Programa de Doctorado (D442) en Ingeniería de la Información y del Conocimiento

MODEL-DRIVEN ENGINEERING AND PREDICTIVE ANALYTICS FOR IMPLEMENTATION OF SUSTAINABLE DEVELOPMENT GOALS

Tesis Doctoral presentada por

EMMANUEL OKEWU

Directors:
DR. LUIS FERNÁNDEZ SANZ
PROF SANJAY MISRA

Alcalá de Henares, 2020

UNDERTAKING

The work presented in my thesis entitled "Model-driven Engineering and Predictive Analytics for Implementation of Sustainable Development Goals", submitted in the University of Alcala de Henares, Spain, for the award of Doctor of Philosophy in Information and Knowledge Engineering, is my original work. I have not copied and/or borrowed and not submitted for award any other degree/certification. In case it is found incorrect, my degree is liable to be cancelled.

Emmanuel Okewu
Date: 22.06.2020
Place: Alcalá de Henares, Madrid

ACKNOWLEDGEMENT

Special thanks to my supervisors, Dr. Luis Fernandez-Sanz and Prof. Sanjay Misra for their immense contributions and guidance in the course of this PhD study.

I also appreciate my family members for the support given to me in the course of the study.

ABSTRACT

Improving the quality of implementation of sustainable development plans remains a concern among involved actors. Measurement, monitoring and evaluation are the three cardinal phases that any sustainable development plan is subjected to in order to guarantee successful implementation. The less-than-impressive implementation of previous global sustainable plans such as the Millennium Development Goals (MDGs) mean that there is need to explore a better approach to measuring, monitoring, and evaluating of plans at national and sub-national levels. The failure of the MDGs (2000-2015) has been partly blamed on inadequate use of data expressed in terms availability on one hand, and inability to detect and predict patterns in the available data on the other hand. In this present work, we improve on measurement and monitoring by promoting understanding and collaboration among stakeholders using model-driven engineering (MDE). MDE simplifies and demystifies system development concepts. This is achieved by graphically demonstrating entities and relationships and quantifying them. We also propose the integration of predictive analytics in the evaluation of sustainable development objectives using deep learning neural networks (DLNN). This machine learning technique detects patterns in existing data and predicts outcome of future data using patterns learnt. The combination of these contributions in improving measurement, monitoring and evaluation is aimed at improving the implementation of present and future global plans such as the Sustainable Development Goals (2015 -2030).

Keywords: evaluation, measurement, models, monitoring, predictive analytics, sustainable development goals

RESUMEN

La mejora de la calidad de la implementación de los planes de desarrollo sostenible sigue siendo una preocupación entre las entidades implicadas. La medición, la supervisión y la evaluación son las 3 fases cardinales a las que está sometido cualquier plan de desarrollo sostenible para garantizar una implementación exitosa. La implementación de planes globales de sostenibilidad previos estuve lejos de ser impactante, como en el caso de los Objetivos de Desarrollo del Milenio (ODM) y eso significa que existe una necesidad de explorar enfoques mejores para medir, supervisar y evaluar tales planes a nivel nacional y local. El fallo de los ODM se ha atribuido, en parte, a un uso inapropiado de los datos en cuanto a disponibilidad, por un lado, y a la incapacidad para detectar y predecir patrones en los datos disponibles, por el otro. En este trabajo, mejoramos la medición y la supervisión al promover un mejor entendimiento entre las entidades implicadas utilizando la ingeniería dirigida por modelos (*model-driven engineering*, MDE). La MDE simplifica y desmitifica los conceptos de desarrollo. Esto se consigue mediante la demostración gráfica de las entidades y sus relaciones y su cuantificación. También proponemos la integración de la analítica predictiva en la evaluación de los objetivos de desarrollo sostenible utilizando redes neuronales de Deep Learning (*deep learning neural networks*, DLNN). Esta técnica de aprendizaje automático detecta patrones en los datos existentes y predice el resultado de datos futuros utilizando los patrones aprendidos. La combinación de estas contribuciones para mejorar la medición, la supervisión y la evaluación está orientada a la mejora de la implementación de los planes globales presentes y futuros como los Objetivos de Desarrollo Sostenible (2015-2030).

Palabras clave: evaluación, medición, modelos, supervisión, análisis predictivos, objetivos de desarrollo sostenible

CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER

1. INTRODUCTION

1.1 INTRODUCTION

Scientific modelling of sustainable development initiatives can be used to offer scientific advice for designing policies, implementing programmes and managing projects. Sustainable development is a research field where the Information and Communications Technology (ICT) value chain has not been fully exploited, leaving gaps (Meadows, 1998; Sustainable Development, 2015). The gaps include inefficient implementation of national and sub-national sustainable development plans occasioned by lack of online real-time strategic stakeholders' engagement for measuring, monitoring and evaluation of the plans. Policy documents on sustainable development like national economic growth and recovery plans are textual and data are hidden in voluminous details which implementation actors may find difficult to comprehend (Kyarem and Ogwuche, 2017). Also, national statistics as provided by the legally backed national bureaus may be too numerical, technical, and voluminous for stakeholders (Kale, 2017). Software models provide a mid-way for simplifying concepts in policy documents and numbers in the national statistical database by using unified modelling language (UML) activity diagrams to show entities and relationships (Sommerville, 2011; Aggarwal and Singh, 2008). Presenting details of implementation in a simplified format prepares stakeholders for the tasks of measuring, monitoring, and evaluating socio-economic development plans objectively. ICT involvement in building sustainable development information systems so far focuses on data collection and dissemination. For a comprehensive technological response, we propose the integration of software models in promoting understanding of stakeholders and collaboration among them when measuring and monitoring development initiatives. There is also the need to incorporate predictive analytics in the detection and prediction of patterns in data for informed decision making in evaluating development plans. While the integration of software models is aimed at promoting stakeholders' understanding of policies and actions, useful and hidden patterns in development-related data could be detected and reliable predictions made with the incorporation of predictive analytics aimed at enhancing stakeholders' capacity of handling socio-economic emergencies.

Improving the implementation of sustainable development programmes requires a multi-stakeholder participatory approach (Guterres, 2019). Global resources may be limited, but a bigger problem is the mismanagement of resources through bribery and corruption fueled by non-transparent governance (Ugaz, 2017; UNODC, 2019). A transparent governance structure that facilitates effective measurement, monitoring and evaluation of programmes is required. We advocate that computational techniques like model-driven engineering and predictive analytics be integrated for realizing this objective. Software models make entities and relationships (which can also be expressed in terms of data) in a domain clearer to stakeholders while predictive analytics are used to detect and predict patterns in data for informed and proactive handling of human emergencies.

The level of success of global sustainable development plans such as MDGs (2000 -2015) and now SDGs (2015 – 2030) remains a source of concern to stakeholders. Poor implementation means not much impact has been made on the welfare and wellbeing of the citizenry. There is need to activate and make more relevant key sustainable development activities like measurement, monitoring and evaluation so that national and sub-national plans could be benchmarked against metrics set in global sustainable plans like MDGs and SDGs. Against the backdrop of the less-than-impressive success recorded in the implementation of the MDGs (2000-2015), the SDGs deliberately inserted Goal 17 to underscore the role of successful implementation in any development plan (Report, 2016). It emphasizes the exigency of strengthening the means of implementation. Among other implementation measures, SDG 17 states that data and technology are invaluable for measurement, monitoring and evaluation of sustainable development initiatives in various countries the vis-à-vis existing worldwide development plan. SDG target 17.8 stresses the need not only to fully operationalize the technology bank and science for least developed countries but also enhance the use of enabling technology, specifically information and communications technology. To underscore the correlation between data, monitoring and accountability, SDG 17.18 seeks to increase the availability of high-quality, timely and reliable data in developing countries, inclusive of Small Island developing States and least developed countries. Furthermore, SDG 17.19 targets 2030 for building on existing initiatives to develop measurements of progress on sustainable development. This will complement gross domestic product, as well as support statistical capacity-building in developing countries.

Proponents of sustainable development have pointed out that apart from the relatively small quantum of data generated during the MDGs era, appropriate technology that detects and predicts patterns in data was not applied. As a result, even when data was available, eliciting hidden and useful patterns in the data for informed decision making was lacking. This means a sub-optimal utilization of resources and less-than-impressive handling of emergencies that bear a lot on the lives and livelihood of the people. In essence, a combination of data and technology is required for efficient and effective measurement, monitoring and evaluation of sustainable development efforts at national and sub-national levels for optimal implementation. To address the implementation problem of global sustainable development plans, we propose the integration of two technologies: model-driven software engineering and predictive analytics. Our proposed model-driven engineering approach involves using unified modelling language (UML) while our predictive analytics cover learning algorithms like naïve Bayesian network, decision tree, and deep learning neural networks. In our study, we use aspects of the SDGs (2015 – 2030) as case studies and show how model-driven software engineering and predictive analytics could enhance measurement, monitoring and evaluation of sustainable development initiatives for better implementation of national and sub-national socio-economic plans.

Software model (architecture) is not only useful in the domain of software development. It has been proven that software architecture could be applied to any problem domain to simplify and demystify concepts particularly at the programme/project design stage (Gorton, 2011; Pressman, 2009). This, in turn, promotes cooperation and collaboration among project stakeholders and fast-track project implementation. By implication, sustainable development activities and objective could be better appreciated by stakeholders, and the activities of measurement and monitoring made easier if proper understanding is promoted using software models. Software models show clearly entities and their relationships in a graphical format for easy comprehension of activities in the domain.

On the other hand, data revolution and explosion currently experienced in the SDGs era (2015 - 2030) as occasioned by ICT devices like biometrics, closed-circuit television, satellites, and drones result in big data with a huge amount of structured and unstructured data. In addition, nations are required to build legally backed national statistical institutions that present national data in line with international best practices (National Bureau, 2017; Kale, 2017). Big data is not appreciated in the sense of its volume but rather in the sense of the value its hidden and useful patterns could

be harnessed for productive purposes. In this regard, there is need to applied technology that detects and predicts patterns in the data, a missing component in the MDGs era. Thus, in this thesis, we propose the integration of deep learning neural networks (DLNN) in sustainable development implementation for better evaluation of plans for optimal outcomes. DLNN is a predictive analytics technology that uses multiple layers of computational neurons to detect patterns in historical data and uses the patterns learnt to predict the outcome of future input. This means that emergencies could be predicted and proactively managed through informed decision making for the sustenance of lives and livelihoods.

The SDGs have 17 thematic areas of sustainable development (Report, 2016; Solomon and Fidelis, 2018). Our thesis however explored 5 aspects as case studies – climate change, national security (peace), productivity, Social safety net, and environmental sustainability. Metrics set in the global SDG framework for these case study areas against which developmental strides at national and sub-national levels are to be benchmarked as outlined in Table 1.

Study area	SDG	Related Targets	Related Indicators
Climate change	Goal 13. Take urgent action to combat climate change and its impacts	13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	13.3.1 Number of countries that have integrated mitigation, adaptation, impact reduction and early warning into primary, secondary and tertiary curricula 13.3.2 Number of countries that have communicated the strengthening of institutional, systemic, and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions
National security (peace and stability)	Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 16. Promote peaceful and inclusive societies for sustainable development, provide	16.5 Substantially reduce corruption and bribery in all their forms	16.5.1 Proportion of persons who had at least one contact with a public official and who paid a bribe to a public official or were asked for a bribe by those public officials, during the previous 12 months. 16.5.2 Proportion of businesses that had at least one contact with a public official and that

	access to justice for all and build effective, accountable and inclusive institutions at all levels		paid a bribe to a public official or were asked for a bribe by those public officials during the previous 12 months.
Productivity	Goal 8. Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all	8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value 8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training. 8.b By 2020, develop and operationalize a global strategy for youth employment and implement the Global Jobs Pact of the International Labour Organization.	8.5.1 Average hourly earnings of female and male employees, by occupation, age and persons with disabilities 8.5.2 Unemployment rate, by sex, age and persons with disabilities 8.6.1 Proportion of youth (aged 15-24 years) not in education, employment or training 8.b.1 Total government spending on social protection and employment programmes as a proportion of the national budgets and GDP
Social safety net	Goal 1. End poverty in all its forms everywhere	1.3 Implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable 1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance 1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	1.3.1 Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, new-borns, work injury victims and the poor and the vulnerable 1.4.1 Proportion of population living in households with access to basic services 1.4.2 Proportion of total adult population with secure tenure rights to land, with legally recognized documentation and who perceive their rights to land as secure, by sex and by type of tenure 1.5.1 Number of deaths, missing persons and persons

			affected by disaster per 100,000 people. 1.5.2 Direct disaster economic loss in relation to global gross domestic product (GDP)a 1.5.3 Number of countries with national and local disaster risk reduction strategies.
Environmental sustainability	Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world 15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type 15.3.1 Proportion of land that is degraded over total land area 15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011-2020

Table 1. Metrics in selected SDGs

1.1.1 Defining the problem

The way sustainable development concepts are analyzed and internalized by stakeholders can impact on transparency and fulfilment of the obligations of measuring, monitoring and evaluating socio-economic initiatives. Lack of transparency in handling public finances and dwindling stakeholders' confidence in governance structure has impaired the implementation of development plans (Prusa and Kilanko, 2018; Kyarem and Ogwuche, 2017). Our motivation in this work is to scale up transparency and improve stakeholders' participation and collaboration in the measurement, monitoring and evaluation of sustainable development initiatives using software models and predictive analytics. We propose that the integration of these scientific techniques will promote transparency, openness, accountability and probity in the management of public resources

for enhanced implementation. Sustainable development is a process of ensuring improved standards of living for a future, we desire (Bamberger et al., 2017). Over time, international standards have been set and plans formulated to achieve the future humanity desires. Such international plans, in recent times, include the Millennium Development Goals – MDGs (2000–2015) and the ongoing Sustainable Development Goals - SDGs (2015-2030). These global sustainable development plans are measured in terms of the number of goals, the number of targets, and the number of indicators. The international metrics provide the basis for monitoring progress at national and sub-national levels where concrete and peculiar sustainable development plans and programmes are formulated for citizen-oriented development as captured in SDG 17.8 and 17.9. Periodically, the national sustainable development plans are evaluated by stakeholders such as international development partners, non-governmental organizations and the citizenry to ascertain how government developmental strides have been able to meet the metrics set in the international development frameworks.

Measurement, monitoring, and evaluation are the cardinal activities of any sustainable development initiative. In our work, we test these ideas using scientific methods (modelling and predictive analytics). For these activities to impact maximally on the output of a sustainable development plan, actors and implementors need to be guided by data and data analytics. Also, policy awareness and robust understanding of sustainable development concepts can be enhanced using computational models. Past global sustainable development frameworks have been less successful due to inadequate data and even the existing data was not properly harnessed to empower the decision-making process that determines the use of scarce public resources for the overall wellbeing of humanity. As a result, this study explores the application of predictive analytics in measuring, monitoring and evaluating sustainable development programmes in different climes. The research questions and sub-questions which are the motivators for conducting the study are as follows:

RQ: Is it possible to improve the implementation of sustainable development initiatives at national and sub-national levels in terms of probity, accountability and transparency for optimal public resource utilization using model-driven engineering and predictive analytics?

1. RSQ1: Can software models be used to promote understanding and collaboration among stakeholders for the purpose of measuring sustainable development activities?

2. RSQ2: What are the constraints in harnessing data for monitoring of sustainable development plans and how can we use data pre-processing to tackle the constraints such that the monitoring process is acceptable to implementation actors?
3. RSQ3: How can predictive analytics be harnessed for addressing the challenge of inadequate evaluation of sustainable development plans?

1.1.2 Literature Review

Over time, diminishing confidence of proponents in the implementation of national and sub-national plans have led to the sub-optimal performance of global sustainable development plans (Oleribe and Taylor-Robinson, 2016). Stakeholders' loss of confidence is hinged on inadequate transparency and accountability in the application of public finance. Our proposed integration of scientific and computational approach is to activate the transparency architecture using software models and data analytics for better implementation.

Sustainable development covers a wide range of areas that affect humanity (Vaessen and D'Errico, 2018). The current global sustainable development plan (the SDGs) articulates sustainable development in the context of 17 goals while its predecessor, MDGs, contextualized sustainable development using only 8 goals. Clearly, SDGs is a broader approach to sustainable development than MDGs. This implies that a larger range of activities is expected in the implementation of SDGs that MDGs. Already the literature has it that one of the key reasons while the MDGs (2000 – 2015) did not meet global development expectations was that inadequate use of data for driving its activities. With data explosion and revolution in the SDGs era (2015 – 2030) occasioned by a preponderance of ICT technologies like smartphones, close circuit television (CCTV), satellite images and drones, focused has shifted from the availability of data to the detection of patterns in the humongous data generated in this millennium for value creation (United Nations, 2019; Verhulst and Young, 2017). Harnessing the big data by generating precise and robust information would enhance the broad range of activities involved in the implementation of the SDGs. Data-driven processes would ensure that the key phases of measuring, monitoring and evaluating respective national sustainable development programmes are well articulated. A platform that enables stakeholders to engage themselves real-time and generates knowledge on real-time basis from existing data for robust decision making can improve implementation (Elgendy et al., 2016). Apparently, SDG implementation activities are many; our literature survey is limited to some areas of sustainable development. Therefore, this section focuses on the literature

related to the background of the research carried out in the articles put together in the thesis. In the respective chapters, we a provide detailed literature survey.

1.1.2.1 Information and Communication Technology in Sustainable Development

We have discussed in (Okewu et al., 2018) the growing role of Information and Communications Technology (ICT) in sustainable development which has given rise to a big field of research called Information and Communications for Development (ICT4D). In view of the failure experienced in the implementation of previous global sustainable development plans such as the MDGs (2000 – 2015), and in a proactive bid to avoid a repeat with existing and future global development agendas, SDG 17 advocates strengthening the means of implementation and revitalization of the global partnership for sustainable development. Among other strategies to be deployed in this respect is the use of data and ICT. The use of technology for successful implementation is well canvased in targets and indicators of SDG 17 as outlined in Table 2 (Report, 2016).

Goal	Targets	Indicators
SDG 17	17.6 Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge-sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism	17.6.1 Number of science and/or technology cooperation agreements and programmes between countries, by type of cooperation
		17.6.2 Fixed Internet broadband subscriptions per 100 inhabitants, by speed
	17.7 Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favorable terms, including on concessional and preferential terms, as mutually agreed	17.7.1 Total amount of approved funding for developing countries to promote the development, transfer, dissemination, and diffusion of environmentally sound technologies
	17.8 Fully operationalize the technology bank and science, technology, and innovation capacity-building	17.8.1 Proportion of individuals using the Internet

	mechanism for least developed countries by 2017 and enhance the use of enabling technology, in particular information and communications technology	

Table 2.Use of technology for enhancing implementation of sustainable development as outline in SDG 17.

The relationship between data, monitoring and accountability has been outlined by SDG 17 targets and indicators as tabulated in Table 3.

Goal	Target	Indicator
SDG 17	17.18 By 2020, enhance capacity-building support to developing countries, including for least developed countries and small island developing States, to increase significantly the availability of high-quality, timely and reliable data disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts	17.18.1 Proportion of sustainable development indicators produced at the national level with full disaggregation when relevant to the target, in accordance with the Fundamental Principles of Official Statistics
		17.18.2 Number of countries that have national statistical legislation that complies with the Fundamental Principles of Official Statistics
		17.18.3 Number of countries with a national statistical plan that is fully funded and under implementation, by source of funding
	17.19 By 2030, build on existing initiatives to develop measurements of progress on sustainable development that complement gross	17.19.1 Dollar value of all resources made available to strengthen statistical capacity in developing countries.

	domestic product, and support statistical capacity-building in developing countries	17.19.2 Proportion of countries that (a) have conducted at least one population and housing census in the last 10 years; and (b) have achieved 100 per cent birth registration and 80 per cent death registration.

Table 3. Relationship between data, monitoring and accountability as outlined in SDG 17

While the outline of SDG 17 provides evidence of measurement of sustainable development activities by setting global quantitative benchmarks, our research focuses on measuring, monitoring and evaluating national and sub-national development agendas and comparing achievements with metrics set in the global SDGs. The lack of transparency in the management of public resources is a major setback in the implementation process (Maendeleo Policy, 2017). As a redress, implementation has to be interlaced with software models and predictive analytics that culminate in intelligent information systems for sustainable development (Siegel, 2013; Sommerville, 2011). Our proposal encompasses software-based solutions that inject transparency by engaging stakeholders online and making real-time information available to them on the utilization of public resources. We used UML activity diagrams for modelling (Aggarwal and Singh, 2008). We test our proposal empirically by experimenting with data, models, and predictive analytics tools as published in our journal papers.

1.1.3 Model-driven engineering for Measurement and Monitoring for Accountability

It is shown (Okewu et al., 2017) that empirical data could be collected, modelled using UML activity diagrams and system developed and implemented to engage community stakeholders for participatory governance. Though many nations have established national statistical institutions that make national data available (National Bureau, 2017), there is a need to use models to interpret the data to stakeholders for the proper fulfilment of their monitoring obligation. The link between data, monitoring and accountability can be strengthened using software models. Entity-relationship diagram, for example, when used to represent sustainable development activities show the relationship among various entities. Entities and relationships are quantified, providing a basis for the sustainable development proponents to monitor activities and make appropriate corrections, should there be deviations. The openness and transparency which models introduce into otherwise

confusing details make accountability by public officials easy. It is an established fact that corruption and bribery thrive in an atmosphere of secrecy. Software models may be a bit technical, but recent developments have made it mandatory for users of software models to provide enough explanation so that all stakeholders in a project could be carried along.

1.1.3.1 Predictive Analytics and Evaluation of Sustainable Development Plans

In (Okewu et al., 2019a; Okewu et al., 2019b), predictive analytics like Bayesian network and deep learning neural network were used to detect patterns in historical data and predict the outcome of future data based on patterns learnt. Predictive analytics is a subset of data analytics. Data analytics refers to data-assisted problem-solving and decision-making that is used to unveil patterns in data, which are invaluable for knowledge and information generation for the purpose of rational and informed decision-making (Li et al. 2016). Evaluation of sustainable development plans at national and sub-national levels should be based on data and data analytics to devoid the process of bias and politics. Objective evaluation allows data to be captured during development activities and such data subjected to analytics to detect and predict patterns in the data. It is the hidden and useful patterns in the data that are used to meaningfully assess the viability or otherwise of sustainable development efforts. With the increased paradigm shift from textual data to image data even in sustainable development activities occasioned by the integration of technologies like biometrics, closed-circuit television, satellite and drones, predictive analytics tools such as artificial neural network are being patronized. In our study, we specifically used deep learning neural networks.

1.2 Research goals

We prioritize the understanding and collaboration of stakeholders for efficient and effective measurement, monitoring and evaluation of sustainable development drives. The following are the goals of the proposed thesis:

1. To improve the decision-making process in sustainable development drive by applying data science and predictive analytics to the implementation of the Sustainable Development Goals (SDGs).

2. To improve sustainable development process through the three critical activities of measuring, monitoring and evaluating the implementation of the SDGs. The work focuses on three linked and high impact methods:
   2.1. To improve the quality of measurement in global sustainable development plans.
   2.2. To produce an empirical model for monitoring sustainable development programmes.
   2.3. To produce a novel method for evaluating sustainable development programmes using predictive analytics.

1.3 Contributions

To start with, we carried out an exhaustive literature survey in the three mentioned fields of measurement, monitoring, and evaluation. We observed that researchers working in the area of sustainable development always focus on galvanizing stakeholders' participation and collaboration for appropriate measurement metrics, enhanced monitoring mechanisms, and strengthening of evaluation frameworks (Bamberger, 2016; Vaessen and D'Errico, 2018). Hence, our contributions as outlined in this thesis revolve around using software architecture and predictive analytics to engage implementation actors online and empower them with accurate real-time information for measuring, monitoring and evaluating sustainable development initiatives. During the literature survey, problems in these areas were identified, and we developed our proposal based on them. The thesis is structured as a compendium of impact publications. This implies that its contribution is based on three publications and several other articles already published in impact journals and conferences as shown in Tables 4, 5, 6 and 7.

