming Global Health, pp.161–178. doi:https://doi.org/10.1007/978-3-030-32112-3_11.

[15] Eduardo Chang Muñoz, Guarín, F., Alpha Nieto Parejo, Nohora Mercado-Caruso, José Fernando Gallego-Nicholls and Patricia, A. (2022). Human-Computer Interaction Activities as a Basis in the Development of Innovations in Process: The Case of the Colombian Exporter SMEs. pp.131–148. doi:https://doi.org/10.1007/978-3-031-18158-0_9.

[16] Adigun, A.A., Alabi, O.O., Ogundoyin, I.K., Adigun, O.I., Ibrahim, M.A., Ozoh, P.O. and Abanikannda, M.O. (2022). Graphical Processing Unit and Central Processing Unit Performance in Human-Computer Interaction. University of Ibadan Journal of Science and Logics in ICT Research, [online] 8(1), pp.19–28. Available at: http://www.journals.ui.edu.ng/index.php/uijslictr/article/view/771 [Accessed 13 Dec. 2023].

[17] Muhammad Sadi Adamu (2021). Rethinking Technology Design and Deployment in Africa: Lessons from an African Standpoint. Lancaster EPrints (Lancaster University). doi:https://doi.org/10.1145/3448696.3448704.

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

[18] Qin, F., Sun, Q., Ye, Y. and Wang, L. (2023). A Multimodal Teaching Model of College English Based on Human–Computer Interaction. International Journal of Human–Computer Interaction, pp.1–9. doi:https://doi.org/10.1080/10447318.2023.2188531.

[19] Rauterberg, M., Nah, F.F.-H., Siau, K., Krömker, H., Wei, J. and Salvendy, G. (2022). HCI International 2022 – Late Breaking Papers: HCI for Today's Community and Economy: 24th International Conference on Human-Computer Interaction, HCII 2022, Virtual Event, June 26–July 1, 2022, Proceedings. [online]

[20] Ardito, C., Lanzilotti, R., Malizia, A., Petrie, H., Piccinno, A., Desolda, G. and Inkpen, K. (2021). Human-Computer Interaction – INTERACT 2021: 18th IFIP TC 13 International Conference, Bari, Italy, August 30 – September 3, 2021, Proceedings, Part II. [online]

[21] Linxen, S. (2022). Perspectives on human-computer interaction and culture - edoc. Unibas.ch. [online] doi:https://edoc.unibas.ch/94393/1/Dissertation_Sebastian_Linxen_UB_NOCV.pdf.

[22] Oguine, M.B., Oguine, C.G. and Oguine, K.J. (2023). My Machine and I: ChatGPT and the Future of Human-Machine Collaboration in Africa. [online] arXiv.org. doi:https://doi.org/10.48550/arXiv.2310.13704.

[23] Ozmen Garibay, O., Winslow, B., Andolina, S., Antona, M., Bodenschatz, A., Coursaris, C., Falco, G., Fiore, S.M., Garibay, I., Grieman, K., Havens, J.C., Jirotka, M., Kacorri, H., Karwowski, W., Kider, J., Konstan, J., Koon, S., Lopez-Gonzalez, M., Maifeld-Carucci, I. and McGregor, S. (2023). Six Human-Centered Artificial Intelligence Grand Challenges. International Journal of Human–Computer Interaction, [online] 39(3), pp.391–437. doi:https://doi.org/10.1080/10447318.2022.2153320.

[24] Rezaei, F., Khalilzadeh, M. and Soleimani, P. (2021). Factors Affecting Knowledge Management and Its Effect on Organizational Performance: Mediating the Role of Human Capital. [online] Advances in Human-Computer Interaction. Available at: https://www.hindawi.com/journals/ahci/2021/8857572/.

[25] Foroughi, B., Madugoda Gunaratnege Senali, Iranmanesh, M., Khanfar, A., Morteza Ghobakhloo, Annamalai, N. and Bita Naghmeh-Abbaspour (2023). Determinants of Intention to Use ChatGPT for Educational Purposes: Findings from PLS-SEM and fsQCA. pp.1–20. doi:https://doi.org/10.1080/10447318.2023.2226495.

[26] Gonçalves, T.G., Loslever, P., de Oliveira, K.M. and Kolski, C. (2020). Investigating Agreement Among HCI Researchers About Human–Computer Interaction in CMMI-DEV Model: A Case Study. Interacting with Computers, 32(1), pp.81–100. doi:https://doi.org/10.1093/iwc/iwaa006.

[27] Laskurain-Iturbe, I., Arana-Landín, G., Landeta-Manzano, B. and Uriarte-Gallastegi, N. (2021). Exploring the influence of industry 4.0 technologies on the circular economy. Journal of Cleaner Production, 321, p.128944. doi:https://doi.org/10.1016/j.jclepro.2021.128944.

[28] Tambare, P., Meshram, C., Lee, C.-C., Ramteke, R.J. and Imoize, A.L. (2021). Performance Measurement System and Quality Management in Data-Driven Industry 4.0: A Review. Sensors, [online] 22(1), p.224. doi:https://doi.org/10.3390/s22010224.

[29] Nhamo, G., Nhemachena, C. and Nhamo, S. (2019). Using ICT indicators to measure readiness of countries to implement Industry 4.0 and the SDGs. Environmental Economics and Policy Studies. doi:https://doi.org/10.1007/s10018-019-00259-1.

[30] Nota, G., Nota, F.D., Peluso, D. and Toro Lazo, A. (2020). Energy Efficiency in Industry 4.0: The Case of Batch Production Processes. Sustainability, [online] 12(16), p.6631. doi:https://doi.org/10.3390/su12166631.

[31] Alao, M.A., Ayodele, T.R., Ogunjuyigbe, A.S.O. and Popoola, O.M. (2020). Multi-criteria decision based waste to energy technology selection using entropy-weighted TOPSIS technique: The case study of Lagos, Nigeria. Energy, 201, p.117675. doi:https://doi.org/10.1016/j.energy.2020.117675.