Impact Article 1

Title	Okewu E., Misra S. and Okewu J. (2017). "Model-Driven Engineering and Creative Arts Approach to Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria", Journal of The Problems of Sustainable Development, Vol. 12 No. 1 2017, European Academy of Science and Arts, Salzburg. *ekorozwoj.pollub.pl › index.php › number-1212017*
Features	The article shows how software models such as Use Cases, Component Diagrams and Class Diagrams could be used to simplify developmental issues that could otherwise pose difficulty for stakeholders to comprehend. Apart from simplifying entities and relationships in domains which may actors and stakeholders may not be familiar with hitherto, empirical data were collected and presented to enhance quantitative measurement of sustainable development activities. Though the software models may themselves be scientific, we offered basic and adequate explanation so that stakeholder could comprehend. Integrating a model-driven engineering approach such as this in sustainable development documents saves stakeholders the energy and time of going through textual policy documents whose technicality and voluminous nature may discourage actors and implementors from

	studying. This negates the principles of openness, transparency and accountability as collective understanding is key to collective collaboration for delivering welfare packages and services.
Impact	The Journal of The Problems of Sustainable Development is an important journal in the area of sustainable development. Otherwise known as Problemy Ekorozwoju, it is a scientific journal from the field of social sciences and philosophy, published under the auspices of the European Academy of Science and Arts (Salzburg, Austria). Annually, two issues are published. Our paper has been cited 4 times since its publication. The journal is an SCI journal with ISSN 1895-6912, 2080-1971. It has ISI JCR impact factor of 0.5777 (2018) and 4-year impact factor of 0.746 (2015 -2018). It has impact factor quartiles of Q4 (Web of Science) and Q3 (Scimago). Its Scopus CiteScore is 0.62 while its Source Normalized Impact per Paper (SNIP) is 0.937.

Table 4. Article published in Journal of The Problems of Sustainable Development

Impact Article 2

Title	Okewu E., Maskeliunas R., Misra S., Damasevicius R., and Fernandez-Sanz L. (2018). "Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem", October 2018, Journal of Sustainability 2018(9). *https://www.mdpi.com/2071-1050/9/10/1857*
Features	Monitoring of national and sub-national sustainable development plans can be made effective and efficient by comparing their development metrics with those set in global sustainable development plans. For efficiency, developmental initiatives have to be quantified and data pre-processed for meaningful usage in addressing socio-economic challenges. In our paper, we show through a series of software experiments that members of a community could be put online for participatory governance which involves leaders and the led expressing opinions on proposed projects. In the process, the stakeholders compare their local developmental metrics with those set in global sustainable development plans. Specifically, the paper addresses the problem of green climate in developing economies. It provides

	guidelines for equitable utilization of ecological funds, including the financial aids from advanced countries to less developed countries. This is indicated in SDG target 13.a and measured by SDG indicator 31.a.1. The advocates mass mobilization of the public on the adverse effects of arbitrary disposal of e-Waste. It also classifies raising the awareness level of the dangers posed by e-waste as a stochastic optimization problem given the uncertainty surrounding efforts in developing climes, given their culture, belief systems, poverty levels, and infrastructural deficit. The essence of the computational modelling using software tools is to enhance understanding of climate change stakeholders as well as enlist their maximum support in guaranteeing environmental sustainability and economic prosperity.
Impact	The paper is published in the Journal of Sustainability. Sustainability is a monthly peer-reviewed, open access, scientific journal that is published by MDPI. Established in 2009, it explores aspects like cultural, environmental, economic and social sustainability for human beings. It has impact factor of 2.075 (2017) and is published by MDPI. The paper has been cited 13 times since its publication. According to the Journal Citation Reports (JCR), the journal has an impact factor of 2.075. It has impact factor quartiles of Q2 (Web of Science) and Q2 (Scimago).Its Scopus CiteScore is 3.10 (2018) while its Scimago Journal Rank is 0.55 for 2018.

Table 5. Article published in Journal of Sustainability

Impact Article 3

Title	Okewu E., Misra S., and Fernandez-Sanz L. (2019). "Deep Neural Networks for Curbing Climate Change-Induced Farmers-Herdsmen Clashes in a Sustainable Social Inclusion", Journal of The Problems of Sustainable Development, Vol. 14 No. 2 2019, European Academy of Science and Arts, Salzburg, Poland. *ekorozwoj.pollub.pl › index.php › number-1422019*

Features	The work shows that predictive analytics could be used to understand behaviours and activities in the sustainable development domain. We applied deep learning neural networks to model data related the farmers-herdsmen clashes to detect and predict patterns in disposition to violence at the slightest provocation. We aimed at improving the capacity of decision-makers to take pragmatic and proactive decisions during emergencies to forestall break down of law and order. This is critical to achieving peace, justices and strong institutions as contained in SDG 16, the bedrock for achieving other SDGs. Sustainable development is all-embracing, and the SDGs are tailored to address every aspect of human development. The SDGs also advocates that no one is left behind as every voice counts in global development. Our investigation revealed that farmers and herdsmen constitute a percentage of the poor and vulnerable whose welfare can be improved by promoting accountability, transparency and probity in the management of scarce resources. The study outcome revealed a strong correlation between effective use of data and the success of socially inclusive measures aimed at reducing risks and global poverty levels as mentioned in SDG 1.3 and measured in SDG 1.3.1. In a closely related paper titled *Experimental Comparison of Stochastic Optimizers in Deep Learning* we published in *Lecture Notes of Computer Science*, we show through series of experiments that predictive analytics like deep learning neural networks has over 98% accuracy rate. This implies that sustainable development decision makers can rely on this tool for 98% accuracy in forecasting when handling emergency situations.
Impact	The Journal of The Problems of Sustainable Development is an important journal in the area of sustainable development. Otherwise known as Problemy Ekorozwoju, it is a scientific journal from the field of social sciences and philosophy, published under the auspices of the European Academy of Science and Arts (Salzburg, Austria). Annually, two issues are published. The paper has been cited 4 times since its publication. The journal is an SCI journal with ISSN 1895-6912, 2080-1971. It has ISI JCR impact factor of 0.5777 (2018) and 4-year impact factor of 0.746 (2015 -2018). It has impact factor quartiles of

	Q4 (Web of Science) and Q3 (Scimago). Its Scopus CiteScore is 0.62 while its Source Normalized Impact per Paper (SNIP) is 0.937.

Table 6. Article published in The Journal of the Problem of Sustainable Development

Besides the scientific validation by the journals' committees, the three contributions are supported by data collection and practical validation.

- The model for the measurement of sustainable development programmes is validated in the context of the socio-economic environment of a country where stakeholders work in synergy for an improved standard of living.
- The model for the monitoring is equally applied in the socio-economic context of a country. We continue this process of practical validation by comparing metrics set in various national sustainable development plans with those in the global SDG plan.
- Lastly, we proposed the integration of predictive analytics in the evaluation of sustainable development programmes. This is after experimentally confirming that deep learning neural network can guarantee over 98% prediction accuracy. We validated using Python deep learning platform.

1.4 Other publications

The three main journal articles apart, we have other publications which are related to the present work. These articles have been summarized in Table 7.

Okewu E,. Misra S., Okewu J., Damasevicius R., and Maskeliunas R. (2019). "An Intelligent Advisory System to Support Managerial Decisions for A Social Safety Net", Adm. Sci. 2019, 9, 55; doi:10.3390/admsci9030055 The paper has been cited 1 time since its publication. *Administrative Sciences* is an international journal with ISSN 2076-3387. It is a peer-reviewed scholarly open access journal published quarterly online by MDPI. It is indexed in the Emerging Sources Citation Index (ESCI) and by extension, indexed in Web of Science. https://www.mdpi.com/2076-3387/9/3/55

Okewu E., Maskeliunas R., Misra S., Damasevicius R., and Fernandez-Sanz L. (2018). "An e-Environment System for Socio-economic Sustainability and National Security", Journal of The Problems of Sustainable Development, Vol. 13 No. 1 2018, European Academy of Science and Arts, Salzburg, Poland. The article has been cited 4 times since its publicationThe journal is an SCI journal with ISSN 1895-6912, 2080-1971. It has ISI JCR impact factor of 0.5777 (2018) and 4-year impact factor of 0.746 (2015 -2018). It has impact factor quartiles of Q4 (Web of Science) and Q3 (Scimago). Its Scopus CiteScore is 0.62 while its Source Normalized Impact per Paper (SNIP) is 0.937.*ekorozwoj.pollub.pl › index.php › number-1312018*
Okewu E. and Misra S. (2016). "Resolving the Recruitment and Selection Problem as NP-Hard Problem", Indian Journal of Science and Technology, Vol 9(22), DOI:10.17485/ijst/2016/v9i22/95255, June 2016. ISSN (Print): 0974-6846, ISSN(Online): 0974-5645. According to SCImago Journal Rank (SJR), it is ranked 0.143. http://52.172.159.94/index.php/indjst/article/view/95255

Table 7- Other publications (conference papers and book chapters)

The paper (Okewu et al., 2019) show how software models could be used to practically and comprehensively enhance social investment programs so that the less privileged could contribute to the socio-economic development of society. The research is aimed at enhancing the implementation of SDG 1 which focuses on ending poverty in all its forms everywhere. SDG 1.3 specifically underscores the need to implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable. We used Bayesian network to develop an intelligent decision support system called the Social Safety Net Expert System (SSNES) to support stakeholders in social safety net programs. The outcome of the research revealed that Artificial Intelligence (AI) could provide vital advisory

for enhancing social safety net and by extension, promote inclusive development. This way, every voice is made to count in global development, and no one left behind.

The article is published in Administrative Sciences journal.

Okewu et al. (2018) focused on using a software system to enhance socio-economic sustainability and national security through environmental justices. Our work is aimed at the successful implementation of SDG 15 which harps on protecting, restoring, and promoting sustainable use of terrestrial ecosystems and sustainably managing forests. Other concerns addressed include combating desertification as well as halting and reversing land degradation loss of biodiversity. We modelled, developed and tested an e-Environment software system using cleanroom software engineering approach. The interactive e-Environment systems enable stakeholders to interactive real-life on environmental issues for the purpose of protecting the environment from harmful human practices. The article is published in the Journal of The Problems of Sustainable Development.

In the article (Okewu et al., 2017), we explained the impact of climate change on sustainable development as enshrined in SDG 13 using model-driven engineering approach. Sample data were collected from a rural setting and analyzed as part of the inclusivity policy of sustainable development. The paper recommends, among others, that sustainable development programmes targeting climate change and environmental justices should be all-inclusive encompassing rural dwellers who fell trees for the purpose of fetching firewood for cooking. Our proposed climate change response system was designed using software engineering design tools like Use Case diagram.

The article was published in the Journal of The Problems of Sustainable Development of the European Academy of Science and Arts, Salzburg.

In the work of (Okewu and Misra, 2016), attempts were made to resolve the problem of recruitment and selection which is critical to sustainable development. For success in policy formulation, programme implementation and project management in sustainable development initiatives, right persons must be in the right roles. Our work compliments SDG target 4.4 which states that by 2030, there should be substantial increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship. This

is measured in SDG indicator 4.4.1. We classified the problem of choosing the best fit in a recruitment and selection process as NP-hard as it involves a multi-stage search process with many variables and yet the candidate solution is an optimal solution and not the optimal solution. This is because, further search could yield better solution.

The article is published in the Indian Journal of Science and Technology, Vol 9(22), June 2016.

The role of Information and Communications Technology (ICT) in the sustainable development process has been emphasized in SDG 17. In particular, SDG target 17.8 canvasses fully operationalized technology bank and science for least developed countries. It equally advocates for them technology and innovation capacity-building mechanism and enhanced use of ICT. This is further highlighted by SDG indicator 17.8.1 that it is measured by proportion of individuals using the Internet. ICT runs on software and gathering requirements in the software development process is critical to having a reliable software and by extension a reliable ICT system. In (Okewu, 2015a), factors responsible for successful requirements engineering were analyzed. Solutions were also proffered to likely challenges that may arise in the course of gathering requirements particularly in developing climes. The article is published by Springer Publishers and it is a contribution at the 2015 International Conference on Computational Science and Its Applications (ICCSA 2015) held in Banff, Canada.

Sustainable development encompasses a wide area of research. There are many ways to improve the implementation of sustainable development programmes. In the above studies, we tried to improve implementation through computational modelling, data science, predictive analytics, among other software engineering techniques. In any case, a lot of research work is required in this area of applying data analytics to sustainable development. Though we are examining in broad perspective the application of data science and data analytics in sustainable development, in this present thesis we have limiting the work to publications in three journals in the areas of measurement, monitoring and evaluation in five aspects of the SDGs – climate change (SDG 13), national security (SDG 16), productivity (SDG 8), social safety net (SDG 1), and environmental sustainability (SDG 15). The links between the four articles are illustrated in Figure 1.

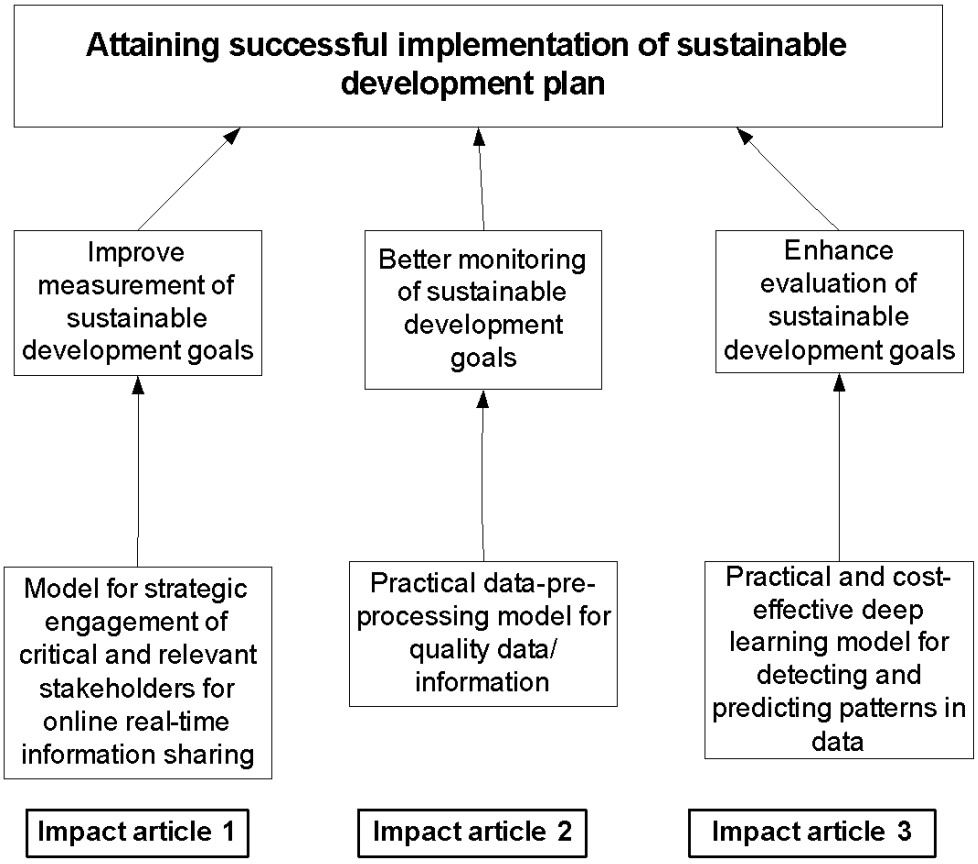

Figure 1.. Relation between the four impact papers in the thesis

In Table 8 below, we explain how the research questions are addressed.

SN	Title of articles	RSQ1: Can software models be used to promote understanding and collaboration among stakeholders for the purpose of measuring sustainable development activities?	RSQ2: What are the constraints in harnessing data for monitoring of sustainable development plans and how can we use data pre-processing to tackle the constraints such that the monitoring process is acceptable to implementation actors?	RSQ3: How can predictive analytics be harnessed for addressing the challenge of inadequate evaluation of sustainable development plans?
1	Okewu E., Misra S. and Okewu J. (2017). "Model-Driven Engineering and Creative Arts Approach to	UML activity diagrams were used to simplify concepts in a bid to promote understanding and		

	Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria", Journal of The Problems of Sustainable Development, Vol. 12 No. 1 2017, European Academy of Science and Arts, Salzburg.	collaboration among stakeholders. Also, prototype online real-time system for strategic engagement tested.		
2	Okewu E., Maskeliunas R., Misra S., Damasevicius R., and Fernandez-Sanz L. (2018). "Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem", October 2018, Journal of Sustainability 2018(9).		Quality data generated through data pre-processing for credibility of the monitoring process.	
3	Okewu E,. Misra S., Okewu J., Damasevicius R., and Maskeliunas R. (2019). "An Intelligent Advisory System to Support Managerial Decisions for A Social Safety Net", Adm. Sci. 2019, 9, 55; doi:10.3390/admsci9030055			Decision tree and Naïve Bayesian probability demonstrated as predictive analytics that could enhance the evaluation process.

Table 8. Links between research questions and articles

1.5 Structure of Thesis

There is a deep sense of disbelief and lack of confidence in the governance structures of many countries, especially developing economies. Since the efficacy of sustainable development plans is measured, monitored and evaluated on a country basis, there is a need to rebuild the confidence of stakeholders in government through a transparent governance structure. Our series of contributions in this thesis focus on building and integrating computational systems using UML activity diagrams and predictive analytics. This scientific approach promotes transparent stakeholders' participation through enhancing understanding and sharing of information on the utilization of public resources. Such openness mitigates corruption and bribery which are known to affect adversely the foundation of any sustainable development plan (Ahmed et al., 2016). The solution we propose is outlined in the structure of the thesis is as follows: the introductory chapter presents a collection of impact publications. Also presented are the links between the papers and how they align with the research

goals. The presentation of the impact contributions is done in a logical sequence, showing the correlation between study objectives and SDGs' targets and indicators. In summary, there is a steady progression from measurement through monitoring to the evaluation of sustainable development initiatives using data and predictive analytics.

- In chapter 2, we formulated models which cover both computational model and creative arts model with the aim of simplifying climate change concept for stakeholders so as to draw their attention to environmentally friendly behaviours and climate adaptation and mitigation strategies. As contained in SDG 13, climate change is a critical sustainable development topic (Lawrence, 2018). To enhance transparent and strategic stakeholders' engagement for appropriate and unbiased measurement of countries efforts in this direction, we used Unified Modelling Language (UML) activity diagrams to express the concepts within the domain in the design stage. Thereafter, we built and tested a Climate Change Response System (CCRS) statically. Apart from providing a platform for transparent engagement of stakeholders for the objective measurement of climate change-related drives, the software models promote understanding, appreciation, collaboration and cooperation among stakeholders toward successful implementation. The study also collected and displayed empirical data to clear doubts about real or perceived threats posed by the climate change phenomenon. This chapter corresponds to the impact article 1.
- In chapter 3, we consolidate on stakeholders' role of monitoring sustainable development plans in the implementation value chain. We harp on the fact that quality data gives rise to quality information (World Bank, 2014). As a result, data pre-processing prioritized. For effective monitoring of sustainable development activities, data collection and modelling are important for injecting transparency and entrenching stakeholders' collaboration. Mismanagement and misappropriate of public resources meant for implementation of sustainable development initiatives in countries thrive in an atmosphere of secrecy (Okolo and Raymond, 2014). To mitigate corruption, our model aims at promoting openness, probity, transparency and accountability by demystifying concepts and engaging stakeholder interactively for online real-time sharing of information on public expenditure. We reviewed the literature on an aspect of sustainable development and identified problem. To empower stakeholders (including citizens) for collective action, requirements were gathered and UML activity diagrams used to explain domain concepts as well as design a prototype online real-

time solution. The online interactive consolidates stakeholders' knowledge on people-oriented project. Additionally, the openness promoted by the availability of real-time information on public expenditure on projects and programmes make monitoring and questioning easy. The aim is to ensure public finance creates optimal value-successful implementation of sustainable development initiatives. The models are described in the impact article 2 as contained in chapter 3 of this thesis.

- The evaluation stage is discussed in chapter 4. The detection of patterns in existing observations and prediction of the outcome of a future input based on patterns learnt for historical data can empower stakeholders for evaluating vital decisions particularly during emergencies. We explained how we used artificial intelligence tools like naïve Bayesian networks and deep learning neural networks for this purpose. The application of predictive analytics is to enable in-depth insight into development-related data. Sufficiently trained neural networks can be used to predict the outcome of future input based on patterns learnt from historical data. This chapter contains two impact articles: in paper 1, we show that decision tree and naïve Bayesian probability could be used in the implementation of social safety net, a critical component of SDG 1 which aims at ending poverty in all its forms (Kale, 2017); in paper 2, we show results of the series of experiments performed to compare the performances of various deep learning neural network algorithms.
- The global results of these contributions are discussed in chapter 5. In chapter 6, we outline the possible future works in this research area of predictive analytics and sustainable development.
- Each impact journal's references have been kept together with the article's text for the purpose of enhancing the readers' understanding. The references in the remaining parts of the thesis such as Introduction, Conclusion, and Future Work are listed as a separate list at the end of the document.
- In Annex I, the summary of the PhD candidate's research profile is presented.

1.6 Acronyms

Acronyms as used in the thesis are defined as follows:

CCTV – Closed Circuit Television

CNN – Convolutional Neural Networks

DBLP - Digital Bibliography and Library Project

DLNN – Deep Learning Neural Network

DOI - Digital Object Identifier

ESCI – Emerging Sources Citation Index

ICAST – International Conference on Adaptive Science and Technology

ICCSA – International Conference on Computer Science and its Application

ICT – Information and Communications Technology

ICT4D – Information and Communications Technology for Development

IEEE – Institute of Electrical and Electronics Engineering

ISI – Institute for Scientific Information

ISSN - International Standard Serial Number

JCR – Journal Citation Reports

JIF – Journal Impact Factor

MDE – Model-Driven Engineering

MDGs – Millennium Development Goals

MDPI – Multidisciplinary Digital Publishing Institute

MNIST – Modified National Institute of Science and Technology

SCI – Science Citation Index

SCIE – Science Citation Index Extended

SDGs – Sustainable Development Goals

SGD – Stochastic Gradient Descent

SNIP – Source Normalized Impact per Paper

SJR – Scimago Journal Ranking

UML – Unified Modelling Language

WoS – Web of Science

CHAPTER

2 SOFTWARE MODELS FOR MEASURING SUSTAINABLE DEVELOPMENT GOALS

Like mathematical models that are applicable in various domains, software models are not just meant to be used in the field of software engineering alone. Software architecture is primarily targeted at simplifying concepts, promoting understanding among stakeholders and eliciting higher levels of collaboration among stakeholders in the implementation stage. As a result, software architecture is being used increasingly to demystify concepts in various fields of endeavor, including sustainable development activities. In our paper on climate change response, we used model-driven engineering to draw the attention of stakeholders to the all-important but elusive and abstract concept of climate change. In another but related paper, same was done when sharing our research on Optimizing Green Computing Awareness for Environmental Sustainability. We provide graphic details, modelling data and other climate-related entities so that stakeholders could measure and appreciate the import of climate change on human developmental activities. SDG 13 focuses on taking urgent action to combat climate change and its impacts as one of the key sustainable development initiatives (Report, 2016). The SDGs document contains global metrics which national development initiatives are benchmarked against. By modelling climate change response systems, we offer to relevant and critical stakeholders deeper understanding of the concept and consequence of climate change. They have a better sense of measuring actions and effects and repositioning themselves for better response. By modelling entities and relationships in the various 17 domains of the SDGs, greater awareness is created and the sense of numeracy deepened for managing socio-economic activities through quantitative measures.