[32] Kamali Saraji, M., Streimikiene, D. and Kyriakopoulos, G.L. (2021). Fermatean Fuzzy CRITIC-COPRAS Method for Evaluating the Challenges to Industry 4.0 Adoption for a Sustainable Digital Transformation. Sustainability, 13(17), p.9577. doi:https://doi.org/10.3390/su13179577.

[33] Mhlanga, D. (2021). Artificial Intelligence in the Industry 4.0, and Its Impact on Poverty, Innovation, Infrastructure Development, and the Sustainable Development Goals: Lessons from Emerging Economies? Sustainability, [online] 13(11), p.5788. doi:https://doi.org/10.3390/su13115788.

[34] Maisiri, W., Darwish, H. and van Dyk, L. (2019). AN INVESTIGATION OF INDUSTRY 4.0 SKILLS REQUIREMENTS. South African Journal of Industrial Engineering, [online] 30(3). doi:https://doi.org/10.7166/30-3-2230.

JDFEWS 4 (2): 178 - 193, 2023
ISSN 2709-4529

[35] Jahani, N., Sepehri, A., Vandchali, H.R. and Tirkolaee, E.B. (2021). Application of Industry 4.0 in the Procurement Processes of Supply Chains: A Systematic Literature Review. Sustainability, [online] 13(14), p.7520. doi:https://doi.org/10.3390/su13147520.

[36] Butt, J. (2020). A Strategic Roadmap for the Manufacturing Industry to Implement Industry 4.0. Designs, [online] 4(2), p.11. doi:https://doi.org/10.3390/designs4020011.

[37] van der Poll, J.A. (2022). Problematizing the Adoption of Formal Methods in the 4IR–5IR Transition. Applied System Innovation, 5(6), p.127. doi:https://doi.org/10.3390/asi5060127.

[38] Ebekozien, A. and Aigbavboa, C. (2021). COVID-19 Recovery for the Nigerian Construction Sites: The Role of the Fourth Industrial Revolution Technologies. Sustainable Cities and Society, 69, p.102803. doi:https://doi.org/10.1016/j.scs.2021.102803.

[39] Shaharuddin, A.B., Aminudin, E., Zakaria, R., Abidin, N.I. and Lau, S.E.N. (2021). Adoption of construction industry 4.0 among small and medium sized contractor in Malaysia. CENTRAL EUROPEAN SYMPOSIUM ON THERMOPHYSICS 2021 (CEST 2021). doi:https://doi.org/10.1063/5.0071094.

[40] Marwala, T. (2022). Closing the Gap: The Fourth Industrial Revolution in Africa. [online] Google Books. Pan Macmillan South africa. Available at: https://books.google.com/books?hl=en&lr=&id=QEytEAAAQBAJ&oi=fnd&pg=PT9&dq=Adoption+of+HCI+in+4IR+technology+in+Energy+Generation.&ots=8eAVkijTKt&sig=lg5reQ3vMXQjjNpa0BTaMZitYFo [Accessed 13 Dec. 2023].

[41] Toyin, T. and Siaminwe, L. (2023). Industry 4.0 Implementation Challenges in an Unfacilitated Environment: A Case of Manufacturing Industries in Zambia. [online] Available at: https://ieomsociety.org/proceedings/2023zambia/13.pdf.

[42] Melville, N.P., Robert, L. and Xiao, X. (2022). Putting humans back in the loop: An affordance conceptualization of the 4th industrial revolution. Information Systems Journal. doi:https://doi.org/10.1111/isj.12422.

[43] Sharma, S., Malik, A., Sharma, C., Batra, I., Mahender Singh Kaswan and Jose Arturo Garza-Reyes (2023). Adoption of industry 4.0 in different sectors: a structural review using natural language processing. International Journal on Interactive Design and Manufacturing (IJIDeM). doi:https://doi.org/10.1007/s12008-023-01550-y.

[44] Meng, Q., Yan, Z., Abbas, J., Shankar, A. and Subramanian, M. (2023). Human–Computer Interaction and Digital Literacy Promote Educational Learning in Pre-school Children: Mediating Role of Psychological Resilience for Kids' Mental Well-Being and School Readiness. International Journal of Human-computer Interaction, pp.1–15. doi:https://doi.org/10.1080/10447318.2023.2248432.

[45] Iulia Ştefan, Barkoczi, N., Тодор Тодоров, I. Peev, Pop, L., Marian, C., Câmpian, C., Munteanu, S.-C., Flynn, P. and Morales, L. (2023). Technology and Education as Drivers of the Fourth Industrial Revolution Through the Lens of the New Science of Learning. Lecture Notes in Computer Science, pp.133–148. doi:https://doi.org/10.1007/978-3-031-34411-4_11.

[46] Senuri Siriwardhana and Moehler, R. (2023). Enabling productivity goals through construction 4.0 skills: Theories, debates, definitions. Journal of Cleaner Production, 425, pp.139011–139011. doi: https://doi.org/10.1016/j.jclepro.2023.139011.

[47] Nishith Reddy Mannuru, Sakib Shahriar, Zoë Abbie Teel, Wang, T., Lund, B., Tijani, S., Chalermchai Oak Pohboon, Agbaji, D., Alhassan, J.K., Galley, J., Raana Kousari, Ogbadu-Oladapo, L., Shubham Saurav, Srivastava, A., Sai Priya Tummuru, Subramanya Uppala and Vaidya, P. (2023). Artificial intelligence in developing countries: The impact of generative artificial intelligence (AI) technologies for development. Information Development. doi:https://doi.org/10.1177/02666669231200628.