PROBLEMY EKOROZWOJU – PROBLEMS OF SUSTAINABLE DEVELOPMENT
2017, vol. 12, no 1, 101-116

Model-Driven Engineering and Creative Arts Approach to Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria

Zastosowanie inżynierii sterowania modelami i sztuk pięknych w przygotowywaniu systemu reagowania na zmiany klimatyczne dla obszarów wiejskich w Afryce: przypadek wspólnoty Adum-Aiona w Nigerii

Emmanuel Okewu*, Sanjay Misra ***, and Jonathan Okewu******

**Centre for Information Technology and Systems, University of Lagos, Lagos, Nigeria*
E-mail: okewue@yahoo.com
***Department of Computer and Information Sciences, Covenant University, Ota, Nigeria*
E-mail: sanjay.misra@covenantuniversity.edu.ng
****Atilim University, Ankara, Turkey*
E-mail: Sanjay.misra@atilim.edu.tr
*****Department of Visual and Creative Arts, Federal University, Lafia, Nigeria*
E-mail: jonathan.okewu@gmail.com

Abstract

Experts at the just concluded climate summit in Paris (COP21) are unanimous in opinion that except urgent measures are taken by all humans, average global temperature rise would soon reach the deadly 2^{o}C mark. When this happens, socio-economic livelihoods, particularly in developing economies, would be dealt lethal blow in the wake of associated natural causes such as increased disease burden, soil nutrient destruction, desertification, food insecurity, among others. To avert imminent dangers, nations, including those from Africa, signed a legally binding universally accepted climate control protocol to propagate and regulate environmentally-friendly behaviours globally. The climate vulnerability of Africa as established by literature is concerning. Despite contributing relatively less than other continents to aggregate environmental injustice, the continent is projected to bear the most brunt of environmental degradation. This is on account of her inability to put systems and mechanisms in place to stem consequences of climate change. Hence, our resolve to use a combination of scientific and artistic models to design a response system for tackling climate challenges in Africa. Our model formulation encompasses computational model and creative arts model for drawing attention to environmentally friendly behaviours and climate adaptation and mitigation strategies. In this work, we focus on rural Africa to share experience of climate change impact on agriculture – mainstay of rural African economy. We examine the carbon footprints of a rural community in Nigeria – the Adum-Aiona community – as case study and for industrial experience. The authors will provide operational data to substantiate claims of existential threats posed by greenhouse gas (GHG) generation on livelihoods of rural dwellers. The study will also design and test a Climate Change Response System (CCRS) that will enable people to adapt and reduce climate change impact. To achieve the research objective, the researchers will review literature, gather requirements, model the proposed system using Unified Modelling Language (UML), and test CCRS statically. We expect that the implementation of the proposed system will enable people mitigate the effects of, and adapt to, climate change-induced socio-economic realities. This is besides the fact that the empirical data provided by the study will help clear doubts about the real or perceived threats of climate change. Finally, the industrial experience and case study we share from Africa using model-driven engineering approach

will scale up the repository of knowledge of both climate change research and model-driven engineering community.

Key words: agriculture, climate change, visual and creative arts model, model-driven engineering, response system

Streszczenie

Eksperci biorący udział w szczycie klimatycznym w Paryżu (COP21) sugerują, że pomimo mimo podejmowanych działań zaradczych, średnia temperatura na naszej planecie podniesie się wkrótce o 2^0C. Gdy to nastąpi, społeczno-ekonomiczne podstawy bytu, szczególnie w krajach rozwijających się, zostaną naruszone w wyniku m.in. przewidywanego wzrostu zachorowań, zniszczenia gleby, pustynnienia i braku zabezpieczenia żywności. Aby zapobiec zbliżającemu się niebezpieczeństwu podpisano prawnie wiążący protokół klimatyczny, zaakceptowany także przez kraje afrykańskie. Jego celem jest uregulowanie i wsparcie dla zachowań prośrodowiskowych w skali globalnej. Opisywana w literaturze wrażliwość klimatu w Afryce wydaje się być szczególnie istotna. Chociaż w porównaniu do innych kontynentów jej udział w emisji zanieczyszczeń do atmosfery jest mniejszy, to właśnie ten kontynent ma dotknąć największy poziom degradacji środowiskowej. Wynika to m.in. z braku możliwości wdrażania kluczowych dla klimatu systemów i mechanizmów. Stąd wynika nasza determinacja w opracowaniu kombinacji naukowych i artystycznych modeli, służących jako narzędzia do formułowania systemu odpowiedzi na czekające Afrykę zmiany klimatyczne. Nasze podejście obejmuje modele obliczeniowy i odnoszący się do sztuk pięknych, które mają pomóc w zwróceniu uwagi społeczeństw na niezbędne zachowania prośrodowiskowe. W badaniach koncentrujemy się na obszarach wiejskich w Afryce, aby przedstawić wpływ zmian klimatycznych na rolnictwo, które stanowi podstawę afrykańskiego systemu ekonomicznego. Zbadaliśmy ślad węglowy obszarów wiejskich w Nigerii, we wspólnocie Adum-Aiona. Autorzy przedstawiają dane pokazujące realne zagrożenia dla ludzi, które niesie ze sobą emisja gazów cieplarnianych. Prezentowany jest także test odnoszący się do Systemu Odpowiedzi na Zmiany Klimatu, który pomoże mieszkańcom nie tylko w adaptacji do, ale także w zmniejszeniu konsekwencji zmian klimatycznych. Dyskusja zostanie wsparta przeglądem literaturowym, pomagającym lepiej określić wymagania, które powinien spełniać model, z wykorzystaniem UML. Należy się spodziewać, że wdrożenie proponowanego systemu przyniesie realne korzyści, także te noszące się do uwarunkowań społeczno-ekonomicznych. Rezultaty przeprowadzonych badań empirycznych precyzują zakres zagrożeń związanych ze zmianami klimatycznymi. W końcowej części odniesiemy się do doświadczeń związanych z przemysłem, także w kontekście Afryki. Zastosowanie inżynierii sterowania modelami wzbogaca zakres wiedzy odnoszący się zarówno w kontekście badań nad zmianami klimatycznymi, jak i możliwych zastosowań inżynierii.

Słowa kluczowe: rolnictwo, zmiany klimatyczne, wizualny i kreatywny model sztuki, inżynieria modelowa, system odpowiedzi

1. Introduction

In this work, we try to measure and simulated a climate-resilient rural Africa using the Adum-Aiona community in Benue State, Nigeria. To achieve this objective, we obtained climate data from the Nigeria Meteorological Agency (NIMET) in the form of its yearly seasonal rainfall predictions spanning 2011-2015. Africa is well known for its reliance on agriculture for socio-economic sustenance (Schroth et al., 2016; Webber et al., 2016). The fact, that this sector is not well developed results in heavy dependence on rain-fed model of agriculture such that weather changes greatly impact of its operations. Though developments in climate change impact other sectors such as transportation, construction, aviation, manufacturing, among others, the agrarian nature of Africa means that particular attention must be given to the agriculture sector (Perez et a., 2015; Li et al., 2015). Hence, the seasonal rainfall predictions of many national meteorological agencies across Africa are predominantly utilized in the agricultural industry (Seo, 2015).

Overtime, the failure of African governments to develop alternative to rain-fed agriculture such as irrigation farming means that the socio-economic lives of the people are impeded when factors such as weather change is not favourable to rain-fed agriculture (Jones et al. 2015). Incidences of drought, delayed rainfall, early cessation and dry spells take heavy toll on the sustenance of lives. The immediate consequences are food insufficiency and insecurity, hunger, poverty, unemployment and attendant social vices such as kidnapping, prostitution, and terrorism. Though there has been deliberate policies in the direction of encouraging irrigation farming, policy inconsistency and somersault over the years in various African countries has been the bane of the project (Kusangaya et al., 2014). As a result, frameworks like dams and river basins that known for potentials to channel surface water for irrigation farming are abandoned or left uncompleted.

On the other hand, activities of urban and rural dwellers continue to heighten greenhouse gasses (GHGs) emission. While in the urban African settlements, carbons emissions are pronounced through the burning of hydrocarbons (Steynor et al., 2016) in

petroleum products such as kerosene, petrol and diesel for transportation, construction and manufacturing, rural communities engage in environmental injustice by felling trees during land preparation for farming, burning of firewood as source of cooking energy, and deliberate deforestation for purposes of transacting log business (Chidiebere et al., 2016). The aggregate effect is that the dearth of clean energy in Africa has increased the contribution of Africa to the rise in global temperature that is feared to be approaching the dangerous 2^{o}C threshold, except concrete steps are taken. Even more concerning is that though Africa contributes least to GHGs emission, ozone layer depletion and aggregate rise in global temperature among all the continents, studies have shown that it suffers most in terms of bearing climate change burden. This is because it has weak climate change response mechanism (Clarke et al., 2016).

In this study, we focus on filling this gap by designing a Climate Change Response System (CCRS). The policy thrust of CCRS is to sensitize people on ecologically friendly behaviours and climate adaptation and mitigation techniques leveraging creative art models such as dance, drama, and visual aid (graphics), communication. Though we take a general look at climate change impacts on both urban and rural Africa, our particular interest is on rural Africa as vast majority of agricultural activities take place there and majority of Africans dwell there. For case study and industrial experience, we use the Adum-Aiona community in Nigeria, precisely in Benue State. The community is an agricultural hub and its host state, Benue, is known as the food basket of the nation. CCRS captures initiatives that promote environmentally friendly behaviours as well as spell out adaptation and mitigation techniques for surviving climate-challenged environment. Using model-driven engineering approach, we design CCRS using unified modelling language (UML) and test the proposed system statically (Sirohi, Parashar, 2013; Gorton, 2011). Besides closing a contextual gap, the case study and industrial experience shared add to bodies of knowledge of both the model-driven research community and climate change research community. The evidence provided by way of literature review of various case studies, and operational data from the Nigerian Meteorological Agency on Seasonal Rainfall Predictions also help in substantiating the existential threats posed by climate change to the human race.

The remaining segments of the article is partitioned thus: In Section 2, there is review of literature; adopted methodology for the research is outlined in Section 3; Section 4 discusses results; and in Section 5, the work is concluded.

2. Review of Literature

2.1. Climate Change and El Niño in Africa

A change in weather patterns measured in statistical distribution, which lasts for a length of time, say decades to millions of years, is termed climate change. Put in another fashion, it refers to average weather conditions alteration. Climate change can also be seen as more or fewer extreme weather events which implies time change in weather around longer-term average conditions. Factors such as changes in solar radiation received by Earth, biotic processes, volcanic eruptions and plate tectonics are responsible for climate change. Also, some human activities are direct or indirect causes of contemporary climate change, called global warming (Kahsay, Hansen, 2016).

Organizations, like Climate Action Network Europe and Germanwatch, are known to be the publishers of the annual publication called *The Climate Change Performance Index* (CCPI). It is a barometer for evaluating 58 countries with regards to climate protection performance and these countries are responsible for more than 90% of world energy-associated CO_2 emissions. In 2013, CCPI publication covered CO_2 generated from sources such as fossil fuels, with the exception of emissions from the shipping sector. Subsequent CCPI publications took into cognisance emissions from waste, deforestation and agriculture. The evaluation is made up of the following compositions: emission trend is 50 %, emission level constitutes 30% while the remainder of 20% comes from assessment of over 200 experts on national and international climate policy. Recent results (as published in December 2014) indicate that more efforts are required to avert dangerous climate change. Hence, no country was ranked one to three in the 2015 results. However, Denmark was acknowledged for her efforts even as she topped the list (Calzadilla et al., 2014).

El Niño Southern Oscillation (ENSO) has a warm phase known as El Niño. In the region of the International Date Line and 120°W (off the Pacific coast of South America inclusive), there is a band of warm ocean water that develops in the central and east-central equatorial Pacific which is associated with El Niño. ENSO can also be seen as the cycle of warm and cold temperatures which is measured by sea surface temperature (SST) of the tropical central and eastern Pacific Ocean. Typically accompanying El Niño is low air pressure in the eastern Pacific and high air pressure in the western Pacific. However, the cool phase of ENSO is known as La Niñais and normally characterised by SST. In the eastern Pacific, it is below average but the air pressures are high in the eastern Pacific and recording low in the western Pacific. Outcomes of the ENSO cycle – both El Niño and La Niña are directed by global changes in temperatures and rainfall (Young et al., 2016).

Study is ongoing on mechanisms that cause the oscillation.

Developing countries such as African countries depend largely on agriculture and fishing for survival. The most affected countries are those bordering the Pacific Ocean (Wündsch et al., 2016). In recent times, climate change tends towards more extreme El Niños, as shown by measurements and simulations. In Africa, the impact of the phenomenon differ from one region to another – in some parts such as Kenya, Tanzania, and South Africa, long rains and wetter-than-normal conditions are experienced between March and May. In others, drier conditions than normal exist such as in Zambia, Zimbabwe, Mozambique, and Botswana from December to February. Direct impacts of El Niño responsible for drier conditions are experienced in some parts of Northern Australia and Southeast Asia resulting in worsening haze, intense bush fires, and significant reduction in quality of air. Conditions that are drier than normal characterise certain parts of the globe at some time of the year (Calatayud et al., 2016).

2.2. Sustainability and Social Consequences of Climate Change in Africa

Human survival is a function of the environment. All aspects of human survival need structures that operate in a given environment, social services (health, education and agriculture) inclusive. The decimation of the environment means livelihoods are directly or indirectly impacted upon negatively. In the Horn of Africa (Ethiopia, Eritrea and Somalia) for example, there is presently humanitarian crisis partly due to drought and food shortage as a result of unfavourable and unpredictable climatic conditions (Clarke et al. 2016). The consequent desert encroachment has not only left in its trail hunger but also diseases (Grace et al., (2015).

The impact of desert encroachment is also taking its toll on Northern Nigeria, where herdsmen are known to be leaving the area massively for Southern Nigeria in a bid to sustain their animals as a critical component of their pastoral (nomadic) life. The adverse effect of climate change has not only shrunk water sources for human and animal consumption (Kusangaya et al., 2014) but equally impacted on irrigation farming (Kahsay, Hansen, 2016; Calzadilla, 2014). On the other hand, the massive migration has resulted in ethno-religious crisis and even ethnic cleansing (Clionadh et al., 2015) in some extreme cases due to frequent clashes between farmers and herdsmen over grazing lands. Consequently, the Nigerian government is currently putting agricultural policies in place in the direction of creating grazing reserves to check the incessant loss of human lives and cater for the animals in the most efficient and effective manner for optimal productivity.

In the coastal cities of Africa, ocean surge has been known to destroy corporate buildings hosting multinational companies and destroying road infrastructure thereby hindering coastal economies (Wündsch et al., 2016). Also, buildings whose initial plans did not envisage or factor in harsh elements of the unfolding climatic conditions, are suffering structural defects (Chinowsky et al., 2014). This has serious implications for commerce and socio-economic development. In Eastern Nigeria, gully erosion has decapitated valuable lands that should have been used for commerce, industries and agriculture. Huge budgetary allocations that otherwise should have been used for enhancing the wellbeing of the citizenry through the provision of social services are being channelled to ecological management (Klausbruckner et al., 2016).

As a mitigation measure, there has been increased emphasis on the use of renewable energy in Africa (Fant et al., 2016) but lack of infrastructure has been the bane of such sustainable development initiative.

2.3. The Nigerian Metrological Agency (NIMET)

The Nigerian Meteorological Agency (NIMET) is a government parastatal that undertakes the production and issuance of seasonal rainfall prediction (SRP) for Nigeria in line with the agency's responsibility of advising government on all matters bothering on weather and climate. The SRP has gained popularity over the years and it is now largely patronized by stakeholders in climate-sensitive sectors of the economy (Bellprat et al., 2015). The scientific information it garners serves as input in planning and decision making.

The predictions are hinged on the intense tele-link between Sea Surface Temperature anomalies, El-Nino/Southern Oscillations (ENSO), and rain-bearing systems in Nigeria. In some years, SRP is predicted under the La-Nina phase and later revised to the neutral phase of the ENSO phenomenon. Despite the alternating affairs between La-Nina and El-Nino, Nigeria is characterised by ENSO-neutral conditions as the most dominating climate scenario. In most parts of the country, the ENSO-neutral phase is responsible for normal weather and climate conditions. In fulfilment of its statutory function of providing credible meteorological information, early warnings, forecasts, and advisory to guarantee informed decisions in all weather-sensitive and climate-conscious sectors of the economy, NIMET predicts annually and presents same to stakeholders for contributions on the socio-economic impacts prior to making predictions public. The release of the SRP is done early in the year so that policy makers will have sufficient time to factor in the critical information and advisories contained in it into the process of decision-making. This way, risks associated with harsh weather and climate are mitigated by the agency, and safety of lives and property guaranteed (Zinyengere et al., 2013). This initiative contributes significantly to Nigeria's sustainable socio-economic development.

NIMET relies on the following input data for the production of the annual SRP:

- Historical daily rainfall, maximum and minimum temperatures.
- Daily solar radiation data.
- Phenological and soil information data.
- El Nino/Southern Oscillation (ENSO) phase as defined by the Sea Surface Temperature irregularities.
- Rain-related synoptic systems for Nigeria.

2.4. A Model-driven Engineering Approach

The term Model-driven Engineering (MDE) is a methodology for software development with focus on exploiting and creating models of domain (Martínez-García et al., 2015; Wautelet, Kolp, 2016). The domain models (task model, quality model, data model, among others) are conceptual models of all aspects of a problem. For example, a climate change response application domain would emphasize representations of environmentally friendly behaviours, climate data local to a region, adaptation and mitigation techniques using standard modelling tools. Thus, MDE concentrates on representing knowledge and tasks in abstract format for guiding a domain application. Computing or algorithmic concepts are not its focus (Riesenfeld et al., 2015; Calegari et al., 2016).

MDE has potential for increasing productivity in that it maximizes systems compatibility by reusing models that are standardized (Davies et al., 2014). Also, by relying on models of the application domain with recurring design patterns, it simplifies the process of design (Gurunule, Nashipudimath 2015). Finally, individuals and teams jointly working on systems can have better communication owing to the use in the application domain of standardized practices and terminology (Barbier et al., 2015).

An MDE modelling paradigm is effective if two conditions are fulfilled – the models make sense to a user that is conversant with the domain, and secondly, they are capable of serving as the basis for implementing systems (da Silva, 2015). Collaborative efforts are involved in models development via intense communication between designers, product managers, users, and developers of the domain application. The completion of the models enhances the development of software and systems (Davies et al., 2015).

Some popular MDE projects includes (Ciccozzi et al., 2013; Rutle et al., 2015): Computer-Aided Software Engineering (CASE), Unified Modelling Language (UML), Object Management Group (OMG), Eclipse ecosystem of programming and modelling tools (Eclipse Modelling Framework), model-driven architecture (MDA), among others. Studies have shown that MDE technologies are promising in addressing the inefficiency of third-generation languages with respect to alleviating platform complexity and expressing domain concepts maximally (Hutchinson et al., 2014; Lütjen et al., 2014).

It is worth reiterating that modern systems design demands efficiency in handling their dynamic complexity (Cervera et al., 2015). In order to reduce the complexity, there is need for overhauling the entire system development process and take a second look at the age-long division among development phases. Since MDE shifts the focus from code to models, it is a veritable way of mitigating development complexity (Wehrmeister et al., 2014). The effective utilization of MDE reduces costs and risks in a number of ways: facilitating efficient modelling and analysis of functional and non-functional requirements; defining and implementing loosely coupled components into assemblies as a way of improving reusability; and in the course of development, making provision for automation where necessary (García-Magariño, 2016).

2.5. Creative Arts Model for Climate Change Sensitization and Mobilization

Creative Arts is the study of the power to form or to build out of nothing or something by force of imagination and talents. It is sub divided into two, namely Visual and Non-visual art (Babatunde, 2007). Visual arts are those aspect of art whose products are visible while Non-visual arts are those whose product cannot be seen with the naked eyes. Non-visual art are mainly for entertainment and recreation. While visual arts are for either beautification or applied.

For the sake of this study, the creative art model for climate sensitization and mobilisation includes one aspect of Non-visual arts and one aspect of Visual arts that has been employed for their effectiveness on how they have been used in different scenarios to effectively tackle societal issues. The two aspects are performing art (Non-visual) and Graphic art (Visual).

Performing (Non-visual) Art includes dance and drama which is performed to inform, sensitise or entertain an audience. Carnival performance is also an aspect of performing art that has been used to sensitise the society in divers ways. According to Akande (Akande, 2016), top government officials unveiled the theme of the 12th edition of the carnival which took place in 2015 as *Climate Change*. They remarked that it was necessary to explore the subject further, as more and more countries in the world continue to show concern for the environment. Thereafter, they led other government officials, the locals and revellers in a five million tree-planting campaign which was also in tune with the theme of the 2015 event (Fig. 1). According to Akande, the governor maintained that his administration will plant five million trees to support afforestation and climate change. In company of acrobatic dancers and music blasting trucks, richly costumed girls in green led each group as revellers took over the carnival routes cheering participants. Other side attractions included celebrities, masquerades, exquisite floats, and notable disc jockeys. Notably, the designs of the floats

Figure 1. Richly costumed girls in green dancing and leading the group at 2015 Calabar carnival in Nigeria tagged *Climate Change*, source: *The News Mongers*

Figure 2. Dignitaries dressed in foliages at 2015 Calabar carnival in Nigeria tagged *Climate Change*, source: *Gist Nigeria Blog*

Figure 3. Graphic art *Do Not Cut Trees Sign*, source: *Free digital photos*

Figure 4. Graphic art *No tree felling, no fires*, source: *Dreams time*

were carefully crafted to depict *Climate Change* (Fig. 2).

True to its name, Graphic (Visual) Art has to do with vision or sight i.e. art works that can be seen. Visual art is also sub divided into the fine and applied arts. Graphics falls under applied art because it aids understanding in reading through visual images and text. Graphic design is a commercial art which service our visual communication system in producing designs like posters, signage, Book covers, labels, packages and so on. Maa Illustrations (2015) opine that to capture public attention, visual images play a significant role. The essence of illustrations in advertising is to pass a strong message to the audience. It presents a strong appeal to the target audience to focus on the advertisement.

Overtime, graphics design as part of the creative art model for climate sensitization and mobilisation has yielded effective way of communicating to members of a society through visual presentations combined with text, it simplifies ideas and makes it understandable to an averagely educated community. Graphics has been used to pass on simple but clear messages of prohibitions such as *Do not cut trees* (Fig. 3) and *No felling and burning trees* (Fig. 4).

Creative arts model for Climate Change Sensitization and Mobilization is a model that is an effective way of disseminating, sensitizing and informing the society of the need to be cautious. It catches the people's attention in terms of performing arts. The society is very much in tune with dance, drama and songs and would quickly align with whatever information that is coming out of these and that is why performing art is strategic to information broadcast to the people. Graphics art as a second tool under this model presents dual advantage for this course. It simplifies information for both learned and an average learned society with the utilisation of images and text.

The creative art model as presented in this study will be appropriate to disseminating information to the populace of Adum-Aiona Community regarding climate change, especially if this model is presented in the indigenous language of the people.

2.6. Related Work

In the literature, previous works that have bearing with model-driven engineering and climate change are as follows: (Lukman et al., 2013; Brunelière et al., 2014; Bubeck et al., 2014; Panesar-Walawege et al. , 2013; Cuadrado et al., 2014; Chabridon et al., 2013; Brambilla, Fraternali, 2014), discussions centred on MDE. The application of model-driven engineering in various fields of endeavours such as software development, industrial robotics, safety stand-

ards, software enterprises, web user interactions, among others were discussed. The authors were unanimous in their submissions that MDE not only enhances stakeholders' understanding of proposed system, it elicits support from stakeholders and engineers their commitment to the implementation of the system. This way, MDE contributes immensely to problem solving. As exhaustive as the discussions were, the authors did not mention the application of MDE for developing climate change response system. This is our key motivation in this work.

Ofoegbu et al. (2016) carried out an assessment of the adaptive capacity of forest-based rural communities and their coping strategies against climate variability using a South African Vhembe district as case study. The study has striking resemblance with ours in that it highlights the many coping initiatives used by forest-based rural settlers in Vhembe District of South Africa in order to acclimatize with climate variability so as to cushion attendant difficulties. The study observed that the nature of climate variability and extreme weather were chief determinants of survival strategies adopted such as rainwater harvesting, for coping with erratic rainfall, tree planting around houses and on farm land to counter the effects of extreme temperature. In addition, household and community demographic characteristics such as education and skills levels impacted on their response capabilities. Other critical factors for adapting and mitigating climate challenges include availability of forest products, institutional services and social infrastructure such as markets and water. The authors concluded that rural communities' resilience to climate change and variability challenges could be enhanced strengthening household's capacity and community infrastructural development. As closely related as the study is, it focused on the local exigencies of a South African communities whereas our study focus on Nigerian communities, using one as case study.

Steynor et al. (2016) shared experiences from urban Africa on co-exploratory climate risk workshops. The treatment opined that co-production has been acknowledged as cardinal to proper use and uptake of climate information into decision-making. Nonetheless, the authors observed, the success of co-production is a function of the natural understanding of the domain in which it is implemented. The article x-rayed the context for a place-based co-exploratory analysis of parameters such as climate risks, the elements and steps incorporated in the approach, among others. The co-exploration approach complements the objectives of the Global Framework for Climate Services just as it underscores heightened integration of climate information into urban adaptation planning in Africa. Despite stressing the benefit of climate time and sufficient information in planning, decision making and project execution in urban Africa, less attention was given to the climate change challenges of rural Africa which forms about 70% of the continent.

On his part, Seo (2014) relied on Agro-Ecological Zone (AEZ) techniques to examine how climate change impacts on decisions bothering on micro farming in sub-Saharan Africa (SSA). Relying on observed farming decisions in SSA, the work focused on understanding agriculture and assessing climate change impact on it with the aid of AEZ methods. Using the AEZ categorization of African continent and the idea of the Length of Growing Period (LGP), the author explained AEZ method. The World Bank household surveys which covered about 8000 farms spread across 9 sub-Saharan countries provided statistics on Farmers' decisions. Despite providing informed direction on effect of climate change on agriculture, the article did not suggest a climate change response system, the main motivation of our study.

In summary, none of the studies reviewed dwelt on closing the gap of designing a climate change response system (CCRS) using model-driven engineering for rural Africa. This is the gap we address in the following sections of the article.

3. Methodology

Our study focused on the carbon and ecological footprints of the Adum-Aiona community, estimating the impact of human activities on greenhouse gases (GHGs) emission into the atmosphere and destruction of soil texture that paves way for soil erosion and allied ecological problems. Our study revealed that both carbon and ecological footprints impact adversely on the livelihoods of the community whose mainstay is agriculture. We tabulate our findings as shown in Table 1.

Against the backdrop of established negative impacts of climate change on socio-cultural and socio-economic lives of Africans in general and rural Africans in particular (Raleigh et al., 2015), a response system that outlines measures for adapting to the new climate-engineering environment and that will also mitigate the adverse resultant effects will be handy in alleviating the sufferings of the people. The response system should also be proactive by adopting measures that promote ecologically-friendly disposition so that people are conscious that their environment-related behaviours have consequence for their continues survival (Grace et al., 2015).

There is no gainsaying the fact that vast majority of Africans rely on agriculture for survival. Hence, weather uncertainties as dictated by climate change has direct implications for livelihoods as Africa relies largely on rain-fed agriculture (Lim et al., 2016). The case study used is the Adum-Aiona community in Benue State of Nigeria. Like many rural African communities, it is an agrarian settlement in the Middle Belt (North Central) region in Nigeria. The so-

Table 1. Carbon and ecological footprints of Adum-Aiona Community

SN	Activity	Impact on Global Warming (El Nino) and Ecology	Effects
1.	Cooking using firewood	Emission of greenhouse gases (GHGs)	Excessive heat waves that cause human discomfort and encourage spread of diseases such as meningitis.
2.	Pressing iron (charcoal iron)	Emission of CO_2 into atmosphere	Heated atmosphere resulting in depletion of ozone layer and attendant consequences.
3.	Tree felling	Destruction of trees that utilizes CO_2 for photosynthesis, in the process reducing CO_2 in the atmosphere. Also, tree roots hold soil tight for water absorption, preventing flooding. Trees absolve GHGs that contribute to GW and CC.	Erosion and degradation of soil nutrients that reduce agricultural productivity leading to food insufficiency and insecurity, unemployment and social tensions.
4.	Bush burning	Release of GHGs into atmosphere	Destruction of soil texture, flora and fauna, impacting on agricultural productivity, hunger and poverty.
5.	Body warming using firewood	Emission of CO_2 into atmosphere	Heated atmosphere resulting in ozone layer depletion and related consequences
6.	Food preservation through smoking	Release of CO_2 into atmosphere	Heated atmosphere resulting in ozone layer depletion and related consequences.
7.	Harmful farming practices	Destroyed soil texture, hence decreased capacity to absolve water leading to flooding	Flooding destroys means of livelihoods and further impoverish the people.
8.	Indiscriminate burning and dumping of waste products	Heated and polluted atmosphere as well as destruction of soil texture	Excessive heat waves and depletion of soil structure. These encourage heat-borne diseases, soil erosion and soil nutrients depletion.

cio-economic lives of the people revolve around rain-fed agriculture with crop planting done during raining season while the dry season is used for harvesting and processing. The raining season typically spans the months of March to October while the dry season covers November to February. Typical crops planted include food crops such as yam, cassava, maize, sorghum, millet, and beniseed. Tree crops found in the community include palm trees and cashew trees while fruits include mango and orange. The seasonal rainfall predictions for year 2016 by NIMET suggests the country will experience late onset of rains and early cessation with dry spells in-between. As indicated in the use case diagram showing the CCRS above, for purposes of acclimatization and mitigation of the consequences of this climate change fall-out, farmers in Adum-Aiona have to be sensitized and educated on climate resilient agriculture via the instrumentality of both formal and informal institutions. Formally, extension services will be used to disseminate information on climate-compliant agricultural practices and inputs as well as rainfall prediction information by NIMET. Informal institutions like worship places (particularly churches since the people are predominantly Christians), town hall meetings, family meetings, and age-grade meetings are further avenues that could be explored for the same purpose which are quiet potent for the domestication and ownership of the climate change response system. The use of drama, dance drama, dance and songs performed in the local Idoma language during informal gatherings will go a long way in driving home the message of potential challenges posed by climate change and the need to take proactive measures. In addition, visual aid such as posters and hand bills illustrated and written in the local language and posted at strategic positions will also lend a voice to the campaign.

In the meantime, our study has revealed that farming practices of the Adum-Aiona farmers could exacerbate climate change impacts. Some of the environmentally unfriendly behaviours include indiscriminate tree felling during land preparation, burning of fossil fuel through the use of firewood for cooking, and indiscriminate cutting of trees for logs (Klausbruckner et al., 2016). While the community justifies deforestation by citing agricultural and commercial expediencies, the use of firewood for cooking has been substantiated by the lack of alternative source of clean energy. Though the community is located in Nigeria, an oil producing country, the inability of the country to curtail gas flaring and use same for supplying clean gas energy means the people continue to burn hydrocarbon fossil fuels – firewood, kerosene, petrol and diesel for survival. Even though the Adum-Aiona community's vegetation is relatively green and dense, these human activities certainly escalate emission of greenhouse gases

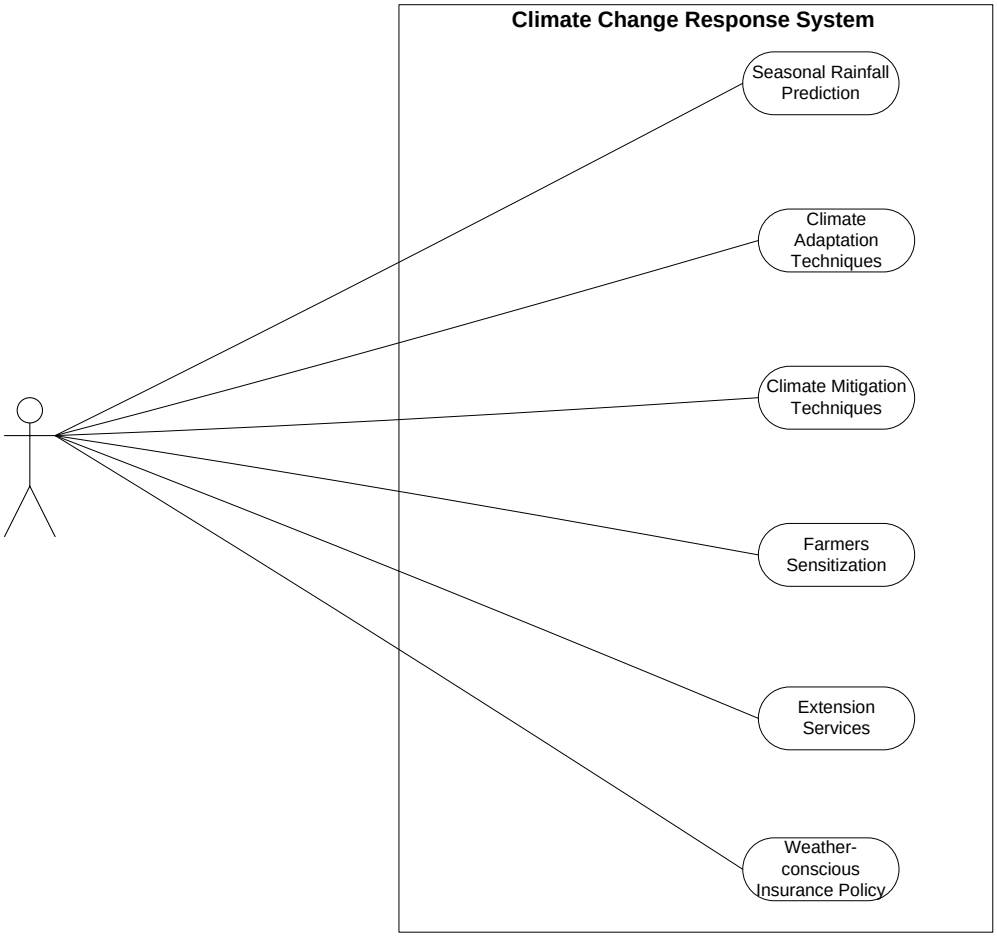

Figure 1. Use Case Diagram for the Climate Change Response System (CCRS)

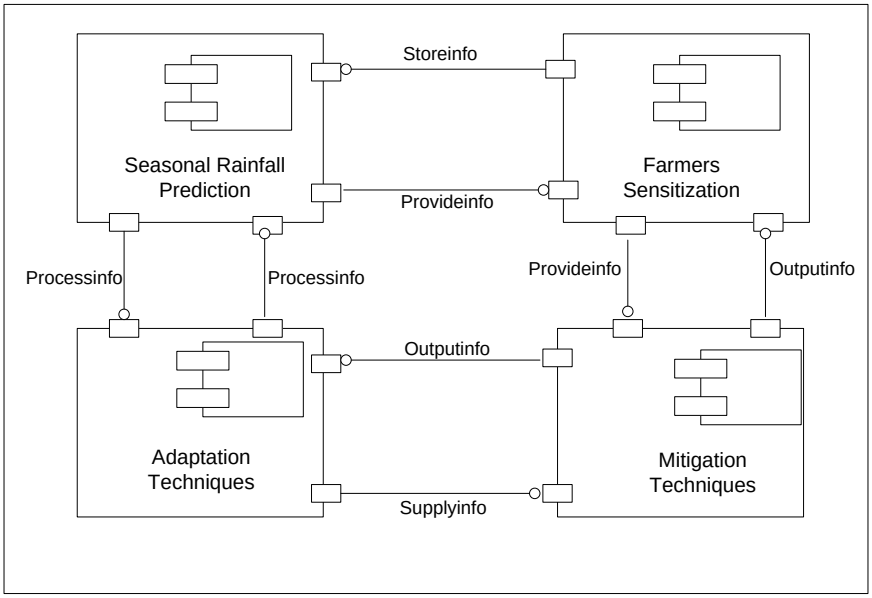

Figure 2. CCRS component diagram

(GHGs), contribute to rise in global temperature tending towards the 2ºC mark, and deplete the ozone layer (Chinowsky et al., 2014). Hence, CCRS contains a component that not only sensitizes and educates the rural dwellers on climate adaptation techniques but also enlightens them on ways of mitigating carbon emissions (van Wesenbeeck et al., 2016).

3.1. Requirements Analysis and Modelling

Our proposed Climate Change Response System (CCRS) contains mechanisms (actions) that promote environmentally friendly disposition and climate-resilient agriculture as depicted in Fig. 1 using Unified Modelling Language (UML). The requirements as captured in the diagram include uses cases (actions) such as *Seasonal Rainfall Prediction, Climate Adaptation Techniques*, *Climate Mitigation Techniques*, *Farmers Sensitization*, *Extension Services* and *Weather-conscious Insurance Policy.*

The *Seasonal Rainfall Prediction* will empower farmers and other climate change stakeholders with information on rainfall patterns as provided by the national meteorological agencies such as the Nigerian Meteorological Agency (NIMET). This will enhance planning, decision making and execution of socio-economic projects in agriculture, construction, transportation, water resource management, telecommunication, among others (Moyo, Nangombe 2015).

The *Climate Adaptation Techniques* component will highlight to farmers and other stakeholders updated techniques for adapting to the climate-induced environment. They include, but not limited to, construction of dams and river basins for harnessing surface and underground waters for irrigation, domestic and industrial purposes. Others are digging of wells, planting crops with short life span, sowing disease resistant crops, growing climate-resistant crops, and provision of social infrastructure and amenities (Fant et al., 2016).

The *Climate Mitigation Techniques* sub-system will provide information on measures to reduce emission of greenhouse gases (GHGs). This includes afforestation, discouraging bush burning, recycling of waste products, and use of clean energy instead of hydrocarbon energy, among others.

The *Farmers Sensitization* use case outlines the use of Creative Art models such as dance, drama, posters and hand bills, dance drama, among others through informal institutions such as worship places, family meetings, festivities, age group meetings, etc. for sensitizing and educating farmers on climate change challenges and ways to adapt and mitigate them. This advocacy initiatives are aimed at helping rural dwellers internalise and institutionalize ecologically friendly behaviours, adapt to climate-induced environments and atmosphere, and mitigate the challenges posed by weather and climate vagaries.

The *Extension Services* is a system component that highlights the various services that government Extension Services render to farmers viz-a-viz ecologically friendly behaviours, climate resilient agriculture and climate change mitigation initiatives. Besides traditional extension services such as information on new farming techniques, new agricultural inputs, irrigation, disease resistant crops, drought-resistant crops, there is increased advocacy by climate experts that seasonal rainfall predictions should be an integral part of the extension service package on account of the overbearing impact of climate on agriculture (Kahsay, Hansen, 2016; Calzadilla et al., 2014).

The *Weather-conscious Insurance Policy* is a safety net measure for losses that may be incurred by farmers as a result of carbon and ecological footprints (climate change-induced challenges) such as drought, flood, late onset and early cessation of rains, dry spells, among others (Perez et al., 2015; Kahsay, Hansen, 2016; Bellprat et al., 2015; Zinyengere et al., 2013).

3.2. System Design

Though there are many functionalities offered by CCRS, they can be broadly categorised into four cardinal components, namely *Seasonal Rainfall Prediction*, *Farmers Sensitization*, *Adaptation Techniques* and *Mitigation Techniques* as shown in the Component Diagram in Fig. 2.

The class diagram in Fig.3 captures interactions among these sub-systems. Both component and class diagrams graphically indicate interactions among the four core components of CCRS – *Seasonal Rainfall Prediction*, *Farmers Sensitization*, *Adaptation Techniques* and *Mitigation Techniques* with varying details. While the component diagram depicts these sub-systems as loosely coupled components capable of independence to some extent, the class diagram gives details of attributes, methods and cardinality. In summary, CCRS relies on *Seasonal Rainfall Prediction (SRP)* for climate data that are disseminated to stakeholders including the rural farmers for purposes of planning, decision making, and execution of socio-economic projects that enhance livelihoods. The *SRP* data serve as input into Farmers *Sensitization* that encompasses the use of advocacy and climate change education through formal and informal institutions using creative arts models (dancing, graphics, posters, handbills, etc.) to drive climate change messages. The interaction with *Adaptation Techniques* sub-system ensures that farmers are abreast of measures such as climate-resistant crops, use of dams and river basins for irrigation farming as alternative to rain-fed agriculture, among other adaptation measures. Finally, the system interaction places the onus on the *Mitigation Techniques* component to avail farmers information on measures to reduce impact of climate change such as afforestation, proper waste disposal initiatives, use of clean energy as alternative to firewood and other sources of fossil fuels, among others.

The database platform of the CCRS is hinged on Seasonal Rainfall Prediction (SRP) data whose entities and relationships are shown in the entity relationship diagram (ERD).

The narrative of the ERD is to the effect that every state in Nigeria has an SRP made available by NIMET. The attributes of a state include cities, *longitude* and *latitude* while the seasonal rainfall predi-

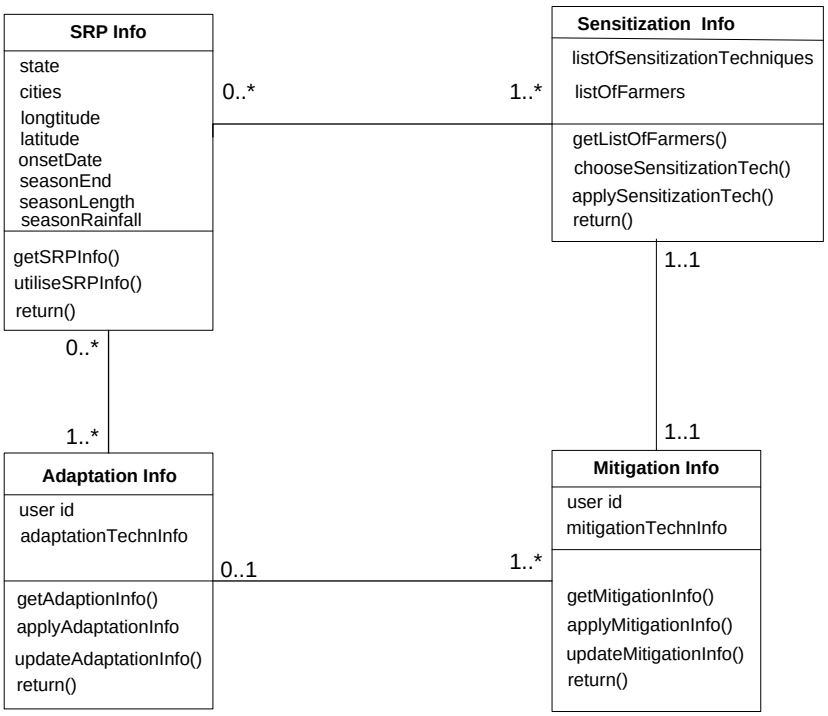

Figure 3. Class Diagram for the Climate Change Response System (CCRS)

ction is characterised by attributes such as *onset date*, *season end*, *season length* and *season rainfall*. The ERD further specifies that every state must belong to one of the agro-ecological zones in Nigeria (*Sahel Savannah, Swamp Forest, Guinea Savannah, Tropical Rain Forest, Sudan Savannah*).

3.3. System Verification and Validation

The climate change response system was validated and verified for requirements-compliance and process-correctness of the climate change adaptation and mitigation architecture by checking the different model representations – design documents, requirements documents, and pseudocode. The focus was to ensure that user requirements were well catered for in each model representation. Also, to be sure that the climate change adaptation and mitigation techniques meet ecologically-friendly and climate-resiliency needs rural dwellers in Adum-Aiona community and other similar rural communities in Africa.

The essence of the validation phase is to scale up confidence that the climate change response architecture is fit for purpose (Gorton, 2011). Our technique for validating this architecture is purely static verification and validation (Sirohi, Parashar, 2013) which uses test scenarios for manual testing of the architecture. The essence is to ascertain if flaws exist in the CCRS design so as to correct them prior to implementation.

We verified and validated the CCRS architecture by checking the various model abstractions – design documents, requirements documents, and pseudocode to ascertain that sufficient mechanisms that drive environmentally friendly behaviours and promote climate-resiliency have been built into the proposed CCRS. The requirements traceability matrix is shown in Table 2.

4. Results and Discussion

4.1. Discussion of Outcomes

NIMET has provided the 2015 SRP (prediction) in fulfilment of its statutory obligation to make available credible meteorological information, advisory, forecasts, and early warnings to guide informed decisions in sectors that are climate and weather-sensitive such as agriculture, construction, etc. Prior to public presentation, the prediction is scrutinized by major stakeholders with a view to making inputs.

Our study focused on Adum-Aiona Community in Orokam, Benue State. Hence, we extracted data from NIMET on the 2015 seasonal rainfall predictions for Benue State located in the middle-belt region of Nigeria. After a careful study of the data, we observed that the database needed to be cleaned up (as there were clear instances of duplicated data) for expected research outcome to be achieve. Hence, we normalize the data by eliminating duplicates, with a new database as shown in Table 3.

The statistics above show the impact of El Nino and climate change on seasonal rainfall pattern in Benue State, North-Central (Middle-Belt) Nigeria. However, for comparative analysis, we further provide seasonal rainfall patterns of the Adum-Aiona community and its surrounding environments in Benue State using SRPs for 2011-2014 as shown in Table 4.