[48] Sutherland, E. (2019). The Fourth Industrial Revolution – The Case of South Africa. Politikon, [online] 47(2), pp.1–20. doi:https://doi.org/10.1080/02589346.2019.1696003.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

A Sensor-Based Data Acquisition System for Soil Parameters to Determine Suitable Crops

Blessing Olatunde ABISOYE
University of Technology, Minna, Niger State, Nigeria; b.abisoye@futminna.edu.ng

Eustace Manayi DOGO
University of Technology, Minna, Niger State, Nigeria

Buhari Ugbede UMAR
University of Technology, Minna, Niger State, Nigeria

Isaac Zhiri MAMMAN
University of Technology, Minna, Niger State, Nigeria

Received: 16 June 2023

Review: 21 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract - Soil parameters monitoring is significant in sustainable crop and food production. The standard strategy of soil parameters monitoring in developing and underdeveloped nations uses manual labor, resulting in wrong decisions in soil management. Inaccurate measurements due to sensor miscalibration or low sensor quality can lead to incorrect soil management decisions and negatively impact crop yield and environmental sustainability. Due to the mentioned challenges, this work aims to develop a Sensor-based Data Acquisition System for Soil Parameters that will enable users to observe various soil parameters like temperature, humidity, water level and soil pH. The system was developed using the combination of hardware and software components. The hardware component comprises of sensory and processing parts. The study calibrates sensors using known pH, moisture, and temperature values for specific crops to grow in Nigeria. The system will aid farmers in determining suitable crops for their farmland and increasing crop yield. The system collects data through a network of sensors installed in the soil and wirelessly transmits the data to a cloud-based server. The collected data is then analyzed and visualized in through a web-based dashboard, providing farmers with information about the state of their soil. The performance evaluation of the system was carried out using response time and accuracy. The average response time of the system was 4 seconds, and the percentage error for temperature and humidity readings when compared to weather forecast readings were 8.20% and 5.08%, respectively. The results show that the proposed system can provide accurate and reliable measurements of soil parameters and can be easily deployed and operated by small-scale farmers. Using this system can result in improved crop yields, reduced wastage, and better overall efficiency in agricultural operations.

Keywords: *Data acquisition, Soil Parameters, Monitoring system, IoT, Sensors*

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

1 Introduction

Agriculture and food production rely heavily on the ever-changing environment, impacting food production and various humans. The components of nature comprise land and water resources and climatic factors, including temperature, precipitation, and relative humidity [1]. Despite significant technical and agricultural yield developments, the environment still hugely impacts food production since solar radiation, temperature, and precipitation are the primary factors affecting crop growth. Soil parameters such as pH, temperature, and water content can directly impact crop growth and yield, and by measuring these parameters, farmers can optimize crop production by adjusting soil conditions through fertilization and irrigation practices [2]. The "master soil variable" is the soil pH, which influences several biological, chemical, and physical aspects and processes that affect plant development and biomass production [3]. Soil pH and other parameters such as soil moisture, temperature and humidity are the main catalysts in determining the yield of crops.

Precision Agriculture (PA) involves the gathering and analysis of a significant volume of crop health data [4]. The benefit of PA is that it helps better use of farmland with few resources. The practice of PA significantly contributes to long-term sustainable farming since it increases crop quality and output while minimizing environmental consequences. Also, PA has recently benefited from the introduction of Internet-of-Things (IoT) technologies. To improve productivity and food security with modern technology, the IoT, a rapidly expanding emergent technology, is being used in agriculture. It is a wide-open, complex network of intelligent objects that can self-organize, share information, data, and resources, and react to environmental occurrences [5]. IoT uses various technologies to monitor physical and other things remotely in the real world. It links sensors and embedded technology on a network that allows for real-time data collection, transmission, and monitoring, often stored in the cloud.

Data Acquisition System (DASs) acts as a link between analog waveforms and computer-operable digital numerical values. They are frequently utilized in laboratories for testing and measurements in many industries and are especially adequate for monitoring voltage signals and currents [6], [7]. In addition to their extensive use in laboratories for testing and measurements, DASs have found wide application in various areas of industry. They play a crucial role in automation and control processes and also act as intermediaries, converting analog signals from sensors and actuators into digital data that can be processed by computers or Programmable Logic Controllers (PLCs). DASs enable real-time monitoring, managing, and enhancing industrial processes, which raises productivity, decreases downtime, and increases safety.

Significant progress has been achieved in monitoring soil parameters, and many open areas of research opportunity remain. Expanding on these works opens areas of opportunity to explore several avenues to enhance the monitoring of soil parameters, such as continuous monitoring of soil pH and nutrient levels. Also, these parameters can help optimize fertilizer application, soil amendment strategies, and nutrient management practices. The novelty of this work is a sensor-based DAS that can recommend appropriate crops to be grown in an area in Nigeria based on threshold data of some specific crops in the country. The contributions of the study are as follows:

1. Development of a cost-effective sensor-based DAS that keeps track of soil parameters such as temperature, humidity, pH, and moisture level.

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

2. Calibration of sensors using a standard range of known pH and temperature values for some specific crops and.
3. Recommend appropriate crops that can be grown in Nigeria to increase crop yield.

The remaining part of this article is organized as follows: section two gives the related work on the subject matter, and section three relates the design process of the proposed sensor-based DAS. Section four provides results, the discussion is based on the testing of the developed system, and section five presents the study's conclusion and proposes future work.

2 Related Work

Plants' optimum development, health, and production are crucial in contemporary agriculture and horticulture. As the global population continues to rise and the need for food and other plant-based goods rises, this process has assumed growing importance in research. One significant benefit of plant monitoring is preventing significant yield losses [8], [9]. Many studies have been carried out to explore the benefits of DASs and IoT systems in agriculture. Ref. [10] proposed a remote monitoring system that measured moisture, temperature, and pH and interfaced with an Arduino. The sensors connected to the Arduino gather the parameter data and then send it to the client's mobile device using an SMS through a GSM network to transfer data. Using less power ensures this method can send data over a long distance. Ichwana *et al.* in ref. [11] designed a DAS in a greenhouse using multiple sensors. Using Arduino and Excel add-ins, the system monitors real-time data from several sensors in the greenhouse. The significant sensors deployed are DHT22 and BH1750, which provide precise temperature, humidity, and light intensity values, respectively. While the system could detect temperature, humidity, and light intensity, it could not monitor soil moisture or pH.

Boobalan., *et al.* in [12] proposed an IoT-based Agriculture Monitoring System using temperature and humidity sensors interfaced with a Raspberry Pi. When obstacles enter the restricted region, a PIR sensor detects and updates the cloud. The user can regulate the functioning of the motor based on this data. While the study could monitor temperature and humidity, it did not cater to other soil parameters like pH and light intensity, as in ref. [10]. This method improves irrigation conservation but does not address the pH of the soil. Rao., *et al.* in ref. [13] developed a monitoring and automation irrigation system for soil parameters using Raspberry Pi and a cloud-based service. It uses a temperature and soil moisture sensor, and it controls irrigation. While the system improved irrigation conservation, the design did not consider soil pH.

According to ref. [7] an IoT-based smart agriculture management system that measures temperature and soil moisture using DHT-11 and Hygrometer was proposed. The sensors are interfaced with a Raspberry Pi 3 and NodeMCU Devkit. The sensed data is sent to a cloud and accessed through a mobile application. It is cost-effective and helps in analyzing sensed data. An embedded system for measuring humidity, soil moisture, and temperature in a polyhouse using an 89E516RD Microcontroller was developed by Kolapkar *et al.* in [14]. The system was conceived and developed to measure, display, and manage polyhouse-related environmental parameters such as humidity, soil moisture, and temperature. The system also provides automated ON-OFF control action for the exhaust fan, heater, and fogger. This system did not cater for the pH of the soil and light intensity.

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

An IoT-based smart agriculture for monitoring soil parameters and controlling soil moisture was proposed in ref. [15]. The system measures soil moisture, humidity, and temperature. Only the soil moisture is controlled. It uses an Arduino Microcontroller and Raspberry Pi; the sensed data is transmitted using ZigBee modules. While this approach provides a way to monitor and control soil parameters, it also requires multiple stations to work effectively, which adds to the system's maintenance cost. Ashifuddin & Rehena in [16] developed an IoT-based intelligent agriculture field monitoring system that performs automatic irrigation using actuators interfaced with an Arduino UNO, a temperature sensor, and a humidity sensor. The system offers Continuous field monitoring, which also sets off the actual events as needed. It somewhat lessens the labour requirements and expenses associated with farming.

Saini & Saini in ref. [17] proposed agriculture monitoring and prediction using IoT. Irrigation is done automatically using the data collected from the sensors, thereby reducing human efforts. It simplifies farming techniques, but the design did not consider the soil pH. Also, an IoT-based smart agriculture system was developed using an ESP8266 WiFi module and the GSM module together with sensors like the LM35 temperature, humidity, and moisture sensors. An Arduino Uno R3 Microcontroller board was interfaced with an Android App that enables the construction of a profile for specified irrigation based on the seasons or daily and weekly modes. Motion sensors were included in the design to identify animal infiltration [18].

Significant advancements have been made in monitoring soil parameters, and a few research works have catered for soil moisture, temperature, humidity, and pH simultaneously, which are the main catalysts for plant growth. Also, little advancement has been made in recommending crops suitable for growing plants in Nigeria. The available research works are peculiar to a country like India. For effective monitoring, the sensor-based DAS for soil parameters utilizes various sensors to keep track of the soil's temperature, humidity, pH, and moisture level while also recommending some specific kind of crop that can be grown in Nigeria to increase crop yield. Because of these, this study develops an efficient and precise data collection method to enable users to make better decisions. The sensor-based DAS for soil parameters collects data such as soil pH, moisture, temperature, and humidity from the farm site. Sensors are calibrated using known pH, moisture, and temperature values for specific crops, aiding farmers in determining suitable crops for their land and increasing crop yield.

3 Materials and Methods

This research paper proposes a sensor-based DAS for soil parameters to determine a suitable crop for cultivating in a particular environment. This technology will provide comprehensive data for enhancing crop production by enabling farmers to make decisions. Data acquired by sensors are sent to the cloud to ease future analysis. In this section, the hardware and software design considerations, together with the crop determination process, are presented.

3.1 Hardware Design Consideration

Hardware design is one of the significant processes in achieving the aim of this study. The major hardware components of the system include temperature, humidity, soil moisture, soil pH sensors, Arduino, and ESP8266

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

- WIFI Module. Table 1 describes the hardware components used and their specifications. When the system is initialized, the sensory parts of the proposed model will conduct data collection of two soil parameters, the soil moisture and soil pH, and two weather data: the temperature and relative humidity. These collected data are sent to the Arduino microcontroller for processing. ESP8266-WiFi Module plays the role of transmitting the sensed soil parameter data to the cloud for analysis. The data collected by the proposed model and the data analysis can be accessed online through a personal computer or smartphone. Figure 1 presents the conceptual framework of the proposed sensor-based DAS.