Table 2. Requirements traceability matrix

Requirement ID	Climate Requirements	CCRS Mechanism	Verification and Validation
CCRS01	Stakeholders to adequately be informed about weather and climate vagaries for planning, decision making and execution of socio-economic initiatives	The Seasonal Rainfall Prediction sub-system	Catered for
CCRS02	Advocacy campaign and education of farmers for ecologically-friendly behaviour	The Sensitization Information sub-system	Catered for
CCRS03	Adaptation for climate-induced environment for survival	The Adaptation Techniques sub-system	Catered for
CCRS04	Minimizing the impact of global warming and El Nino on means of human livelihoods	The Mitigation Techniques sub-system	Catered for

Table 3. Normalized 2015 Seasonal Rainfall Predictions for Benue State, Nigeria (Source: NIMET)

State	City	Longitude	Latitude	Onset date	Season end	Season length days	Annual Rainfall (mm)
Benue	Gboko	09.00	07.32	11/4/2015	26/11/2015	231	1484
	Markurdi	08.54	07.73	1/5/2015	17/11/2015	200	1068
	Otukpo	08.14	07.20	9/4/2015	27/11/2015	233	1519
	Aliade	08.48	07.30	10/4/2015	26/11/2015	231	1490
	Oju	07.91	07.38	11/4/2015	26/11/2015	229	1466
	Ugbokpo	07.88	07.66	15/4/2015	23/11/2015	223	1388
	Wanunne	08.89	07.57	13/4/2015	24/11/2015	225	1413
	Anyiin	08.58	07.71	15/4/2015	23/11/2015	222	1375
	Okpoga	07.80	07.04	7/4/2015	29/11/2015	236	1567
	Orokam	07.55	06.97	7/4/2015	30/11/2015	238	1589
	Egumale	07.96	08.80	5/4/2015	1/12/2015	242	1643
	Idekpa	07.93	07.23	10/4/2015	27/11/2015	233	1510
	Obagaji	07.91	07.88	17/4/2015	21/11/2015	219	1330
	Kyado	09.72	07.65	14/4/2015	23/11/2015	224	1391
	Zaki Biam	09.61	07.51	13/4/2015	25/11/2015	227	1430
	Katsina Ala	09.28	07.16	9/4/2015	28/11/2015	234	1531

Table 4. 2014 Seasonal Rainfall Predictions for Benue State, Nigeria (Source: NIMET)

Year	City	Longitude	Latitude	Onset date	Season end	Season length days	Annual Rainfall (mm)
2014	Gboko	09.00	07.32	1st April	3rd Dec	238	1579
	Markurdi	08.54	07.73	20th April	22nd Nov	203	1046
	Otukpo	08.14	07.20	30th March	4th Dec	240	1618
	Aliade	08.48	07.30	1st April	3rd Dec	239	1585
	Oju	07.91	07.38	2nd April	3rd Dec	237	1559
	Ugbokpo	07.88	07.66	5th April	30th Nov	231	1472
	Wanunne	08.89	07.57	4th April	1st Dec	233	1499
	Anyiin	08.58	07.71	6th April	30th Nov	230	1457
	Kyado	09.72	07.65	5th April	30th Nov.	232	1475
	Zaki Biam	09.61	07.51	3rd April	1st Dec	234	1518
	Katsina Ala	09.28	07.16	30th March	4th Dec	241	1632
2013	Gboko	07.32	09.02	23rd April	10th Nov	202	1000
	Markurdi	09.00	08.00	21st April	17th Nov	210	1189
	Otukpo	07.18	08.13	12th April	16th Nov	219	1217
2012	Gboko	09.02	07.32	7th April	11th Nov	216	1422
	Markurdi	09.00	08.00	16th April	11th Nov	204	1227
	Otukpo	08.13	07.18	5th April	11th Nov	218	1466
2011	Gboko	07.32	09.02	25th April	6th Nov	192	1009
	Markurdi	09.00	08.00	12th April	9th Nov	209	1242
	Otukpo	07.18	08.13	13th April	9th Nov	207	1209

Table 5. Summary of 2011-2015 SRPs in terms of agro-ecological zones (Source: Nigerian Meteorological Agency – NIMET)

Agro-Ecological Zones	States covered	Onset dates	Cessation Dates	Length of Growing (Planting) Seasons (in days)	Seasonal Rainfall Amount (mm)
Swamp Forest	Lagos, Bayelsa, Rivers, Akwa Ibom, Cross River, etc	24 Feb - 30 March	4 - 11 November	227 - 266	1200 - 2700
Tropical Rain Forest	Ogun, Ondo, Osun, Edo, Imo, Delta, etc	7 March - 3 April	3 - 16 November	220 - 247	1200 - 2700
Guinea Savannah	Kwara, Kogi, Niger, Benue, Abuja, Taraba, Oyo, Enugu	23 March - 2 June	5 - 12 November	163 - 233	900 - 1700
Sudan Savannah	Bauchi, Yola, Gombe, Kano, Kaduna, Plateau, etc	9 May - 10 June	16 Oct - 7 November	129 - 183	800 - 1100
Sahel Savannah	Borno, Sokoto, Zamfara, Katsina, Kebbi, Adamawa	15 June - 30 June	3 - 22 October	93 - 150	300 - 800

In a bid to provide an aggregate view of the impact of global warming and El Nino on rainfall as an important weather and climate variable for the study period of 2011-2015, Table 5 shows the summary of the 2011-2015 SRPs in terms of Agro-Ecological zones in Nigeria.

The data show decreasing rainfall from the Swamp Forest region of Nigeria to the Sahel Savannah region; a reflection of the growing impact of desertification on Northern Nigeria. The Adum-Aiona Community is in the Guinea Savannah region with SRP of 900-1700 mm. Overtime, the data indicates that the onset dates are becoming late while the cessation dates are getting early, all pointing to the growing influence of climate vagaries on the environment. To survive, mitigation and acclimatization techniques are required by the rural farmers in Adum-Aiona just as in other rural African communities.

The data is a confirmation that human impacts such as deforestation, fossil fuel burning, among others account for carbon dioxide emission into the atmosphere that in turn result in climate change harsh conditions such as late onset and early cessation of rains, flash flooding, gully erosion, coastal erosion, caked soil, loose of soil nutrients, just to mention a few. The resultant effect is depletion in agricultural yield with dire implications for food insufficiency and insecurity, hunger, social tensions, unemployment, kidnapping and terrorism.

The proposed Climate Change Response System (CCRS) is promising for re-orientating rural dwellers on ecologically-friendly behaviours such as afforestation, discouraging bush burning practices, and use of clean energy for cooking. It also facilitates the ability of rural dwellers to adjust to weather and climate vagaries as well as mitigate their negative impacts by embracing climate-resilient agriculture. CCRS relies on its creative art-modelled sensitization campaign sub-system for achieving the trio of environmentally-friendly behaviours, adaptation and mitigation strategies. The use cases (tasks) of CCRS are mechanisms that reposition rural African dwellers for bracing up to the realities of climate unpredictability: Sensitization and education of farmers, for example, will not only promote environment-friendly behaviours but will teach them adaptation and mitigation techniques; the climate change insurance policy will encourage the introduction and implementation of weather insurance policy to safeguard against climate change-related agricultural losses; Dams and river basins revitalization will harness surface water for irrigation farming as complement of rain-fed agriculture; Harnessing of underground water through digging of community wells and boreholes will augment traditional techniques for adaptation and mitigation, hence promoting domestication and ownership of CCRS; Extension services will ensure that farmers are enlightened on climate-resilient agricultural practices and inputs; Packaging and dissemination of meteorological forecasts through formal institutions (extension services) and informal institutions (worship places, town hall meetings, and age-grade group meetings, among others) will promote proactive actions by farmers and all stakeholders in combating the menace of climate change.

4.2. Evaluation Threats

It is not impossible that an expanded evaluation of the respective modules of the CCRS could unveil fresh dimension of the impact of global warming and El Nino on rural African communities like the Adum-Aiona community. In any case, the seasonal rainfall prediction data used for our evaluation of the existential threat posed by climate change to human livelihoods are real-life operational data obtained from the Nigerian Meteorological Agency (NIMET). NIMET over the years have built sufficient capacity in availing climate, weather, and water information for safety and sustainable development which encompasses information of expected rainfall pattern that is valuable for planning, decision making and execution of socio-economic development projects. As a result, they can make objective annual

prediction that impact various sectors such as agriculture, aviation, transportation, water resources, telecommunication, and construction, among others. Hence, NIMET's views can be taken seriously (Host et al., 2000; Runeson, 2003; Sauro, Kindlund, 2005; Svahnberg et al., 2008). In addition, only 5-year seasonal rainfall predictions were used in the assessment, which has the potential of constraining the statistical significance of study findings (Nielsen, Landauer, 1993; Turner et al., 2006). In any case, the outcome of the survey is indicative that the combined effects of global warming and El Nino have impacted significantly on rainfall patterns in Africa and rural Africa in particular with evidence of early cessation and late onset of rains. This underscores the need for updated adaptation and mitigation techniques for Africans to survive environments imposed by climate change. In our view, this is a significant result since at this juncture in the study, the key objective is to secure an impression of the impact of climate change on livelihoods in rural Africa and how a climate change response system can aid adaptation and mitigation. Hence, in spite of the limited seasonal rainfall prediction data used in the evaluation, there is sufficient ground to infer that climate vagaries affects human livelihoods and a response system for climate change has the potential to strengthen adaptation and mitigation. We can thus generalize that the model-driven climate change response system is effective for instituting ecologically friendly behaviors and driving climate-resilient means of livelihood among both rural and urban African folks.

5. Recommendations

To cushion the challenge of climate change, CCRS is inbuilt with mechanisms for behaviour change, adaptation and mitigation. With these measures, it is hoped that the adverse impact of El Nino as expressed in unfavourable temperatures and rainfall will be reduced. Based on the study outcome, we advise that the following measures be put in place to help rural African dwellers to cope with the negative impact of climate vagaries on livelihoods:

1. Sustained sensitization and education of rural dwellers on dangers of environmentally unfriendly activities such as deforestation and indiscriminate burning of fossil fuel as exemplified in the Creative arts model. Formal method (extension services) and informal methods (worship places, age groups, town hall meetings, etc.) could be harnessed.
2. Extension services should be revamped at all levels of government to reach out to farmers with latest information on new farming techniques and inputs that promotes climate-resilient agriculture.
3. In the light of established agricultural impact of climate vagaries, the scope of extension services should be expanded to include seasonal rainfall predictions (SRPs) by meteorological agencies. The SRP information will guide farmers in decision making.
4. There is need for agricultural policy consistency particularly with respect to construction and maintenance of dams and river basins for irrigated farming to complement the dominant rain-fed agriculture in Africa.
5. The various traditional approaches adopted by locals in the past for adapting and reducing climate change impact should be integrated in any climate change response system for communities to domesticate and take ownership of such system.
6. Government and the private sector should start thinking of implementing climate change insurance policy as safety net for those who may suffer agricultural loses as a result of the weather vagaries.
7. Appropriate pricing for kerosene, cooking gas, and petrol should take into account the purchasing power of the rural poor. This way, alternative to the use of firewood is formulated, discouraging deforestation and strengthening afforestation drive.

6. Conclusion

We have provided both computational and artistic impressions of the effect of El Nino and climate vagaries on rural Africa using the Adum-Aiona community as case study. In the face of growing impact of El Nino on livelihoods of rural Africans, measures to promote afforestation, shift to clean energy and climate-resilient agriculture and construction cannot be overemphasized. El Niño gives rise to global changes in rainfall and temperatures. Simulations and measurements have shown that climate change is contributing to extreme El Niños in recent years with visible impact on human lives as evident in humanitarian crisis in the horns of Africa – Ethiopia and Eritrea. It confirms the sentiment that the most affected are developing countries bordering the Pacific Ocean whose means of livelihood are agriculture and fishing. This study has provided empirical evidence to the effect that climate change threats on man and his means of livelihood are real. The study equally designed a climate change response system for aiding climate change adaptation and mitigation. We concluded by recommending a number of measures that will promote ecologically friendly behaviours and protect rural African dwellers from the negative impacts of climate change. Future research is needed to institute and strengthen weather-conscious insurance policy for African farmers as a mitigation strategy for climate-induced loss of agricultural products.

Acknowledgement
We appreciate the University of Lagos authorities for providing access to online scholarly databases which we used for literature survey.

References

1. AKANDE V., 2016, *Calabar Carnival 2016 to Explore Climate Change Again*, http://thenationonlineng.net/calabar-carnival-2016-to-explore-climate-change-again (15.04.2016).
2. BABATUNDE H.O., 2007, *A Comprehensive Approach to Visual and Creative Arts*, Agege, Lagos, HOB Designs Nig. Limited, p. 9.
3. BARBIER G., CUCCHI V., HILL R.C.D., 2015, Model-driven engineering applied to crop modeling, in: *Ecol. Informatics* 26, p. 173-181.
4. BELLPRAT et al., 2015, Unusual past dry and wet rainy seasons over Southern Africa and South America from a climate perspective, in: *Weather and Climate Extremes* 9, p. 36-46.
5. BRAMBILLA M., FRATERNALI P., 2014. Large-scale Model-Driven Engineering of web user interaction: The WebML and WebRatio experience, in: *Science of Computer Programming* 89, p. 71-78.
6. BRUNELIERE H. et al., 2014, MoDisco: A model driven reverse engineering framework, in: *Information and Software Technology* 56, p. 1012-1032.
7. BUBECK A., MAIDEL B., LOPEZ F.G., 2014, Model driven engineering for the implementation of user roles in industrial service robot applications, in: *Proc. Technology* 15, p. 605-612.
8. CALATAYUD et al., 2016, Can climate-driven change influence silicon assimilation by cereals and hence the distribution of lepidopteran stem borers in East Africa?, in: *Agriculture, Ecosystems and Environment* 224, p. 95-103.
9. CALEGARI D., MOSSAKOWSKI T., SZASZ N., 2016, Heterogeneous verification in the context of model driven engineering, in: *Science of Computer Programming* p. 1-33.
10. CALZADILLA A.,, ZHU T., REHDANZ K., ehdanz, TOL R.S.J., RINGLER C., 2014, Climate change and agriculture: Impacts and adaptation options in South Africa, in: *Water Resources and Economics* 5, p. 24-48.
11. CERVERA et al., 2015, On the usefulness and ease of use of a model-driven Method Engineering approach, in: *Informat. Systems* 50, p. 36-50.
12. CHABRIDON S. et al., 2013, Building ubiquitous QoC-aware applications through model-driven software engineering. *Science of Computer Programming* 78, p. 1912-1929.
13. CHIDIEBERE O., CHIRWA P.W., FRANCIS J., BABALOLA F.D., 2016, Assessing forest-based rural communities' adaptive capacity and coping strategies for climate variability and change: The case of Vhembe district in South Africa, in: *Environmental Development*.
14. CHINOWSKY P., SCHWEIKERT A., HAY-LES C., 2014, Potential Impact of Climate Change on Municipal Buildings in South Africa, in: *Proc. Econ. and Finance* 18, p. 456-464.
15. CICCOZZI F., CICCHETTI A., SJODIN M., 2013, Round-trip support for extra-functional property management in model-driven engineering of embedded systems, in: *Information and Software Technology* 55, p. 1085-1100.
16. CUADRADO J.S. et al., 2014, Applying model-driven engineering in small software enterprises, in: *Science of Computer Programming* 89, p. 176-198.
17. CLARKE et al., 2016, Climatic changes and social transformations in the Near East and North Africa during the 'long' 4th millennium BC: A comparative study of environmental and archaeological evidence, in: *Quaternary Science Reviews* 136, p. 96-121.
18. DAVIES et al., 2014, The CancerGrid experience: Metadata-based model-driven engineering for clinical trials, in: *Science of Computer Programming* 89, p. 126-143.
19. DAVIES et al., 2015, Formal model-driven engineering of critical information systems, in: *Science of Computer Programming* 103, p. 88-113.
20. FANT C., SCHLOSSER A., STRZEPEK K., 2016, The impact of climate change on wind and solar resources in southern Africa, in: *Applied Energy* 161, p. 556-564.
21. GARCIA-MAGARINO G. PALACIOS-NAVARRO, 2016, A model-driven approach for constructing ambient assisted-living multi-agent systems customized for Parkinson patients, in: *The Journal of Systems and Software* 111, p. 34-48.
22. GORTON I., 2011, *Essential Software Architecture*. Springer.
23. GRACE et al., 2015, Linking climate change and health outcomes: Examining the relationship between temperature, precipitation and birth weight in Africa, in: *Global Environmental Change* 35, p. 125-137.
24. GURUNULE D., NASHIPUDIMATH M., 2015, *Analysis of Aspect Orientation and Model Driven Engineering for Code* Generation, in: Procedia Computer Science 45, p. 852-861.
25. HOST M., REGNELL B., WOHLIN C., 2000, Using students as subjects - a comparative study of students and professionals in lead-time impact assessment, in: *Empirical Software Engineering* 5(3), p. 201-214.
26. HUTCHINSON J., WHITTLE J., ROUNCEFIELD M., 2014, Model-driven engineering practices in industry: Social, organizational and managerial factors that lead to success or failure, in: *Science of Computer Programming* 89, p. 144-161.
27. JONES M.R., SINGELS A., RUANE A.C., 2015, Simulated impacts of climate change on water use and yield of irrigated sugarcane in South Africa, in: *Agricultural Systems* 139, p. 260-270.
28. KAHSAY G.A, HANSEN L.G., 2016, The effect of climate change and adaptation policy on agricultural production in Eastern Africa, in: *Ecological Economics* 121, p. 54-64.
29. KLAUSBRUCKER et. al, 2016, A policy review of synergies and trade-offs in South African climate change mitigation and air pollution control strategies, in: *Environmental Science & Policy* 57, p. 70-78.

30. KUSANGAYAS. et al., 2014, Impacts of climate change on water resources in southern Africa: A review, in: *Physics and Chemistry of the Earth* 67/69, p. 47-54.
31. LI et al., 2015, Hydrological projections under climate change in the near future by RegCM4 in Southern Africa using a large-scale hydrological model, in: *Journal of Hydrology* 528, p. 1-16.
32. LIM S. et al., 2016, 50,000 years of vegetation and climate change in the southern Namib Desert, Pella, South Africa, in: *Palaeogeography, Palaeoclimatology, Palaeoecology* 451, p. 197-209.
33. LUKMAN T. et al., 2013, Model-driven engineering of process control software – beyond device-centric abstractions, in*: Control Engineering Practice* 21, p. 1078-1096.
34. LUTJEN M. et al., 2014, Model-driven logistics engineering – challenges of model and object transformation, in: Procedia Technology 15, p. 303-312. 15, p. 303-312.
35. MARTINEZ-GARCIA et al., 2015, Working with the HL7 metamodel in a Model Driven Engineering context, in: *Journal of Biomedical Informatics* 57, p. 415-424.
36. MOYO E.N., SHINGIRAI S., 2015, Southern Africa's 2012-13 Violent Storms: Role of Climate Change, in: *Procedia IUTAM* 17, p. 69-78.
37. NIELSEN J., LANDAUER T., 1993, A mathematical model of the finding of usability problems, in: *Proceedings of ACM INTERCHI'93 Conference*, p. 206-213.
38. PANESAR-WALAWEGE R.K., SABETZADEH M., BRIAND L., 2013, Supporting the verification of compliance to safety standards via model-driven engineering: Approach, tool-support and empirical validation, in: *Information and Software Technology* 55, p. 836-864.
39. PEREZ et al., 2015, How resilient are farming households and communities to a changing climate in Africa? A gender-based perspective, in: *Global Environmental Change* 34, p. 95-107.
40. RALEIGH C., CHOI H.J., KNIVETON D., 2015, The devil is in the details: An investigation of the relationships between conflict, food price and climate across Africa, in: *Global Environmental Change* 32, p. 187-199.
41. RIESENFELD R.F., HAIMES R., COHEN E., 2015, Initiating a CAD renaissance: Multidisciplinary analysis driven design Framework for a new generation of advanced computational design, engineering and manufacturing environments, in: *Comput. Methods Appl. Mech. Engrg.* 284, p. 1054-1072.
42. RUNESON P., 2003, Using students as Experiment Subjects – An Analysis on Graduate and Freshmen Student Data, in: (ed.) Linkman S., 7th International Conference on Empirical Assessment & Evaluation in Software Engineering (EASE'03), p. 95-102.
43. RUTLE A. et al., 2015, Model-Driven Software Engineering in Practice: a Content Analysis Software for Health Reform Agreements, in: *Procedia Computer Science* 63, p. 545-552.
44. SCHROTH G. et al., 2016, Vulnerability to climate change of cocoa in West Africa: Patterns, opportunities and limits to adaptation, in: *Science of the Total Environment* 556, p. 231-241.
45. SAURO J., KINDLUND E., 2005, A Method to Standardize Usability Metrics into a Single Score, in: *Proceedings of ACM SIGCHI Conference on Human Factors in Computing Systems*, ACM, p. 401-409.
46. SEO S.N., 2014. Evaluation of the Agro-Ecological Zone methods for the study of climate change with micro farming decisions in sub-Saharan Africa, in: *Europ. J. Agr.* 52, p. 157-165.
47. Da SILVA R., 2015, Model-driven engineering: A survey supported by the unified conceptual model, in: *Computer Languages, Systems & Structures* 43, p. 139-155.
48. SIROHI N., PARASHAR A., 2013, Component Based System and Testing Techniques, in *Advanced Research in Computer and Communication Engineering*, 2(6), p. 33-42.
49. STEYNOR et al., 2016, Co-exploratory climate risk workshops: Experiences from urban Africa, in: *Climate Risk Management*.
50. SVAHNBERG M., AURUM A., WOHLIN C., 2008, Using students as Subjects -An Empirical Evaluation, in: *Proc. 2nd International Symposium on Empirical Software Engineering and Management ACM*, p. 288-290
51. TURNER C.W., LEWIS J.R., NIELSEN J., 2006, Determining usability test sample size, in: (ed.) Karwowski W., *International Encyclopaedia of Ergonomics and Human Factors*, CRC Press, Boca Raton, p. 3084-3088.
52. WAUTELET Y., KOLP M., 2016, Business and model-driven development of BDI multi-agent system, in: *Neurocomputing* 182, p. 304-321.
53. WEBBER H., GAISER T., EWERT F., 2014, What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa?, in: *Agricultural Systems* 127, p. 161-177.
54. WEHRMEISTER et al., 2014, Combining aspects and object-orientation in model-driven engineering for distributed industrial mechatronics systems, in: *Mechatronics* 24, p. 844-865.
55. van WESENBEECK C.F.A., 2016, Localization and characterization of populations vulnerable to climate change: Two case studies in Sub-Saharan Africa, in: *Appl. Geogr.* 66, p. 81-91.
56. WUNDSCH M. et al., 2016, Sea level and climate change at the southern Cape coast, South Africa, in: *Palaeogeography, Palaeoclimatology, Palaeoecology* 446, p. 295-307.
57. YOUNG A.J. et al. 2016, Biodiversity and climate change: Risks to dwarf succulents in Southern Africa, in: *J. of Ar. Env.*129, p. 16-24.
58. ZINYENGERE N., CRESPO O., HACHIGONTAS., 2013, Crop response to climate change in southern Africa, in: *Global and Planetary Change* 111, p. 118-126.

2.1 Summary of impact article 1

In this chapter, we showed that the sense of measuring sustainable development activities among stakeholders could be improved upon using software models. Though scientific, they break down sustainable development activities in terms of entities and relationships in a quantified format. This makes it easy for implementation actors to come to terms on policy formulation, programme implementation and project management. We aimed at using software models to reduce qualitative details that often make sustainable development documents to clumsy for stakeholders to comprehend, let alone garner their support in the implementation process.

In the next chapter, we will focus on using data pre-processing to package data in a form that it would be most useful for monitoring of national and sub-national sustainable development priorities. Monitoring is a critical determinant of the success of any sustainable development plan as it enables stakeholders to proactively gauge the viability or otherwise of initiatives rolled out by various national and sub-national entities committed to actualizing development objectives outlined in global development plans. Data explosion and revolution in recent times give rise to big data, but there is need to properly streamline the development data so that stakeholders who may not necessarily be data scientists can seamlessly have access to data that is critical to their monitoring functions. Such monitoring stakeholders include development partners, non-government organizations, and public-spirited individuals.

CHAPTER

3 DATA, DATA PRE-PROCESSING AND MONITORING OF SDG

As discussed above, the modelling of entities and relationships in sustainable development activities enhances stakeholders' perception and measurement capacity. Another important consideration is the quality of the data. Data from individuals as well as that supplied by the national bureau of statistics (National Bureau, 2017; Kale, 2017) should be well treated to enhance the outcome of monitoring. The outcome of a computational system depends largely on the quality of data. Since informed decision making is based on the quality of information from a computational system, there is a need for a quality assurance value chain that starts with reliable data. Sustainable development stakeholders are better positioned for the task of monitoring development activities if armed with the right data and information. The knowledge engineering chains recognize data pre-processing as a vital stage that precedes knowledge elicitation. For the monitoring process to be credible, reliable data and information must be generated. Past sustainable development plans such as the MDGs failed partly because of the dearth of reliable data for precise monitoring and reporting of sustainable development activities in many countries. Our contribution in this regard is highlighted in two journal papers which focus on two different aspects of the SDGs – national security and job security. SDG 16 advocates the promotion of peaceful and inclusive societies for sustainable development as well as provision of access to justice for all as antidote national security. On the other hand, SDG 8 focuses on promoting sustainable economic growth through full and productive employment and decent work for all. We show in the two papers how raw data could be improved upon using data pre-processing. We refine data by removing duplicates, making up for missing data, removing irrelevant details, among others measures so that information derives from such data could be very reliable for monitoring sustainable development activities for the purpose of enhancing the implementation of development plans such as SDGs. We aim at improving the monitoring process of sustainable development activities by using data science which offers quality assurance in data handling prior to processing.

sustainability

MDPI

Article

Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem

Emmanuel Okewu [1], Sanjay Misra [2,3], Rytis Maskeliūnas [4,*], Robertas Damaševičius [4,*] and Luis Fernandez-Sanz [5]

1 Centre for Information and Technology, University of Lagos, Lagos 100001, Nigeria; eokewu@unilag.edu.ng
2 Department of Computer Engineering, Atilim University, Incek 06836, Ankara, Turkey; sanjay.misra@atilim.edu.tr or sanjay.misra@covenantuniversity.edu.ng
3 Department of Electrical and Information Engineering, Covenant University, Ota 0123, Nigeria
4 Department of Multimedia Engineering, Kaunas University of Technology, Kaunas LT-44249, Lithuania
5 Department of Computer Sciences, University of Alcala, Alcalá de Henares 28871, Spain; luis.fernandezs@uah.es
* Correspondence: rytis.maskeliunas@ktu.lt (R.M.); robertas.damasevicius@ktu.lt (R.D.)