Table 1: Hardware Components Specification

S/N	Components	Operating Voltage	Operating Current
1	Soil pH sensor	3.3~5V	1.2mA
2	Soil moisture sensor	5V	15mA
3	Temperature and humidity sensor	3.3V or 5V	0,3mA
4	Arduino	3.3~5V	20-30mA
5	ESP8266 - WIFI Module.	3.3V	70-250mA

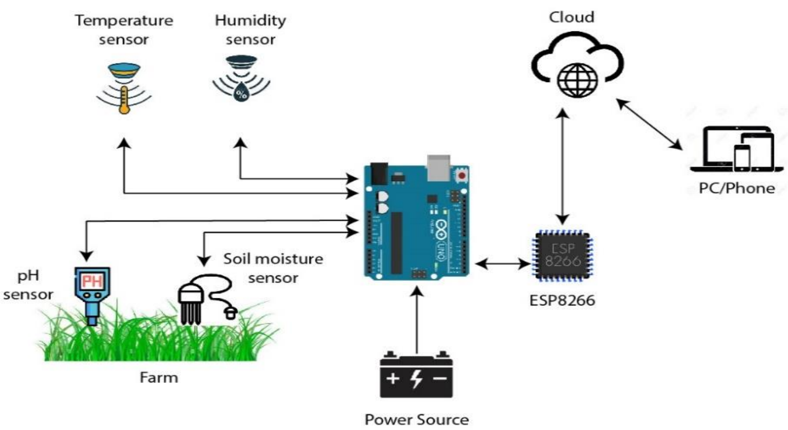


Figure 1: Conceptual Framework of the Proposed Sensor-based DASs

3.2 Software Design Consideration

Another critical step in developing the sensor-based DAS for soil parameters is the software design process. Arduino Development Environment is used to write code that enables the sensor-based DAS process. One of the advantages of this environment is that it is an open-source platform. Through this environment, the sensors' initialization, functions to take a reading by the sensors, processing of the data, sending of the data to the cloud and displaying the appropriate crop for the farmland are enabled. Also, a cloud-based database makes up another

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

software in this work. The ThingSpeak platform allows the user to visualize and analyze the acquired values from the sensors. It also provides the scalability and flexibility of a cloud platform.

3.3 Crop Determination

In determining the crop that will grow on the farmland, the data acquired by the sensors are compared with the standard pH range, temperature, and soil moisture to help users know if certain crops will grow on a particular farmland. Optimal values for some specific crops grown in Nigeria have been outlined in Table 2. When the sensed readings match the threshold values in Table 2, the sensor-based DAS displays the crop that will grow.

Table 2: Threshold sensor values for specific crops to grow in Nigeria *[19, 20, 21, 22, 23, 24, 25, 26].*

Moisture (%)	Temperature	pH	Humidity	Crop
65-75	25-30	5.5-6.5	70-80	Yam
60-70	25 -35	4.5-7.0	60-90	Cassava
70-80	20-30	5.5-6.5	70-80	Sweet potato
70-80	18 -22	4.8-5.5	70-80	Potato
12-14	20-30	5.5-7.0	60-70	Maize
12-14	20 -35	6.0-7.0	70-80	Rice
11-13	25 -35	5.5-7.5	60-90	Sorghum
9-13	20 -35	5.0-7.0	60-80	Millet
60-80	21 -27	6.0-7.0	50-70	Tomato
50-75	15 -20	6.0-7.5	50-70	Cabbage
60-80	25-30	5.5-7.0	50-70	Okra

For instance, if the values acquired from the sensors align with the threshold range values required for cassava to grow, which is 60%-70% for moisture, 25°c -35°c for temperature, 4.5-7.0 for soil pH, 60%-90% humidity, it displays cassava alongside the acquired soil parameters else, it only shows the obtained soil parameters. The values obtained are sent to the cloud storage in real-time.

The system design and construction were carried out with a step-by-step approach to ensure proper integration of the entire system. The hardware was constructed with all sensors and microcontrollers tested to ensure proper functioning. Figure 4 depicts the fabrication prototype of the sensor-based DAS.

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

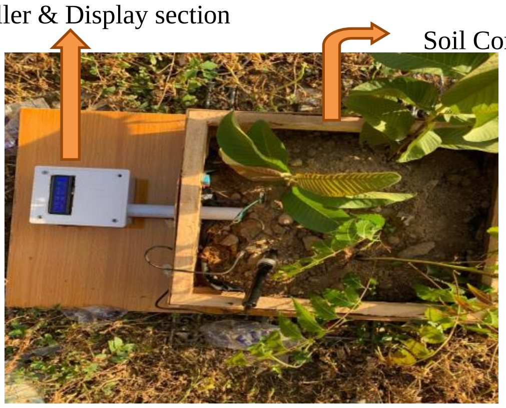


Figure 4: Prototype of the Smart Data Acquisition System

4 Evaluation of Response Time Results

The response time metric was evaluated, and the time taken to send and receive 18 samples of acquired values for temperature, humidity, soil moisture, and soil pH to the cloud was recorded. Table 3 shows the result of the test. The average response time of the system was 4 seconds. Response time for 18 samples, as displayed in Table 3, revealed a slight difference in the results. The values recorded varied from 3 to 9, potentially due to the poor GSM network service. The recorded average reaction time was 4 seconds. It took roughly 4 seconds to send the acquired sensor values to the database when the system was initialized. This value is average satisfaction. Microsoft Excel is used to show a graphical illustration of the system's response. Figure 5 represents the data visualization of the system's response time. The graph is zigzag due to the effectiveness of the GSM network service. The shooting of the graph to 9 seconds at the fifth instance might be due to the sensors' response in the proposed system.

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

Table 3: Response Time for the System

Trial(s)	Soil Moisture (%)	Soil pH	Temp (°c)	Humidity (%)	Time Received (T_R)	Time Sent (T_s)	Response Time (T_R-T_s) (sec)
1	28	8	33.2	56.4	10:42:12	10:42:09	3
2	30	8	33.3	56.0	10:43:30	10:43:27	3
3	30	8	33.4	56.1	10:44:12	10:44:07	5
4	32	7	32.4	48.9	18:21:06	18:21:04	2
5	32	7	33.3	51.0	18:22:23	18:22:14	9
6	32	7	33.4	50.6	18:23:59	18:23:57	2
7	32	7	33.4	50.3	18:24:24	18:24:18	6
8	31	7	33.4	50.1	18:26:32	18:26:28	4
9	32	7	33.4	50.1	18:27:58	18:27:55	3
10	31	7	33.4	49.8	18:28:05	18:28:00	5
11	31	7	33.5	49.6	18:29:07	18:29:04	3
12	31	7	33.6	49.6	18:30:03	18:30:00	3
13	32	7	33.6	49.7	18:31:10	18:31:06	4
14	32	7	33.6	49.7	18:32:11	18:32:05	6
15	32	7	33.6	49.6	18:33:05	18:33:01	4
16	32	7	33.6	49.6	18:34:27	18:34:24	3
17	31	7	33.7	49.6	18:35:30	18:35:26	4
18	32	7	33.7	49.5	18:36:26	18:36:23	3
Average RT							**4**

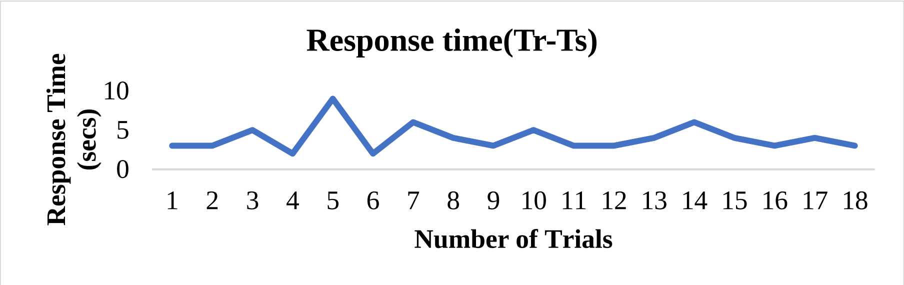


Figure 5: Graph for the Response time of the System

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

4.1 Accuracy Evaluation

Three days' worth of tests were carried out regularly: morning, afternoon, and night. The temperature and humidity levels from the system were recorded and compared with the weather forecast figures for the temperature and humidity of that particular time. Table 4 shows the results obtained.

As shown in Table 4, sensor readings revealed a significant difference in the result. An average error of 2.52 and an average percentage error of 8.20% was discovered. This is potentially due to time lags from the weather forecast models. Weather conditions can change rapidly, and the sensor may not be able to capture up-to-date information at a specific moment. Figure 6 compares the temperature sensor readings of the proposed system and the weather forecast readings. The two lines in the graph are similar, which show the accuracy of the proposed sensor-based DAS. Also, the graph reveals some significant differences between the weather forecast data and the proposed sensor-based DAS data, which might result from the position placement of the temperature sensor.

Table 4: Comparison of proposed systems temperature readings with temperature weather forecast readings.

Day	Period	Temp (°c)	Temp weather forecast (°C)	|Error|	|%Error|
First	10:00am	24.0	30.0	6.00	20.00
	3:00pm	31.0	36.0	5.00	13.89
	9:00pm	31.8	31.6	0.16	0.51
Second	10:00am	27.3	29.0	1.70	5.86
	3:00pm	32.8	35.0	2.20	6.29
	9:00pm	29.4	29.5	0.10	0.34
Third	10:00am	28.2	24.0	4.20	17.50
	3:00 pm	33.2	36.0	2.80	7.78
	9:00 pm	30.5	31.0	0.50	1.61

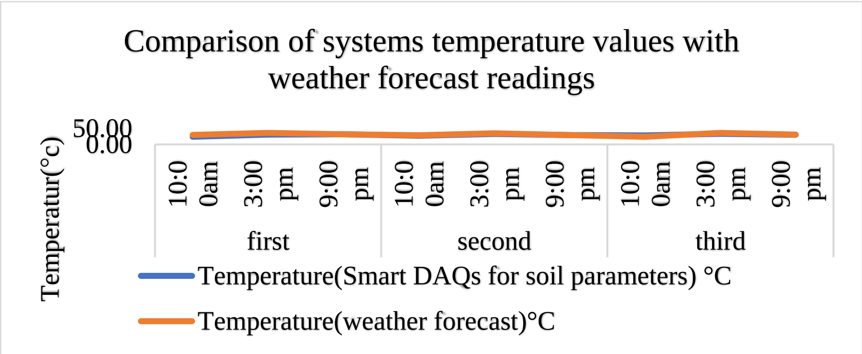


Figure 6: Graph for Comparison of systems temperature values with weather forecast readings.

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

As shown in Table 5, an average error of 3.92 and an average percentage error of 5.08% were estimated from the proposed system reading for humidity and weather forecast data. Figure 7 plots the percentage humidity reading of the proposed system and the weather forecast reading. The difference in the plot is due to time lags from the weather forecast models. Weather conditions can change rapidly, and the sensor may not be able to capture up-to-date information at a specific moment. Another reason might be the position placement of the sensor.

Table 5: Comparison of systems humidity sensor with weather forecast readings for humidity.

Day	Period	Humidity (%)	Humidity (weather forecast %)	|Error|	|% Error|
First	10:00 am	80	83.8	3.79	4.52
	3:00 pm	60	63.3	3.32	5.24
	9:00 pm	65	71.0	6.00	8.45
Second	10:00 am	73	79.9	6.85	8.58
	3:00 pm	66	67.9	1.90	2.80
	9:00 pm	74	74.4	0.44	0.59
Third	10:00 am	74	74.4	0.40	0.54
	3:00 pm	67	68.5	1.54	2.25
	9:00 pm	75	86.0	11.00	12.79