Received: 21 September 2017; Accepted: 6 October 2017; Published: 18 October 2017

Abstract: The role of automation in sustainable development is not in doubt. Computerization in particular has permeated every facet of human endeavour, enhancing the provision of information for decision-making that reduces cost of operation, promotes productivity and socioeconomic prosperity and cohesion. Hence, a new field called information and communication technology for development (ICT4D) has emerged. Nonetheless, the need to ensure environmentally friendly computing has led to this research study with particular focus on green computing in Africa. This is against the backdrop that the continent is feared to suffer most from the vulnerability of climate change and the impact of environmental risk. Using Nigeria as a test case, this paper gauges the green computing awareness level of Africans via sample survey. It also attempts to institutionalize green computing maturity model with a view to optimizing the level of citizens awareness amid inherent uncertainties like low bandwidth, poor network and erratic power in an emerging African market. Consequently, we classified the problem as a stochastic optimization problem and applied metaheuristic search algorithm to determine the best sensitization strategy. Although there are alternative ways of promoting green computing education, the metaheuristic search we conducted indicated that an online real-time solution that not only drives but preserves timely conversations on electronic waste (e-waste) management and energy saving techniques among the citizenry is cutting edge. The authors therefore reviewed literature, gathered requirements, modelled the proposed solution using Universal Modelling Language (UML) and developed a prototype. The proposed solution is a web-based multi-tier e-Green computing system that educates computer users on innovative techniques of managing computers and accessories in an environmentally friendly way. We found out that such a real-time web-based interactive forum does not only stimulate the interest of the common man in environment-related issues, but also raises awareness about the impact his computer-related activities have on mother earth. This way, he willingly becomes part of the solution to environment degradation in his circle of influence.

Keywords: green computing; economic security; environmental sustainability; information economy; sustainable development; Sub-Saharan Africa

1. Introduction

In recent times, there has been unprecedented growth in Africa's cyberspace leading to socioeconomic growth and sustainable development. This is particularly so as more original equipment manufacturing (OEM) companies are imbibing the philosophy of inclusive innovation, propelling them to develop relatively cheap technologies that fit the purchasing power of users in developing economies [1,2]. Hence, cheaper phones, computers, telecommunication equipment and other accessories purposely built for emerging markets are strengthening the vision of digital inclusion. However, associated with this development is the need to promote environmentally sustainable computing that limits the impact of global warming and environmental degradation [3]. This is particularly concerning in that projected figures of Africa's vulnerability to climate change and environment risk by global environmental assessing bodies like IPDA, the UN, and so forth, are quite alarming. Already, flash floods [4], gully erosion, coastal erosion, and desert encroachment are threatening livelihood, posing economic insecurity challenges, and in extreme cases, culminating in humanitarian crisis.

Green computing embraces green infrastructure [5] and refers to the efficient and effective handling of computers, servers and accessories such as printers, monitors, networking/communication gadgets, and storage devices with minimal or zero environmental impact by studying and adopting global best practice in their design, manufacture, usage, and disposal [6]. Preliminary investigation revealed that despite the expansion of the African computing community, there is low level of green computing awareness. The implication is that Africans continue to use information and communication technology (ICT) to support their livelihoods with little concern for the adverse impact of computing on the environment. Meanwhile, computing by both corporate and individual users have been known to scale up global warming through carbon emission, degrade the environment through release of hazardous chemicals, and deplete energy availability. Many computing businesses depends on fuel generators for power supply in the absence of regular electricity from national grids. The presence of carbon in each hydrocarbon fuel (petroleum, natural gas, and coal) entails that it is released as carbon dioxide (CO_2) during combustion [7]. Conversely, non-combustible sources such as sunlight, wind, nuclear, and hydropower [8] do not have the capacity to transform hydrocarbons to CO_2, which is widely acknowledged as a heat-trapping greenhouse gas [9,10]. As acknowledged by scientists, the release into the atmosphere of greenhouse gases (GHGs) adversely impacts on the climate system. Nonetheless, since cost-benefit analysis indicates that the benefits of ICT way outweighs its costs, measures have to be put in place for environmentally sustainable usage of ICT in Sub-Saharan Africa.

In this work, we proposed that one of such measures is stepping up green computing [5] awareness in Africa's cyberspace. Educating computer users will empower them with the right information to be innovative and creative about the use of ICT facilities vis-a-vis the environment [11]. An adequate green computing campaign can be launched in each African country in the fight against the adverse effect on climate change. Although a number of campaign initiatives are available, we concern ourselves basically with the solution option with maximum impact. Hence, we investigated an optimization problem. For the success of any green computing campaign nationally, support from government in terms of resources and enforcement systems are needed. It is therefore a source of concern that Africa's socioeconomic landscape is characterised by deficient legal system, poor regulatory framework, weak institutions, infrastructure deficit, and near non-existent standards [12], among others. The combined effect is a precarious climate that breeds corruption, mutual distrust and low productivity across all sectors, including the computing sector. This underscores the fact that the decision to optimize green computing awareness in a social-economic system with stochastic behaviour is a stochastic optimization problem [13].

Having classified the problem, we identified effective actions that could move the process from one state to another along the green computing awareness creation value chain as a knowledge gap analysis, the identification of suitable campaign initiative in socio-cultural context, the application of preferred initiative and, finally, an impact assessment of the initiative on computer users' behaviour.

We then mathematically modelled the African green computing awareness decision environment as sequential decision-making under uncertainty using stochastic finite automaton [14]. Subsequently, the authors applied metaheuristic algorithm [15,16] to the sequencing and selection process to ascertain the best-known awareness campaign initiative to be used. The outcome led to the use of a software engineering approach (component-based software engineering or CBSE) for the design and development of a web-based e-Green Computing system. The proposed n-tier solution is aimed at promoting environmentally sustainable computing education for positive behavioural change towards the environment [17].

The rest of the article is partitioned as follows: in Section 2, we provide the background of the study and related work; methodology and a selected case study are presented in Section 3; in Section 4, the results are discussed; and we conclude the paper in Section 5.

2. Background and Related Work

2.1. Electronic Waste

Electronic waste (e-waste) refers to electronic products that have attained the end of useful life and as such have become obsolete, unwanted, non-working and can be discarded. Nonetheless, they can be useful to some people or industry as raw material. Many electronic products have the propensity to become waste after some few years of usage on account of rapid technological advancement. For example, scenarios of e-waste generation include replacement of VCRs by DVD players, and also the replacement of DVD players by Blu-ray players. Anything electronic (TV, computer, monitors, cell phones, VCR, PDAs, fax machines, CD players, printers) creates waste.

2.2. Green Computing and Sustainable Development

Green computing refers to the efficient utilization of computers and accessories such that they contribute minimally to environmental degradation. These devices are known to contain harmful chemicals and emit gaseous emissions when in use and out of use. It also encompasses efficient energy utilization. Socioeconomic activities that contribute to national economic indicators such as real gross domestic product (GDP), income, employment, manufacturing and retails sales [18] have to take into cognisance an environment that is humanly friendly as captured by the global policy framework called sustainable development goals [19]. This means both the natural environment and social environment [20] have to be protected. Though computing contribute greatly to socioeconomic activities [21,22], it has been observed that e-waste from the use of information and communication technologies (ICTs) have to be properly articulated to guarantee a friendly ecosystem [1] for socioeconomic and sustainable development activities to thrive. Plastic and metallic e-wastes, for example, are known to be non-biodegradable and can harden the soil when disposed indiscriminately, resulting in flooding [4]. E-waste apart, the design, production and usage of ICTs should minimize the amount of energy consumed by ICT so that green computing [5] can contribute maximally to sustainable development. Apart from the hazardous greenhouse gases (GHGs) that emanate from e-waste during their disposal into the atmosphere [7], many business centres rely on generators in developing economies to power their businesses. Equally, highly automated corporate businesses do same to be able to survive in the less than impressive business environment in which they operate. As result, a lot of carbon fuel is burnt to sustain computer-driven businesses with implications for CO_2 emissions into the atmosphere. The advocacy for clean energy [21] in emerging economies is receiving little attention owing to poverty levels [2,23]. In any case, in the context of the reality on ground, green computing awareness has to be intensified across all strata of businesses to ensure the environment is not devastated [3] by ICT-related activities. For instance, corporate organizations through their corporate social responsibility (CSR) portfolio [24] could raise green computing awareness among computer users and merchants [25]. Such campaigns will purely target

acceptable environmental behaviours [17] that protect and preserve the natural and social environments for sustainable development.

2.3. Metaheuristic Algorithm for Optimal Green Computing Awareness

Our study assessed a number of potential initiatives for creating users awareness on green computing in the African context. The initiatives examined are:

- establishing functional regulatory bodies;
- use of traditional media awareness;
- use of web-based social media;
- organizing workshops and seminars;
- establishing waste collection and quantification systems; and
- organizing a road walk campaign.

An emerging market such as Africa is characterized uncertainties [26] predicated on constraints such as resource availability, literacy level, infrastructure deficit, epileptic power supply, and weak institutions, among others. Hence, our decision to create optimal green computing education in a geopolitical space with stochastic (probabilistic) behaviour exhibits trappings of stochastic finite automaton [14] as shown in Figure 1.

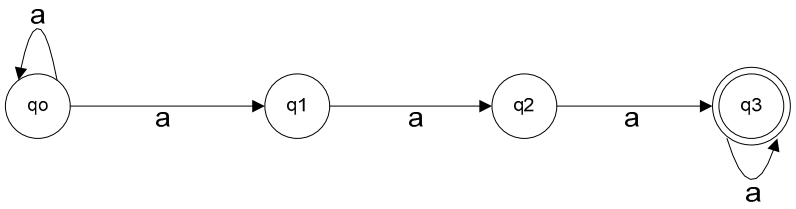

Figure 1. Stochastic finite automaton for green computing awareness creation process.

This is mathematically expressed as M* = (Q,A,q_0,∂, p, F) such that

Q = set of states that is finite
A = set of actions that is not empty
q_0 ϵ Q = start state
F Q = set of final states;
Q A Q = finite set of transition between states; where
p is a function ∂ [0,1] and all q ϵ Q; for all a ϵ A
$\sum p(q, a, q') = 1$.

For a finite state automaton to be stochastic, the transition rules have to be defined by transition probabilities while the initial and final states have to be defined by probability distributions [13]. In this instance, the inputs into the sequential decision making process of the green computing awareness campaign are:

a_0 = Knowledge gap analysis of computer end-users in Sub-Saharan Africa
a_1 = Identification of suitable campaign option for creating maximum awareness in the socio-cultural context of each African country
a_2 = Application of identified approach
a_3 = Evaluation of the impact of applied approach.

The function P (∂→[0,1]) entails that the occurrence of each outcome has a probability value assigned to it.

In any case, the research focus was to get the best way to execute the campaign, taking into cognizance each socio-cultural context. This means optimal decision has to be taken amid uncertainties that are hallmarks of developing economies in Africa. We therefore x-rayed each of the green computing awareness-creating initiatives, focusing on capacity to engineer environmentally sustainable computing behavioural change measured by power of attraction, speed of message delivery, and message retention.

Since the solution space is populated with viable alternatives, with each having potential for delivery, the quest for the best-known solution took centre stage. The researchers thus applied Tabu Search, a metaheuristic Algorithms 1 and 2, as follows:

Algorithm 1: Tabu Search

```
s ← s0
sBestInitiative ← s
awarenessTabuList ← null
 while (not awarenessSearchStoppingCondition())
    awarenessCandidateList ← null
    for(awarenessCandidate in searchNeighborhood)
         if(not containsTabuElements(awarenessCandidate,
         awarenessTabuList))
              awarenessCandidateList ← awarenessCandidateList
              + awarenessCandidate
         end
    end
    awarenessCandidate ←
    LocateBestAwarenessCandidate(awarenessCandidateList)
    s ← awarenessCandidate
    if(fitness(awarenessCandidate) > fitness(sBestAwareness))
       awarenessTabuList ←
       featureDifferences(awarenessCandidate,
       sBestAdmission)
       sBestAwareness ← awarenessCandidate
       while(size(awarenessTabuList) >
             maxAwarenessTabuListSize)
       ExpireFeatures(awarenessTabuList)
             s ← awarenessTabuLIstFirstElements
        end
   end
 end
 return(sBestAwareness)
```

Using parameters likes power of attraction, speed of message delivery and message retention capability, the metaheuristic search indicated that of all the aforementioned green computing enlightenment strategies, a web-based social media platform would best serve the purpose of maximum green computing awareness. Hence, the researchers relied on software design and development skills to actualize a multi-tier web-based e-Green computing system. Specifically, component-based software engineering (CBSE) approach was applied. +

Meanwhile, mathematically, the optimization problem is:

Algorithm 2: Green Computing Awareness Maximization Function

```
Max
            Green Computing awareness
Subject to
            Availability of funds
            Access to network infrastructure
            Literacy level
```

2.4. Related Work

Previous efforts that have bearing with the subject matter in the literature are presented as follows.

Saha [27] defined green computing as the act of sustaining computing performance while ensuring that computing resources are utilized in an environment friendly manner. After a literature survey of green computing, the author emphasized its significance to sustainable development. The study emphasized that an organization (United Nations Framework Convention on Climate Change or UNFCCC) has been working hard towards circumventing adverse anthropogenic (human-induced) climate change. Already, manufacturers of ICT accessories have been compelled to meet various energy standards owing to a combination of factors that includes consciousness of global warming and promulgation of environmental regulations and laws. The paper concluded that the present and future technological needs will not be compromised in that green computing will achieve a healthier, safer and greener environment via its structured, methodical and sustainable approach. Though the study highlighted efforts being made globally to promote environmentally tolerable behaviours, it did not state specifically state how to optimize green computing awareness in an emerging economy like Africa that is faced with uncertainties, which is the key motivation for our study.

Mittal and Kaur [28] conducted a survey to gauge the common man's understanding of issues related to green computing. A survey questionnaire incorporating major green computing was administered in the first instance as a pilot study before the actual survey. The paper opined that green computing is an effective approach aimed at energy efficient products. The authors are of the view that with the aid of green computing, we can achieve the dual objectives of saving energy and shielding the environment from adverse impacts of computers and its accessories. While decrying the low-level of awareness about the harmful impacts of the use of computer on environment, the study stressed that most of the CO_2 emission is produced through the heat generated by the computer and its devices. Another challenge posed to the environment by computing is energy consumption by various computing devices. Despite comprehensively highlighting factors related to green computing and measuring the common man's awareness level of the subject, the study stopped short of suggesting ways to scale up awareness level. Neither did it consider making and implementing such a decision under uncertainty like this African study presents.

Shinde et al. [29] is an expository study on green computing, also called green technology. The paper posited that it is the efficient and effective use of computers and accessories such as printers, monitors, networking/communication systems, and storage devices such that there is minimal or zero impact on the environment. The work stressed that green computing will optimize energy efficiency in the lifetime of a product, mitigate usage of hazardous materials, and ensure that factory waste and defunct products can be recycled and biodegradable. The study observed that the upsurge in the use of computers for domestic, official and business purposes has led to unprecedented increase in the quantity of electricity they consumed and scaled up atmospheric carbon content. Against this reality, measures are now being taken by people to minimize the power usage of computers as the reduction in the use of energy occasioned by green computing techniques will scale down carbon dioxide emissions. This arises from reduction in amount of fossil fuel utilized in transportation and power plants. Resource conservation entails less energy is needed for product development, usage and

disposal. In the same vein, prudence in the use of energy and resources saves money. The researchers are of the view that change in government policy to facilitate recycling, as well as scaling down energy usage by both businesses and individuals, are the two cardinal objectives of green computing. Though the authors mentioned that people have taken appropriate measures, they were not specific. In our study, we advocate a cohesive national programme for raising green computing awareness among numerous computer users.

Therese and Albert [13] worked on sequential decision-making in unpredictable circumstances and opined that stochastic finite automata can be used as a mathematical model for decision making under uncertainty. They emphasized that decisions such as launching a comprehensive green computing campaign in an emerging economy can be an uphill task that likely involves to some extent uncertainty. A decision environment refers to a set of information, values, preferences, and alternatives made available at the decision moment while a sequential decision problem encompasses sequential states that are likely interdependent or independent. Thus, in each state action has to be taken, and a sequence of actions is required to obtain a solution. A decision taken at a state based on an action is transferred to next subsequent state, and the entire decision chain is a function of all decisions taken at all the states. The study reiterated that complex systems exhibiting stochastic behaviour in a finite manner can be modelled mathematically using stochastic finite automata. The authors concluded that in the event transition rules are measured by transition probabilities then the finite state automaton is categorized as stochastic just as probability distributions are used to define final and initial states. Though the study did not specifically focus on the green computing awareness problem, it provided a framework for rightly classifying such an exercise in an emerging economy with trademark uncertainties and instabilities.

Silberholz and Golden [15] used solution quality and runtime as barometers for comparing metaheuristics. They opined that since metaheuristics are meant to overrun exact approaches in terms of giving quality solutions in runtimes that exact approaches cannot boast of, they can only be meaningful if acceptable solutions are given within reasonable time. A metric that represents solution quality is required as benchmark for comparing two algorithms in the context of solution quality, and comparison should be done over same problem instances as comparison over different instances are weaker since they have un-identical structures, difficulties and optimal values. Besides demonstrating good solution quality, another critical necessity is that they must have a fast runtime. Otherwise, we cannot justify the preference of metaheuristics over exact algorithms. The authors stressed that making runtime comparisons are difficult in nature. Challenges involved in comparing runtimes of algorithms compiled with different compilers and executed on heterogeneous computers, potentially on different testbeds, have aggravated the situation. Despite comparing and discussing how to secure greater value from optimization techniques, the work did not dwell on optimizing green computing awareness under uncertainty.

Glover [16] chronicled the creation of Tabu Search as a metaheuristic algorithm. It can be applied to stochastic optimization problems. These are problems that require optimal sequencing and selection of best-known solution under uncertainty. The author emphasized that local (neighbourhood) searches such as picking best-known green computing awareness creation strategy from a pool of strategies take a potential solution to a problem and investigate its proximate neighbours with a view to obtaining a better solution. There is the propensity for local search methods to become stuck where many similar solutions exist. In such suboptimal scenarios (or plateaus) of equally fit solutions, Tabu Search pushes the limits by using memory structures. The memory structures describe and harbour user-provided collection of rules and already visited solutions, thereby enhancing performance. The algorithm avoids considering a solution repeatedly by ensuring that if such solution has been hitherto visited within a particular short-term period or has contradicted a rule, it is logged as Tabu. This means forbidden. Among other application areas, the author confirmed that it is also used in resource planning—this is key to mobilizing human and material resources towards environmentally sustainable computing. Though the study outlined the modus operandi of Tabu Search and reiterated its potentials for tackling

resource planning problem, it was silent on the impact of green computing awareness on environmental sustainability and economic security.

3. Methodology—The e-Green Computing System

In identifying requirements for the e-Green Computing system and to get an insight into current trend in cyberspace, relevant literature was consulted, interviews held, questionnaire administered and the Nigerian cyberspace observed as a reasonable representation of Sub-Saharan Africa.

Green computing process and procedures were modelled using the Universal Modeling Language; specifically, we used use cases, collaboration diagrams, sequence diagrams, class diagram and deployment diagram.

The Microsoft SharePoint was then used as implementation platform for a prototype after designing and developing the proposed solution leveraging CBSE approach. The proof-of-technology was set up at the Centre for Information Technology and Systems (CITS), University of Lagos, Lagos, Nigeria, and tested from Abuja and Lagos, respectively. Microsoft SharePoint supports four major components namely: Document Library; Custom List, Task, and; Site. The tool was used because it supports the doctrine of component reusability with COM+ as its component model. It is also a web-based platform that supports distributed computing.

The researchers performed a number of controlled experiments using real-life and simulated data. The participants in the experiments had ample opportunity to interact with the system. Thereafter, they shared their insights on the potency of the proposed social media application to drive online real-time conversations between green computing stakeholders, achieve the goal of promoting environmental friendly computing education and ultimately stimulate appropriate end-user behaviour. The authors then evaluated possible threats to research outcome.

We used Nigeria as a case study amid established concerns that it has one of the largest ICT users' population on the African continent. Besides representing in microcosm the African continent in terms of demography, Nigeria accounts for 29% of internet usage on the continent, making it Africa's largest ICT market [30]. To actualize the proposed e-Green Computing system as a measure for promoting environment-friendly computing behaviours in the African cyberspace and computing community in general, CBSE lifecycle activities were used guided by the objective-methodology mapping shown in Table 1.

Table 1. Objective-Methodology Mapping.

SN	Objective	Methodology
1.	To drive online real-time conversation on environmentally friendly computing in the African cyberspace	Design and implement an e-Green Computing system
2.	To ascertain proposed system can bring about desired end-user behaviour	Verify and validate the e-Green Computing system

3.1. Requirements Analysis and Specification

In this section, we give a breakdown of the requirements for the e-Green Computing system. The requirements were gathered by interview, questionnaire and observation of the Nigerian cyberspace and computing community. The social functions required are access information, add information, delete information, and edit information (Table 2). The quality (non-functional) requirements are security, performance, aesthetics, usability, availability, scalability, reliability, modifiability, fault tolerance, interoperability and portability. The web-based n-tier e-Green Computing system has inbuilt mechanisms that meet these requirements.

Table 2. Functional Requirements.

Requirement ID	Requirement	Brief Description
R01	Add Information	The e-Green Computing system will allow computer users to add information on green computing techniques based on assigned rights and privileges
R02	Access Information	The e-Green Computing system will allow computer users to retrieve and view information on green computing practices within assigned rights and privileges
R03	Edit Information	The e-Green Computing system will allow computer users to edit information related to environmentally friendly computing in line with assigned rights and privileges
R04	Delete Information	The e-Green Computing system will allow users to delete information from the database based on allocated rights and privileges

Use case modelling was used (Figure 2) to consolidate requirements analysis in a bid to comprehend the core functionalities and usage scenarios associated with the proposed system's requirements. The researchers, in attempt to capture the functional aspects of the e-Green Computing system, used the use case diagram to graphically depict actors' interactions with the system [31].

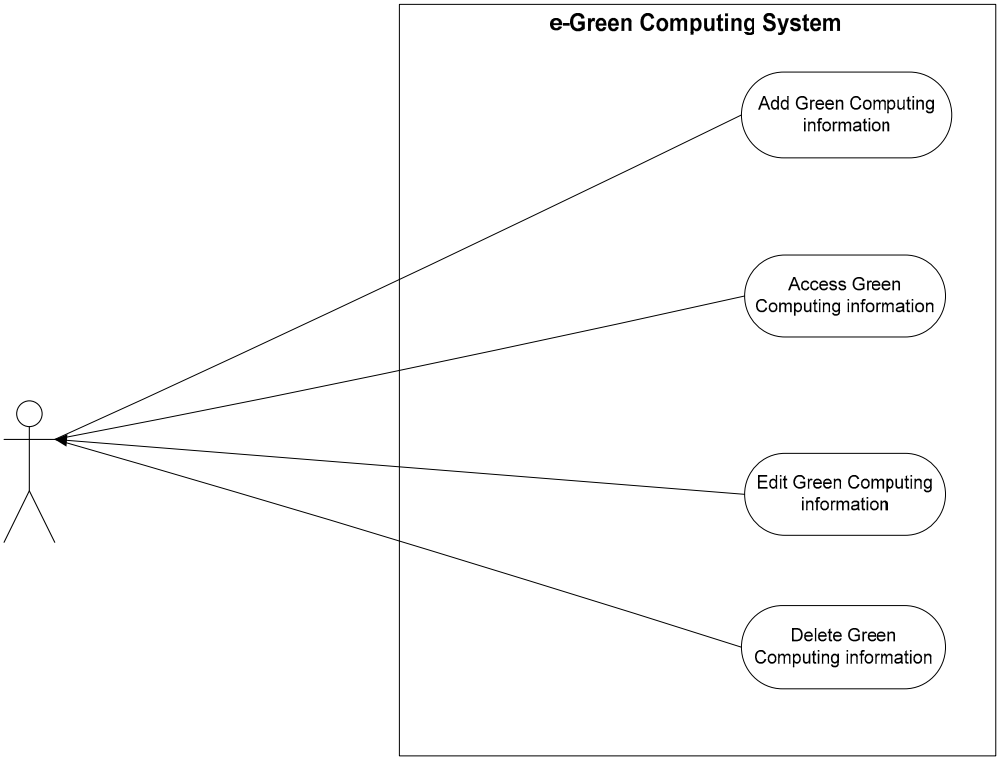

Figure 2. Use Cases for e-Green Computing System.