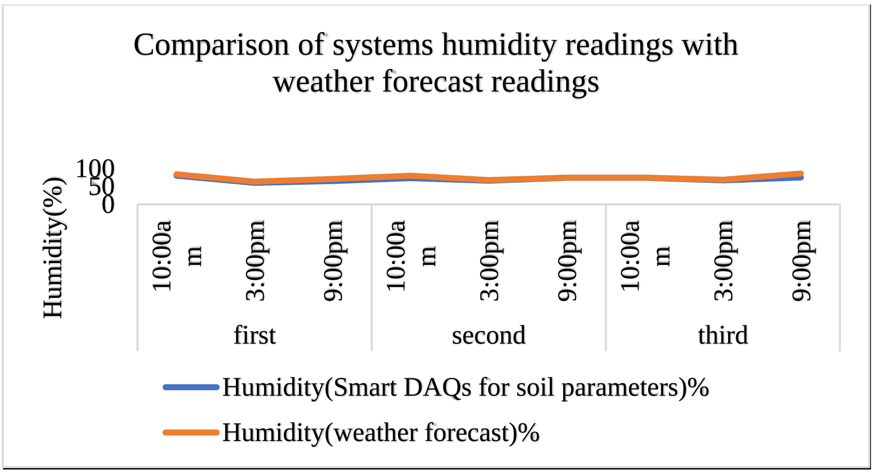


Figure 7: Graph for Comparison of systems humidity readings with weather forecast readings.

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

5 Conclusion

Human supervision and control of farming operations have proven inefficient as humans are prone to many errors, fatigue, and forgetfulness. Also, agriculture production is greatly hampered by ongoing climate change; hence, there is a need for a sensor-based data acquisition system for soil parameters. Some crops cannot grow or bear fruit in places where the climate is not conducive to their development. Moreover, some existing DASs for soil parameters give inaccurate measurements due to the sensors' lack of proper calibration, resulting in significant errors in the measured values. The effect of calibration on the accuracy of soil pH measurements is essential for accurate pH measurements. All these challenges make it difficult to assess soil conditions accurately and can lead to problems such as crop failures, poor resource management, and decreased crop yields. To address these difficulties, this study developed an efficient and precise means of data collection to enable users to make better decisions. The developed sensor-based DAS for soil parameters was used to collect soil pH, moisture, temperature, and humidity from a farm site. Sensors are calibrated using known pH, moisture, and temperature values for specific crops, aiding farmers in making well-informed choices on the best crops to grow and the best times to plant. The performance evaluation of the developed system was carried out using response time and accuracy. The results revealed that the system response time was 4 seconds, and the percentage error for temperature and humidity readings compared to weather forecast readings was 8.20% and 5.08%, respectively. The results show that the proposed system can provide accurate and reliable measurements of soil parameters and can be easily deployed and operated by small-scale farmers. The system can help bridge the technology gap in precision agriculture and promote the adoption of sustainable farming practices. The future direction of this study is to integrate real-time actions such as irrigation systems in the proposed system. Moreover, incorporating renewable energy, such as solar systems, for adequate power supply for the proposed system is another future direction.

6 References

[1] F. O. Idumah, C. Mangodo, U, B. Ighodaro, & P. T. Owombo. (2016). Climate Change and Food Production in Nigeria: Implication for Food Security in Nigeria. *Journal of Agricultural Science*, *8*(2), 74. https://doi.org/10.5539/jas.v8n2p74

[2] P. Divya Vani, & K. Raghavendra Rao. (2016). Measurement and monitoring of soil moisture using Cloud IoT and android system. *Indian Journal of Science and Technology*, *9*(31). https://doi.org/10.17485/ijst/2016/v9i31/95340

[3] D. Neina, (2019). The Role of Soil pH in Plant Nutrition and Soil Remediation. In *Applied and Environmental Soil Science* (Vol. 2019). Hindawi Limited. https://doi.org/10.1155/2019/5794869

[4] U. Shafi, R. Mumtaz, J. García-Nieto, S. A. Hassan, S. A. R. Zaidi, & N. Iqbal, (2019). Precision agriculture techniques and practices: From considerations to applications. In Sensors (Switzerland) (Vol. 19, Issue 17). MDPI AG. https://doi.org/10.3390/s19173796

[5] S. Madakam, R. Ramaswamy, & S. Tripathi, (2015). Internet of Things (IoT): A Literature Review. Journal of Computer and Communications, 03(05), 164–173. https://doi.org/10.4236/jcc.2015.35021

[6] P. Sharma, A Singh, C. S. Kahlon, A. S. Brar, K. K. Grover, M. Dia, & R. L. Steiner, (2018). The role of cover crops towards sustainable soil health and agriculture—A review paper. *American Journal of Plant Sciences*, *9*(9), 1935-1951.

[7] R. Nagarajan, S. Y, Hong, J. H. & Kang, (2019). Impact of low-quality sensors on soil moisture measurements. IEEE Sensors Journal, 19(18), 7803-7810.

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

[8] D. Vyas, A. Borole,, & S Singh, (2016). Smart Agriculture Monitoring and Data Acqusition System. In *International Research Journal of Engineering and Technology*. www.irjet.net

[9] T. Thamaraimanalan, S. P. Vivekk, G. Satheeshkumar, & P. Saravanan, (2018). Smart garden monitoring system using IoT. *Asian Journal of Applied Science and Technology (AJAST)*, *2*(2), 186-192.

[10] S. Biswas, (2018). A remotely operated Soil Monitoring System: An Internet of Things (IoT) Application. *International Journal of Internet of Things and Web Services*, *3*.

[11] P. CHINWUBA Ike, O. EMMANUEL Inoni,, & D. State, (2006). Determinants Of Yam Production And Economic Efficiency Among Small-Holder Farmers in Southeastern Nigeria In *Journal of Central European Agriculture* (Vol. 7, Issue 2).

[12] J. Boobalan, V. Jacintha, J. Nagarajan, K. Thangayogesh, K., & S. Tamilarasu, (2018, April). An IOT based agriculture monitoring system. In *2018 international conference on communication and signal processing (ICCSP)* (pp. 0594-0598). IEEE.

[13] R. N. Rao, & B. Sridhar, (2018, January). IoT based smart crop-field monitoring and automation irrigation system. In *2018 2nd International Conference on Inventive Systems and Control (ICISC)* (pp. 478-483). IEEE.

[14] M. M Kolapkar, P. W. Khirade, & S. B. Sayyad, (2016). Design and development of embedded system for measurement of humidity, soil moisture and temperature in polyhouse using 89e516rd microcontroller. *International Journal of Advanced Agricultural Sciences and Technology*, *5*(1), 96-110.

[15] A Srivastava, D. K. Das & R. Kumar, (2020, July 10). Monitoring of soil parameters and controlling of soil moisture through IoT based smart agriculture. *2020 IEEE Students' Conference on Engineering and Systems, SCES 2020*. https://doi.org/10.1109/SCES50439.2020.9236764

[16] M. AshifuddinMondal, & Z. Rehena, (2018, January). Iot based intelligent agriculture field monitoring system. In *2018 8th International Conference on Cloud Computing, Data Science & Engineering (Confluence)* (pp. 625-629). IEEE.

[17] M. K. Saini & R. K. Saini, (2020, November). Agriculture monitoring and prediction using Internet of Things (IoT). In *2020 Sixth International Conference on Parallel, Distributed and Grid Computing (PDGC)* (pp. 53-56). IEEE.

[18] G. Sushanth & S. Sujatha, (2018, March). IOT based smart agriculture system. In *2018 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)* (pp. 1-4). IEEE.

[19] I. S. Ichwana, Nasution, S Sundari, & N. Rifky, N. (2020). Data Acquisition of Multiple Sensors in Greenhouse Using Arduino Platform. *IOP Conference Series: Earth and Environmental Science*, *515*(1). https://doi.org/10.1088/1755-1315/515/1/012011

[20] A. G. Adeyonu, O. L. Balogun, B. O. Ajiboye, I. B. Oluwatayo, & A. O. Otunaiya, A. O. (2019). Sweet potato production efficiency in Nigeria: Application of data envelopment analysis. *AIMS Agriculture and Food*, *4*(3), 672–684. https://doi.org/10.3934/agrfood.2019.3.672

[21] E. S. Ikuemonisan, T. E. Mafimisebi, I. Ajibefun, I., & K. Adenegan, (2020). Cassava production in Nigeria: trends, instability and decomposition analysis (1970–2018). *Heliyon*, *6*(10). https://doi.org/10.1016/j.heliyon.2020.e05089

[22] I. M. Azare, I. J. Dantata, M. S. Abdullahi, A. A. Adebayo, & M. Aliyu, (2020). Effects of climate change on pearl millet (*Pennisetum glaucum* [L. R. Br.]) production in Nigeria. *Journal of Applied Sciences and Environmental Management*, *24*(1), 157. https://doi.org/10.4314/jasem.v24i1.23

[23] A. S. Ajala., & A Gana, (2015). Analysis of Challenges Facing Rice Processing in Nigeria. *Journal of Food Processing*, *2015*, 1–6. https://doi.org/10.1155/2015/893673

[24] Ahmad Yahaya, M., Shimelis, H., Nebie, B., Ojiewo, C. O., & Danso-Abbeam, G. (2022). Sorghum production in Nigeria: opportunities, constraints, and recommendations. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, *72*(1), 660–672. https://doi.org/10.1080/09064710.2022.2047771

[25] O. Adebisi-Adelani, & O. B. Oyesola, (2014). Farmers' Perceptions of the Effect of Climate Change on Tomato Production in Nigeria. *International Journal of Vegetable Science*, *20*(4), 366–373. https://doi.org/10.1080/19315260.2013.813890

JDFEWS 4 (2): 194 - 206, 2023
ISSN 2709-4529

[26] J. O. Olaniyi, & A. E. Ojetayo. (2011). Effect of fertilizer types on the growth and yield of two cabbage varieties. In *Journal of Animal & Plant Sciences* (Vol. 12). http://www.biosciences.elewa.org/JAPS;

7 Authors

Blessing Olatunde Abisoye is a PhD student at the University of Johannesburg, Department of Electrical and Electronic Engineering Science, South Africa. He attended the University of Ilorin, Nigeria, where he obtained his B.Eng., MEng. Degree in Electrical and Electronic Engineering. His research interests are Machine Learning, Optimization, Renewable Energy and Control systems. He has served as a Lecturer I in the Department of Computer Engineering, Federal University of Technology, Minna, Nigeria, from 2017 till date. He has many publications in reputable journals and conferences. He is a Registered member of the Council for the Regulation of Engineering in Nigeria (COREN) and the Nigeria Society of Engineers (NSE)**.**

Eustace Manayi Dogo holds B.Sc and M.Eng degrees in Electrical Engineering from St. Petersburg State Technical University, Russia (Now known as Peter the Great St. Petersburg Polytechnic University, Russia) and a Ph.D degree in Electrical and Electronic Engineering (Artificial Intelligence and Machine Learning) from the University of Johannesburg, South Africa. He is a Registered Engineer with the Council for the Regulations of Engineering in Nigeria (COREN). Engr. Dr. E. Dogo is currently a Senior Lecturer and Head of the Department of Computer Engineering at the Federal University of Technology.

Umar Buhari Ugbede holds B.Eng. degrees in Electrical/Electronic Engineering, M. Eng and Ph.D degree in Computer Engineering (Artificial Intelligence and Machine Learning) from the Federal University of Technology, Minna, Nigeria. He is a Registered Engineer with the Council for the Regulations of Engineering in Nigeria (COREN). Engr. Dr. B U Umar is currently Lecturer in the Computer Engineering Department at the Federal University of Technology.

Mamman Isaac Zhiri is a graduate of Computer Engineering at the University of Technology, Minna, Nigeria. His interests are Machine Learning, Optimization, Renewable Energy and Control systems.