The use cases empower the computing community to articulate and share information on global best practices on e-waste management, carbon emission and computer-related energy efficiency schemes. The end goal is to promote environmentally acceptable computing habits and behaviours.

3.2. System and Software Design

Distributed computing and component reusability are closely linked in an enterprise application such as the e-Green Computing system. To leverage this relationship, a multi-tier enterprise architecture was designed for the proposed solution. It has inbuilt mechanisms that meet user requirements.

The n-tier architecture is made up of presentation layer, logic layer and database layer. While corporate and individual ICT users operate at the presentation layer as end-users using devices like personal computers and phones to contribute or access information on environmentally tolerable practices, the logic layer made of clustered application servers process the information which is stored in the database layer. The essence of networking these layers is to make dialogue online real-time.

The links between respective e-Green Computing components are shown in Figure 3. Though the COM+ component model is not visibly represented in the software architecture in line with best practices [32], its role in the architecture is critical as it offers support services to, and provides standards for the system components. The interdependence between Access Information, Add Information, Delete Information, and Edit Information as graphically shown underpins the reality that conversations on green computing initiated by one party can be supported or debunked by another, and it is expected that such healthy online social media debate will translate into enlightened computers users with responsibility for the environment. Hence, appropriate habits and behaviours towards the environment are cultivated. This way, the green computing awareness campaign would have made significant impact on the environment.

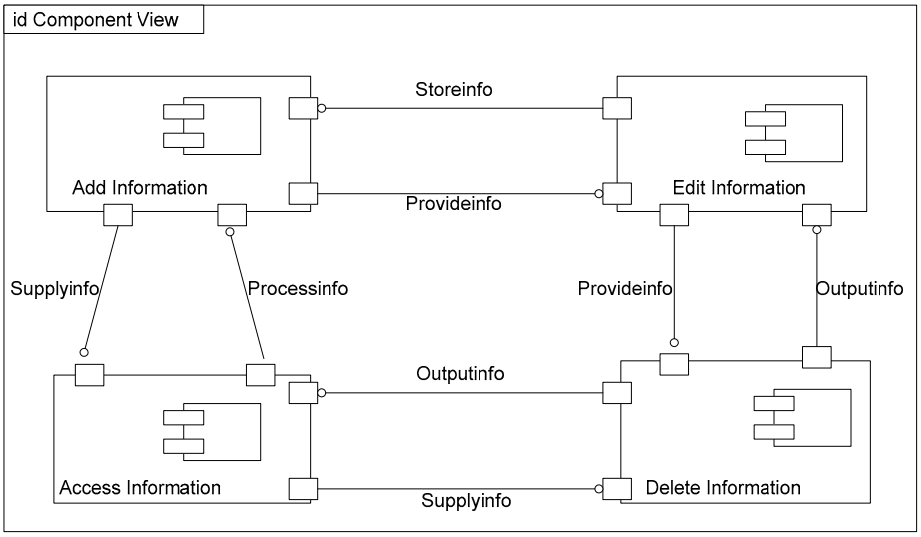

Figure 3. e-Green Computing component diagram.

The e-Green Computing reusable components (Access Information, Add Information, Delete Information and Edit Information) were subsequently built using Microsoft SharePoint standard components.

The class diagram for the e-Green Computing system is given in Figure 4 below.

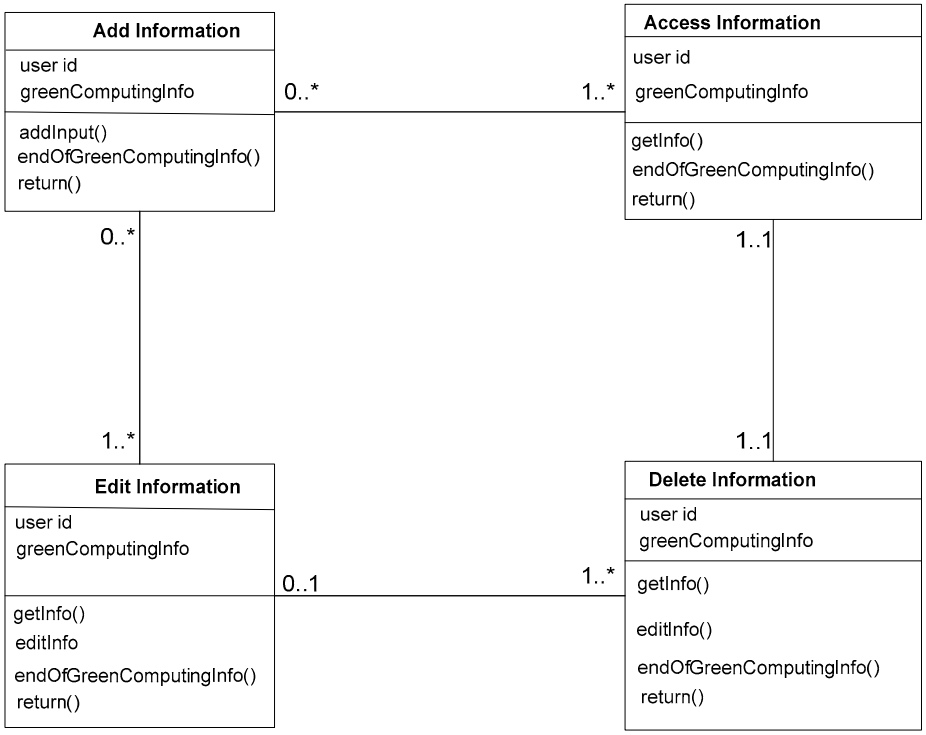

Figure 4. e-Green Computing class diagram.

Other design tools we used include a collaboration diagram, sequence diagrams, a class diagram, an analysis class, a design component and an elaborated design class, class elaboration, an algorithm, composite (appropriate) interfaces, and an elaborated deployment diagram [33,34].

The researchers used a deployment diagram to represent the location of key packages or components of the e-Green system [33]. The study equally used class elaboration and an algorithm to present abstraction details of the components and social functions of the proposed e-Green Computing system.

3.3. Implementation and Unit Testing

The study used as development tool Microsoft SharePoint for the tailor-made e-Green Computing system. The testbed was set up at the University of Lagos Centre for Information Technology and Systems (CITS), Lagos, Nigeria. As a web-based enterprise development tool, SharePoint makes components (also referred to as services) available for reuse. Besides providing an integrated development environment (IDE), it uses Microsoft COM+ as component model for enhancing interoperability among system components. Its traditional components are distributed as well as independent [32] and include Custom List, Document Library, and Tasks. We developed the e-Green Computing system on an incremental basis. The addInformation module was the minimal e-Green Computing system to commence with followed by the addition of other modules. Since black box testing is more suitable for component-based systems, the authors used it [35].

3.4. System Integration

With addInformation as minimal e-Green Computing system, we carried out regression test with the addition of subsequent modules with a view to ascertaining the presence of any interface errors. If in the event of adding a module an error emerged, debugging was done prior to adding another module. Ultimately, the addInformation function was the most tested component in the e-Green Computing system. It is the most referenced component in the proposed system. Prior to integrating the various components, each was tested using test cases. At the integration point, we used system test

cases for regression tests. As expected of component-based systems, black box testing was performed for all components [36]. Table 3 shows the function points.

Table 3. Component Testing—Function Points.

SN	Component	Function Points
1.	e-Green Computing	Add Green Computing Info, Access Green Computing Info, Edit Green Computing Info, Delete Green Computing Info

Hence, besides developing and implementing test case for each of the e-Green Computing reusable components (Access Information, Add Information, Delete Information and Edit Information), the system test case was administered at the point of integrating each to ensure the robust regression test revealed any existing error.

3.5. System Verification and Validation

The requirements-compliance and process-correctness of the proposed systems were verified and validated by an assessment of the respective software representations that include design documents, requirements documents, and program code. We focused on ensuring that in the build-up process, each software representation was well catered for. We likewise ensured that both emergent properties and user operational needs were met by the software product.

3.6. Operation Support and Maintenance

Role-based training was conducted for select technical personnel and end-users for the purpose of test-running the application. The technical staff were saddled with the responsibility of providing system support, whereas end-users operated the software.

4. Results and Discussion

The study extracted information and measured outcomes in two ways—software experiment and sample survey of computer users. We also evaluated possible threats to the research outcomes. Our evaluation mechanics are presented as follows:

4.1. Results of Software Experiment

The e-Green Computing site was created as a community site using Microsoft SharePoint enterprise development platform. As the name goes, it is a site where cyberspace members discuss topics that bother on environmentally friendly utilization of computers and accessories. The underlying message of this software engineering is that conscious and concerted efforts towards preventing computer-related environmental degradation can add mileage to ongoing global efforts to mitigate the adverse effect of climate change. This is to be achieved by leveraging online real-time discussion between cyberspace participants on new techniques of green computing. We set up an experimental design in University of Lagos, Nigeria, precisely at the Centre for Information Technology and Systems (CITS) and test-run the system from nearby (Lagos environs) and remote locations like Abuja, both in Nigeria. By this act, the researchers used a multi-tier web-based e-Green Computing system to mimic the sensation of sustained dialogue between African computing community members.

The simulation experiment affirmed that ICT could be instrumental to solving the problem e-waste and energy conservation management through sustained online real-time green computing conversations and education. The subjects who participated in the experiment concurred that the output of the experimental survey was a seamless and robust online real-time communication among cyberspace stakeholders on topical green computing services that geared toward the protection

and management of the environment. The endgame is that the e-Green Computing dialogue framework engendered a sense of users' awareness on the role green computing plays in environmental sustainability and economic security. Though we experienced platform- and hardware-dependent challenges particularly testing from remote location like and Abuja, this buttressed the fact that the problem is a stochastic optimization problem in which we attempted to maximize the gains of creating green computing awareness under uncertainty.

Figures 5 and 6 are snapshots from the experiment.

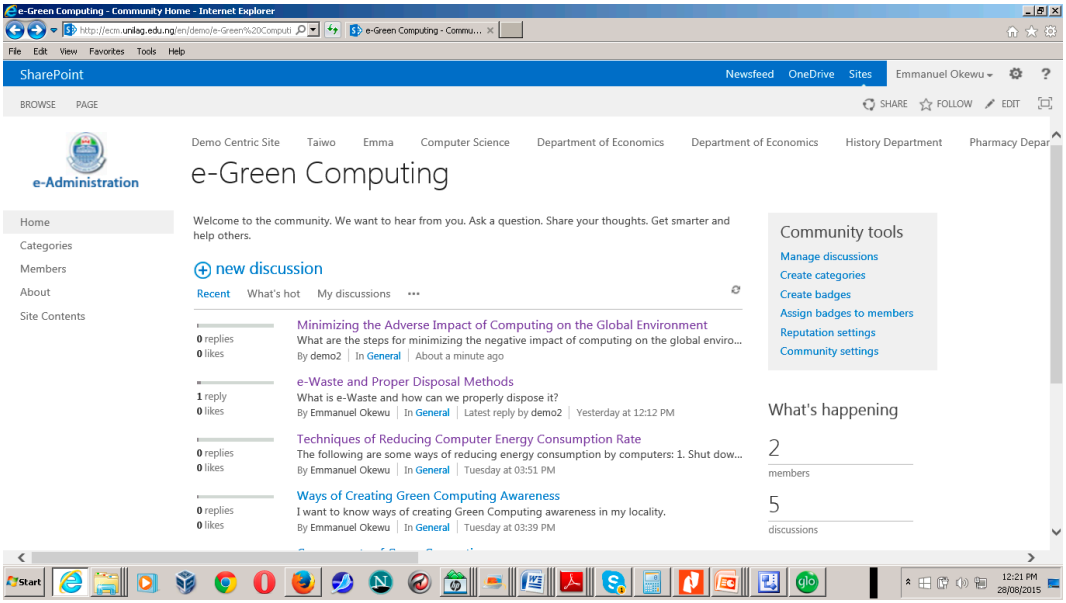

Figure 5. The e-Green Computing site showing community discussion forum for computer users on environmentally friendly computing techniques.

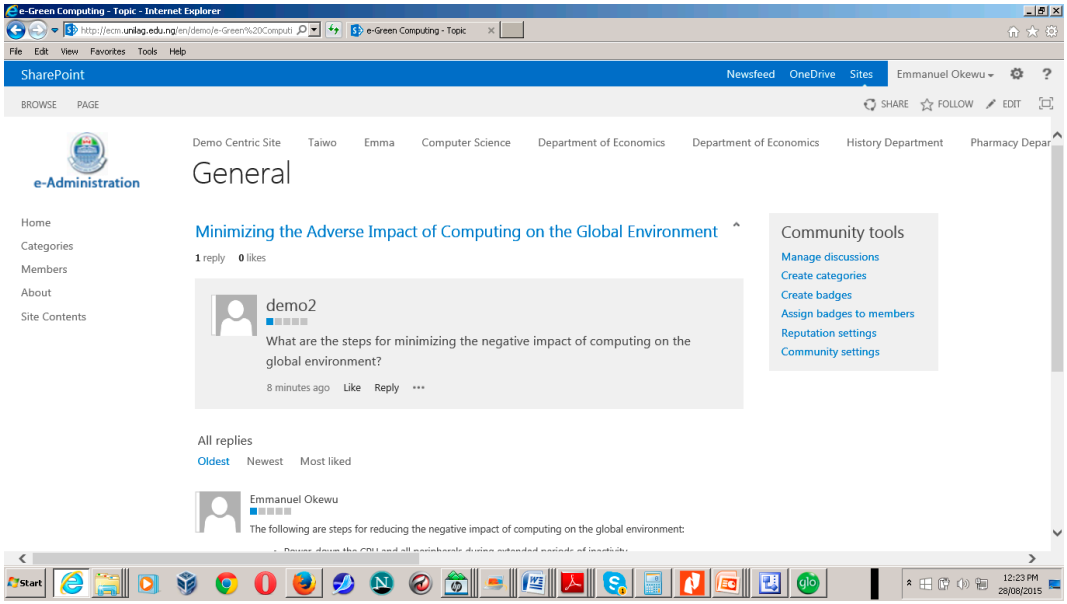

Figure 6. Sample posting by a user seeking to know ways of minimizing the negative impact of computer usage on the environment.

4.2. Results of End-Users Survey

We substantiated our assertion that there is a low level of green computing awareness in Africa by providing empirical data from survey conducted in University of Lagos. For the sample survey, we targeted ICT professionals (network administrators, database administrators, programmers, and students of Information Technology) to gauge their level of green computing awareness. Of the total questionnaires administered, we retrieved 20. A sample size of 50 was used though only 20 responses were received and subsequently used for analysis. Their responses are tabulated in Table 4.

Table 4. Sample Survey Responses.

SN	Statement	Response			
		Yes	**No**	**Abstained**	**Total**
1.	Familiar with Green Computing?	3 (15%)	15 (75%)	2 (10%)	20 (100%)
2.	Green Computing is also referred to as environmentally sustainable computing?	4 (20%)	12 (60%)	4 (20%)	20 (100%)
3.	The aim of Green Computing is to mitigate hazardous material and protect our environment.	7 (35%)	11 (55%)	2 (10%)	20 (100%)

Figure 7 presents graphical view of respondents; responses.

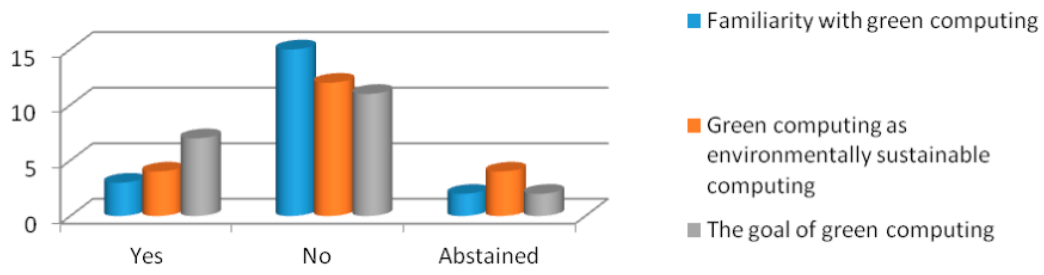

Figure 7. Graphical view of respondents' responses.

From the above respondents' responses, a whopping 75% of the ICT professionals surveyed indicated they had no knowledge of green computing, while a paltry 15% are in the affirmative and 10% refrained from answering. Using this as benchmark to measure the level of green computing awareness among the computer users in the African cyberspace, it is apparent that the continent is lagging behind in environmentally acceptable computing behaviours. Juxtaposing this with the continent's predicted disturbing figures for climate change vulnerability and environmental risk, there is clearly a problem to address as environmental destruction now results in the decimation of livelihoods, economic insecurity and humanitarian crisis. Hence, this attempt to optimize green computing awareness even under uncertainties that are typical of an emerging socioeconomic system like Africa's.

4.3. Evaluation Threats

There is the possibility that an expanded evaluation of the respective components of the e-Green system could unearth fresh perspectives. In any case, the people (Nigerians) that took part in the application test run and sample survey have the required experiential knowledge of the Nigerian cyberspace. They also practiced sufficiently with the e-Green system. Hence, they were in good stead to make objective assessment of the impact of the proposed solution on the green computing awareness campaign. As a result, we took their views seriously [37–40].

Also worthy of mention is the fact that only a select number of computer users where involved in the test run and sample survey, which in some sense has the potential to make the outcome less statistically significant [41,42]. Nonetheless, the sample survey outcome confirmed low-level green computing awareness in the Nigeria computing environment and underscored the need to upgrade efforts in this regard. Likewise, result of the prototype experiment clearly indicates that online real-time sharing of information on moderns steps to green computing could go a long way in achieving environmentally acceptable behaviours. At this juncture in the research project, this is a good result since the main objective is to have an impression of the degree of green computing awareness that can be created by the e-Green Computing system amid uncertainty characterizing the Nigerian socioeconomic terrain. So, in spite the constraint of using few evaluators, it is adequate to conclude that people are favourably disposed to the e-Green Computing system as a tool for promoting environmentally sustainable computing. It means that even in the face of socioeconomic uncertainties, optimizing green computing awareness via online real-time interactions is a reality. We can thus generalize that applying metaheuristic algorithm to the quest for optimal green computing education can enhance environmental sustainability and economic security in Sub-Saharan Africa.

5. Conclusions

The rapid growth of Africa's computing community means a cohesive programme of managing solid e-waste, carbon emission, and conserving energy for other developmental purposes is required. This will ensure that Africa's contribution to global warming and environmental degradation [3] is mitigated. It will also put the continent on the path of sustainable development [7]. Governmental regulation apart, there is need for self-discipline and ecologically friendly disposition to the environment [17] by computer users, and this can be achieved via proper green computing education and awareness campaigns. This study identified various ways national green computing campaigns can be carried out in Africa's socio-cultural context. The researchers considered that despite the emerging nature of African economies and associated stochastic behaviours, optimizing green computing awareness is a possibility though with probable outcomes. We applied metaheuristic algorithm to the stochastic optimization problem to search for the best-known green computing awareness creation solution. Our experiment with Tabu Search indicated that an online real-time dialogue platform will serve the purpose best. Hence, we designed, developed and implemented an e-Green Computing system that proved effective. Component-based software engineering approach was used for reusability of modules across African countries adapting the solution [43].

Acknowledgments: Thanks to the authorities of the University of Lagos, Nigeria for availing the platform for doing this research study. Support also came from Covenant University Centre for Research and Innovation Development, Ota, Nigeria; Kaunas University of Technology, Kaunas, Lithuania; and University of Alcala, Spain.

Author Contributions: Emmanuel Okewu, Sanjay Misra and Luis Fernandez-Sanz conceived and designed the experiments; Emmanuel Okewu performed the experiments; Emmanuel Okewu, Sanjay Misra, Robertas Damaševičius, Rytis Maskeliūnas and Luis Fernandez-Sanz analyzed the data; Emmanuel Okewu and Sanjay Misra wrote the paper.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Michałowski, A. System aspects research of ecosystem services in the economy for sustainable development. *Probl. Sustain. Dev.* **2014**, *9*, 71–80.
2. Ravikumar, V.; Chandrakumarmangalam, S. Impoverishment—The Threat for Sustainable Developments in Developing Countries. *Probl. Sustain. Dev.* **2016**, *11*, 105–112.
3. Sztumski, W. Sustainable development—Unbalanced devastation of the environment and its consequences. *Probl. Sustain. Dev.* **2014**, *9*, 89–96.
4. Kundzewicz, Z.W.; Kowalczak, P. Urban Flooding and Sustainable Land Management—Polish Perspective. *Probl. Sustain. Dev.* **2014**, *9*, 131–138.

5. Zareba, A. Multifunctional and Multiscale Aspects of Green Infrastructure in Contemporary Research. *Probl. Sustain. Dev.* **2014**, *9*, 149–156.
6. Murugesan, S. Harnessing Green IT: Principles and Practices. *IEEE IT Prof.* **2008**, *10*, 24–33. [CrossRef]
7. Liu, H. Biofuel's Sustainable Development under the Trilemma of Energy, Environment and Economy. *Probl. Sustain. Dev.* **2015**, *10*, 55–59.
8. Kośmicki, E.; Pieńkowski, D. Renewable Energy and Socio-Economic Development in the European Union. *Probl. Sustain. Dev.* **2013**, *8*, 105–114.
9. Hoeller, P.; Wallin, M. *Energy Prices, Taxes and Carbon Dioxide Emissions*; OECD Economic Studies No. 17, Autumn 1991; OECD: Paris, France, 2010; p. 92.
10. The National Academies. *Understanding and Responding to Climate Change*; U.S. National Academy of Sciences: Washington, DC, USA, 2008.
11. Venckauskas, A.; Stuikys, V.; Damasevicius, R.; Jusas, N. Modelling of Internet of Things units for estimating security-energy-performance relationships for quality of service and environment awareness. *Secur. Commun. Netw.* **2016**, *9*, 3324–3339. [CrossRef]
12. Okewu, E.; Misra, S.; Okewu, J. Model-Driven Engineering and Creative Arts Approach to Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria. *Probl. Sustain. Dev.* **2017**, *12*, 101–116.
13. Therese, K.; Albert, J. Stochastic Finite Automata: A Mathematical Model for Sequential Decision Making under Uncertainty. *Int. J. Appl. Math. Model.* **2014**, *2*, 1–14.
14. Therese, K.; Albert, J. Stochastic Regular Language: A Mathematical Model for the Language of Sequential Actions for Decision Making under Uncertainty. *Int. J. Math. Comput. Appl. Res.* **2013**, *3*, 1–8.
15. Silberholz, J.; Golden, B. *Comparison of Metaheuristics*; Springer Int'l Publishing: Cham, Switzerland, 2010.
16. Glover, F. Tabu Search—Part 2. *ORSA J. Comput.* **1990**, *2*, 4–32. [CrossRef]
17. Ciszek, M. Environmental ethics from a Thomistic-personalistic perspective (implications for the sustainable development concept). *Probl. Sustain. Dev.* **2014**, *9*, 97–106.
18. Skowron, S.; Szymoniuk, B. Marketing and Sustainable Development. *Probl. Sustain. Dev.* **2014**, *9*, 39–46.
19. Crespo, B.; Míguez-Álvarez, C.; Arce, M.E.; Cuevas, M.; Míguez, J.L. The Sustainable Development Goals: An Experience on Higher Education. *Sustainability* **2017**, *9*, 1353. [CrossRef]
20. Gawor, L. Walery Goetel and the Idea of Sozology. *Probl. Sustain. Dev.* **2013**, *8*, 83–89.
21. Kośmicki, E.; Pieńkowski, D. In Search of the Present Economy and Society Modernisation Concept (An Attempt to Explain the Main Problems). *Probl. Sustain. Dev.* **2013**, *8*, 115–123.
22. Hack, S.; Berg, C. The Potential of IT for Corporate Sustainability. *Sustainability* **2014**, *6*, 4163–4180. [CrossRef]
23. Moelders, T.; Szumelda, A.; Winterfeld, U.V. Sufficiency and subsistence—On two important concepts for sustainable development. *Probl. Sustain. Dev.* **2014**, *9*, 21–27.
24. Wolczek, P. The concept of corporate social responsibility and sustainable development. *Probl. Sustain. Dev.* **2014**, *9*, 157–166.
25. Radu, L.-D. Determinants of Green ICT Adoption in Organizations: A Theoretical Perspective. *Sustainability* **2016**, *8*, 731. [CrossRef]
26. Okewu, E. Requirements Engineering in an Emerging Market. In *Proceedings of the 2015 International Conference on Computational Science and Its Applications (ICCSA 2015), Banff, AB, Canada, 22–25 June 2015*; Springer Publishers: Cham, Switzerland, 2015.
27. Saha, B. Green Computing. *Int. J. Comput. Trends Technol.* **2014**, *14*, 46–50. [CrossRef]
28. Mittal, P.; Kaur, N. Green Computing—A Survey. *Int. J. Comput. Trends Technol.* **2013**, *4*, 839–845.
29. Shinde, S.; Nalawade, S.; Nalawade, A. Green Computing: Go Green and Save Energy. *Int. J. Adv. Res. Comput. Sci. Softw. Eng.* **2013**, *3*, 1033–1037.
30. Investment Development Authority of Lebanon (IDAL). *The ICT Market in Nigeria, 2015*; IDAL: Beirut, Lebanon, 2015.
31. Aggarwal, K.K.; Singh, Y. *Software Engineering*; New Age International Publishers: Delhi, India, 2008.
32. Gorton, I. *Essential Software Architecture*, 2nd ed.; Springer: Berlin/Heidelberg, Germany, 2011.
33. Pressman, R.S. *Software Engineering: A Practitioner's Approach*, 7th ed.; McGraw-Hill: New York, NY, USA, 2009.
34. Martin, R.C. *UML Tutorial: Sequence Diagrams*; Engineering Notebook Column; Springer Int'l Publishing: Cham, Switzerland, 1998.

35. Sirohi, N.; Parashar, A. Component Based System and Testing Techniques. *Int. J. Adv. Res. Comput. Sci. Softw. Eng.* **2013**, *2*, 33–42.
36. Beydeda, S.; Gruhn, V. An Integrated Testing Technique for Component-Based Software. In Proceedings of the ACS/IEEE International Conference on Computer Systems and Applications, Beirut, Lebanon, 25–29 June 2001; pp. 328–334.
37. Host, M.; Regnell, B.; Wohlin, C. Using students as subjects—A comparative study of students and professionals in lead-time impact assessment. *Empir. Softw. Eng. Int. J.* **2000**, *5*, 201–214. [CrossRef]
38. Runeson, P. Using students as Experiment Subjects—An Analysis on Graduate and Freshmen Student Data. In Proceedings of the 7th International Conference on Empirical Assessment & Evaluation in Software Engineering (EASE'03), Keele University, Staffordshire, UK, 8–10 April 2013; Linkman, S., Ed.; pp. 95–102.
39. Sauro, J.; Kindlund, E. *A Method to Standardize Usability Metrics into a Single Score*; ACM, CHI: New York, NY, USA, 2005.
40. Svahnberg, M.; Aurum, A.; Wohlin, C. Using students as Subjects—An Empirical Evaluation. In Proceedings of the 2nd International Symposium on Empirical Software Engineering and Management ACM, Kaiserslautern, Germany, 9–10 October 2008; pp. 288–290.
41. Nielsen, J.; Landauer, T. A mathematical model of the finding of usability problems. In Proceedings of the ACM INTERCHI'93 Conference, Amsterdam, The Netherlands, 24–29 April 1993; pp. 206–213.
42. Turner, C.W.; Lewis, J.R.; Nielsen, J. Determining usability test sample size. In *International Encyclopedia of Ergonomics and Human Factors*; Karwowski, W., Ed.; CRC Press: Boca Raton, FL, USA, 2006; pp. 3084–3088.
43. Okewu, E.; Daramola, O. Component-based Software Engineering Approach to Development of a University e-Administration System. In Proceedings of the IEEE 6th International Conference on Adaptive Science and Technology (ICAST), Ota, Nigeria, 29–31 October 2014.

3.1 Summary of impact article 2

In this chapter, we introduced data pre-processing for monitoring of sustainable development activities at national and sub-national levels. In as much as computational models and systems could empower stakeholders for online real-time deliberations and monitoring of policies, programmes and projects, there is a need for the systems to be fed with quality data. Quality data gives rise to quality information (Aaronson, 2019; Meier*, 2015*). By their nature, sustainable development plans are executed at national and sub-national levels, given their peculiar socio-economic realities. However, a common denominator is that lives and livelihoods should be improved upon regardless of the economic approach adopted. One of the ways to adequately monitor the various developmental initiatives in each country is to rely on huge data generated in the process of human activities. The data would make more meaning to monitors such as international development partners, non-governmental organizations and public-spirited individuals if the data is streamlined and put in proper context using data pre-processing as demonstrated in this chapter.

After using improving measurement and monitoring of sustainable development processes using software models and data pre-processing, our next task is to improve on evaluation using predictive analytics. In the following chapter, we explain how to improve the evaluation of sustainable development activities using deep learning neural networks.

CHAPTER

4 PREDICTIVE ANALYTICS AND EVALUATION OF SUSTAINABLE DEVELOPMENT GOALS

In benchmarking national and sub-national sustainable development plans against the global SDGs, data per see may not suffice. There is need for insight into data to reveal hidden and useful patterns that enhance the decision-making process. The failure of earlier development plans like the MDGs is partly blamed on inability to detect and predict patterns in data. As a result, proactive steps for forestalling or reducing adverse impact of emergencies could not be taken by critical stakeholders, resulting in less-than-impressive implementation of such global plans. To address this problem, we discussed the use of data analytics for detecting and predicting patterns in sustainable development data. Though data analytics tools are many, we focus mainly on artificial neural networks (ANN) as a foremost machine learning tool. Initially, we experimented with decision tree and naïve Bayesian networks. To offer greater insights, we used deep neural networks which use multiple layers of computational neurons for learning patterns in historical data for the purpose of predicting outcome of future data based on patterns learnt in related data. In our journal papers, we show that data analytics is a strong tool for generating robust and reliable information for enhancing the decision-making process (Marr, 2015). While SDG 1 concentrates on ending poverty in all its forms everywhere, SDG target 1.4 emphasizes that by 2030, the poor and the vulnerable should have equal rights to economic resources and access to basic services. Hence, we used deep neural networks to model data on the farmers-herdsmen clashes which impact adversely on the lives and livelihoods of rural farmers who are among the poor and vulnerable (Okewu et al., 2019). In a related paper captioned “Experimental Comparison of Stochastic Optimizers in Deep Learning”, we present experimental results of applying deep learning algorithms to image dataset using convolutional neural networks. This is in view of the growing relevance of image data in sustainable development activities as evident in the patronage of biometrics, closed circuit television, satellite images and drones. Compared to other forms of data, image data seems to be more acceptable to sustainable development stakeholders in terms of reliability and robustness. Hence, its increased used in public financial management systems. To show that deep learning neural networks offers high prediction accuracy which could be harnessed for evaluating

sustainable development initiatives, we conducted series of experiments using a standard dataset of image data and convolutional neural networks (CNN) on the Python deep learning platform. In the first instance, we modelled the MNIST dataset using CNN and the trained the model using stochastic optimization algorithms (Torres, 2018; Walia, 2017; Yalçın, 2018) Though the experiments involved comparing a number of established stochastic gradient descent algorithms for training deep neural networks such as rmsprop, adagrad, adam, adadelta and sgd, we outline below results obtained using adam, a foremost algorithm for training deep neural networks. The image classification problem is a multi-class classification problem with 10 different classes. The series of experiments revealed that deep neural networks (DNN) as a predictive analytics tool offer over 98% accuracy in classifying data and predicting outcomes. This proves that DNN can effectively and efficiently guide proactive decision-making involving resource utilization thus reducing wastage. Details of our experimental results are outlined in Tables 9 - 13.

Number of images used for training = 60,000

Number of images used for evaluation (testing) = 10,000

Experiment 1			Experiment 2			Experiment 3		
Iteration (Epoch)	Loss	Accuracy	Iteration (Epoch)	Loss	Accuracy	Iteration (Epoch)	Loss	Accuracy
1	0.2022	0.9397	1	0.2160	0.9353	1	0.2158	0.9345
2	0.0826	0.9748	2	0.0900	0.9726	2	0.0867	0.9736
3	0.0590	0.9811	3	0.0615	0.9808	3	0.0596	0.9814
4	0.0458	0.9850	4	0.0467	0.9852	4	0.0477	0.9844
5	0.0363	0.9880	5	0.0383	0.9872	5	0.0372	0.9877
6	0.0292	0.9903	6	0.0294	0.9902	6	0.0301	0.9899
7	0.0266	0.9912	7	0.0271	0.9909	7	0.0262	0.9909
8	0.0229	0.9919	8	0.0218	0.9924	8	0.0228	0.9919
9	0.0204	0.9930	9	0.0216	0.9929	9	0.0213	0.9929
10	0.0185	0.9936	10	0.0192	0.9934	10	0.0167	0.9942
Average		**0.98286**			**0.98209**			**0.98214**

Table 9. Experimental results of stochastic optimizer - adam

Iteration (Epoch)	Loss	Accuracy
1	0.5017	0.8572
2	0.2265	0.9334
3	0.1780	0.9473
4	0.1534	0.9546
5	0.1342	0.9603
6	0.1205	0.9639
7	0.1118	0.9671

Iteration (Epoch)	Loss	Accuracy
8	0.1030	0.9685
9	0.0958	0.9699
10	0.0910	0.9721
Average		**0.94943**

Table 10. Experimental results of stochastic optimizer - sgd

Iteration (Epoch)	Loss	Accuracy
1	0.1978	0.9406
2	0.0823	0.9755
3	0.0643	0.9809
4	0.0529	0.9846
5	0.0464	0.9870
6	0.0408	0.9885
7	0.0365	0.9893
8	0.0351	0.9897
9	0.0296	0.9915
10	0.0275	0.9923
Average		**0.98199**

Table 11. Experimental results of stochastic optimizer - rmsprop

Iteration (Epoch)	Loss	Accuracy
1	0.2068	0.9377
2	0.0844	0.9747
3	0.0582	0.9824
4	0.0453	0.9863
5	0.0359	0.9894
6	0.0304	0.9906
7	0.0247	0.9923
8	0.0216	0.9932
9	0.0171	0.9945
10	0.0156	0.9952
Average		**0.98363**

Table 12. Experimental results of stochastic optimizer - adadelta

Experiment 1			Experiment 2		
Iteration (Epoch)	Loss	Accuracy	Iteration (Epoch)	Loss	Accuracy
1	0.2325	0.9307		0.2206	0.9345
2	0.1146	0.9664		0.1102	0.9674
3	0.0893	0.9735		0.0834	0.9758
4	0.0733	0.9784		0.0695	0.9794
5	0.0634	0.9811		0.0605	0.9824
6	0.0557	0.9829		0.0540	0.9840

Experiment 1			Experiment 2		
7	0.0499	0.9855		0.0486	0.9856
8	0.0459	0.9854		0.0436	0.9874
9	0.0417	0.9878		0.0401	0.9884
10	0.0399	0.9882		0.0373	0.9890
Average		**0.97599**			**0.97739**

Table 13. Experimental results of stochastic optimizer - adagrad

As shown in Table 9, a popular deep learning algorithm like Adam (Brownlee, 2019; Koushik and Hayashi, 2017) recorded average of above 98% prediction accuracy. This implies that sustainable development stakeholders can be rest assured that decision making and forecasting would be enhanced if predictive analytics is integrated in the implementation process. The fact that we experimented with image data is also a morale booster for relevant and critical stakeholders of sustainable development given the growing use of image data. This has been fuelled by the use of ICT devices like smart phones, CCTV, satellite, and drones which are largely used for capturing image data (Bahrini and Qaffas, 2019).

Deep neural network training operations are basically mathematical operations that are executed in computational nodes for detecting patterns in the data (Pandey, 2018). The training operations involve forward pass and backward pass. The forward pass produces prediction values (y_1, y_2, .. y_7) at the output layer. In the event any output value does not match its corresponding actual value, an error occurs. The vectorization and matrix operations for the forward pass in Figure 2 above is as follows:

$$[i_1\ i_2 \ldots i_{69}].\begin{bmatrix} w_{11} & w_{12} & w_{13} & w_{14} & w_{15} \\ w_{21} & w_{22} & w_{23} & w_{24} & w_{25} \\ & & \ldots & & \\ w_{69,1} & w_{69,2} & w_{69,3} & w_{69,4} & w_{69,4} \end{bmatrix} = [j_1\ j_2\ j_3\ j_4\ j_5].\begin{bmatrix} w_{11} & w_{12} & w_{13} & w_{14} & w_{15} \\ w_{21} & w_{22} & w_{23} & w_{24} & w_{25} \\ w_{31} & w_{32} & w_{33} & w_{34} & w_{35} \\ w_{41} & w_{42} & w_{43} & w_{44} & w_{55} \\ w_{51} & w_{52} & w_{53} & w_{54} & w_{55} \end{bmatrix} =$$

$$[k_1\ k_2\ k_3\ k_4\ k_5].\begin{bmatrix} w_{11} & w_{12} & w_{13} & w_{14} & w_{15} & w_{16} & w_{17} \\ w_{21} & w_{22} & w_{23} & w_{24} & w_{25} & w_{26} & w_{27} \\ w_{31} & w_{32} & w_{33} & w_{34} & w_{35} & w_{36} & w_{37} \\ w_{41} & w_{42} & w_{43} & w_{44} & w_{45} & w_{46} & w_{47} \\ w_{51} & w_{52} & w_{53} & w_{54} & w_{55} & w_{56} & w_{57} \end{bmatrix} = [l_1\ l_2\ l_3\ l_4\ l_5\ l_6\ l_7\ ]$$

While error at the output node is calculated using actual output, error in hidden layer is computed using backpropagation. The error at the output layer is propagated backward by splitting and

distribution among the contributing links across the hidden layers to the input layer. Using the error at one node as example, the process of backpropagation of error is as follows:

$e_{hidden2,1}$= sum of split errors on links w_{11}, $w_{12,}$ w_{13}, $w_{14,}$ w_{15}, $w_{16,}$ w_{17}

$$e_{hidden2,1} = e_{output,1} * \frac{w_{11}}{w_{11} + w_{21} + w_{31} + \cdots + w_{71}} + e_{output,2} * \frac{w_{12}}{w_{12} + w_{22} + w_{22} + \cdots + w_{72}} + \ldots + e_{output,7} * \frac{w_{17}}{w_{17} + w_{27} + w_{37} + \cdots + w_{77}}$$

The next step after the backpropagation of error is weight recalibration (Brownlee, 2019). This is achieved by finding how error E changes as the weight changes (the slope of the error function) in the direction of minimum. Mathematically, it is represented as:

$$\frac{\partial E}{\partial w_{jk}}$$

Using activation function (say sigmoid), the slope of the error regarding the link weights between the hidden and the output layers is represented as (Pandey, 2018) :

$$\frac{\partial E}{\partial w_{jk}} = -(t_k - O_k).\text{sigmoid}(\sum j\ W_{jk}.O_j)(1\text{-sigmoid}(\sum j\ W_{jk}\ .O_j)).\ O_j$$

The slope of the error function for any other weights is:

$$\frac{\partial E}{\partial w_{ij}} = -(e_j).\text{sigmoid}(\sum j\ W_{ij}.O_i)(1\text{-sigmoid}(\sum j\ W_{ij}\ .O_i)).\ O_i$$

The refinement of weight is done using the formula:

$$\text{New } w_{jk} = \text{old } w_{jk} - \eta.\frac{\partial E}{\partial w_{jk}}$$

where η is the learning rate, a factor that moderates the strength of the changes so that loss function does not overshoot the minimum.
For weights between hidden and output layer, the update is as follows:

$$\text{New } w_{jk} = \text{old } w_{jk} - \eta.\frac{\partial E}{\partial w_{jk}}$$

For weights between input and output layer, the update is as follows:

$$\text{New } w_{ij} = \text{old } w_{ij} - \eta.\frac{\partial E}{\partial w_{ij}}$$

Weight update continues until the error value is within acceptable limits and the training stops.

The forward and backward operations in deep neural networks as mathematically explained above are typical of any application of deep neural networks in any domain, including sustainable development domains. In the impact article below, we show how this machine learning technique is applied in resolving farmers-herdsmen clashes as part of efforts to ensure peace and justices as enshrined in SDG 16 (Report, 2016) which is the foundation for actualizing other SDGs (Bamberger et al., 2017).

PROBLEMY EKOROZWOJU – PROBLEMS OF SUSTAINABLE DEVELOPMENT
2019, vol. 14, no 2, 143-155

Deep Neural Networks for Curbing Climate Change-Induced Farmers-Herdsmen Clashes in a Sustainable Social Inclusion Initiative

Wykorzystanie głębokich sieci neuronowych w ograniczaniu zmian klimatycznych związanych z konfliktem farmerów i pasterzy w ramach inicjatywy na rzecz zrównoważonej integracji społecznej

Emmanuel Okewu*, Sanjay Misra,***, Luis Fernandez Sanz****, Foluso Ayeni*****, Victor Mbarika*****, Robertas Damaševičius******

**University of Lagos, Lagos, Nigeria,*
E-mail: eokewu@unilag.edu.ng
*** Covenant University, Canaanland, Nigeria,*
****Atilim University, Ankara, Turkey*
E-mails: Sanjay.misra@covenantuniversity.edu.ng, sanjay.misra@atilim.edu.tr
***** University of Alcala, Alcala De Henares, Madrid, Spain*
E-mail: luis.fernandezs@uah.es
******Southern University, Baton Rouge, USA*
E-mails: foluso.ayeni@icitd.com, victor_mbarika@subr.edu
******* Kaunas University of Technology, Kaunas, Lithuania*
E-mail: robertas.damasevicius@ktu.lt

Abstract

Peaceful coexistence of farmers and pastoralists is becoming increasingly elusive and has adverse impact on agricultural revolution and global food security. The targets of Sustainable Development Goal 16 (SDG 16) include promoting peaceful and inclusive societies for sustainable development, providing access to justice for all and building effective, accountable and inclusive institutions at all levels. As a soft approach and long term solution to the perennial farmers-herdsmen clashes with attendant humanitarian crisis, this study proposes a social inclusion architecture using deep neural network (DNN). This is against the backdrop that formulating policies and implementing programmes based on unbiased information obtained from historical agricultural data using intelligent technology like deep neural network (DNN) can be handy in managing emotions. In this vision paper, a DNN-based Farmers-Herdsmen Expert System (FHES) is proposed based on data obtained from the Nigerian National Bureau of Statistics for tackling the incessant climate change-induced farmers-herdsmen clashes, with particular reference to Nigeria. So far, many lives have been lost. FHES is modelled as a deep neural network and trained using farmers-herdsmen historical data. Input variables used include land, water, vegetation, and implements while the output is farmers/herders disposition to peace. Regression analysis and pattern recognition performed by the DNN on the farmers-herdsmen data will enrich the inference engine of FHES with extracted rules (knowledge base). This knowledge base is then relied upon to classify future behaviours of herdsmen/farmers as well as predict their dispositions to violence. Critical stakeholders like governments, service providers and researchers can leverage on such advisory to initiate proactive and socially inclusive conflict prevention measures such as people-friendly policies, programmes and legislations. This way, conflicts can be averted, national security challenges tackled, and peaceful atmosphere guaranteed for sustainable development.

Key words: climate change, deep neural network, farmers-herdsmen clashes, policies and programmes, social inclusion

Streszczenie

Pokojowe współistnienie rolników i pasterzy staje się coraz mnie realne, co ma negatywny wpływ na rewolucję rolniczą i globalne bezpieczeństwo żywnościowe. Cele zrównoważonego rozwoju (SDG 16) obejmują promowanie tworzenia pokojowych i zintegrowanych społeczeństw na rzecz zrównoważonego rozwoju, zapewnienie wszystkim dostępu do uczciwego wymiaru sprawiedliwości i tworzenie skutecznych, odpowiedzialnych i integrujących instytucji na wszystkich poziomach. W ramach łagodnego podejścia i długofalowego podejścia do problemu konfliktów rolników-pasterzy w kontekście kryzysu humanitarnego, w niniejszym artykule zaproponowano architekturę integracji społecznej wykorzystującą głęboką sieć neuronową (DNN). Formułowanie polityki i wdrażanie programów w oparciu o obiektywne informacje uzyskane z historycznych danych przy użyciu inteligentnej technologii, takiej jak głęboka sieć neuronowa (DNN), może być przydatne w zarządzaniu emocjami. W niniejszym artykule zaproponowano oparty na danych uzyskanych od Nigeryjskiego Narodowego Urzędu Statystycznego system ekspercki rolników-pasterzy (FHES) oparty na DNN w celu przeciwdziałaniu nieustannym starciom rolników-pasterzy wywołanych zmianami klimatu, ze szczególnym uwzględnieniem Nigerii. Do tej pory wiele było ofiar. System FHES jest modelowany jako głęboka sieć neuronowa, przy użyciu danych historycznych hodowców-pasterzy. Zastosowane zmienne wejściowe obejmują ziemię, wodę, roślinność i narzędzia, podczas gdy zmienne wyjściowe to rolnicy-pasterze skłonni do pokoju.

Analiza regresji i rozpoznawanie wzorców przeprowadzone przez DNN na danych rolników-pasterzy wzbogaci mechanizm wnioskowania systemu FHES o wyodrębnione reguły (baza wiedzy). Podstawą tej wiedzy jest klasyfikacja przyszłych zachowań pasterzy/rolników, a także przewidywanie ich skłonności do przemocy. Krytyczni interesariusze, tacy jak rządy, dostawcy usług i naukowcy, mogą wykorzystać takie doradztwo do zainicjowania proaktywnych i społecznie włączających środków zapobiegania konfliktom, takich jak przyjazne dla ludzi polityki, programy i prawodawstwo. W ten sposób można uniknąć konfliktów, stawić czoła wyzwaniom bezpieczeństwa narodowego i zagwarantować pokojową atmosferę dla zrównoważonego rozwoju.

Słowa kluczowe: zmiany klimatu, głęboka sieć neuronowa, konflikty rolników-pasterzy, polityki i programy, włączenie społeczne

1. Introduction

In a bid to improve forecasting capacity of policy makers and service providers in the agricultural sector particularly with respect to farmers-herdsmen conflict, there is need to rely on historical data for knowledge engineering. Qazi et al. (2015**)** opine that knowledge engineering tools like data mining and machine learning are capable of eliciting robust and credible information from historical antecedents for formulating polices, implementing programmes, managing projects and making pronouncements that are equitable and socially inclusive. Once the sedentary farmers and mobile pastoralists have a sense that justice is served through such public instruments, they are likely to be favourably disposed to peaceful coexistence, a sine qua non for sustainable development. The adverse impact of climate change all over the world is also evident in the Lake Chad Basin (Ndehedehe et al., 2016; Buma and Lee, 2016). As nations and development partners such as UNESCO are making conscious and concerted efforts to safeguard the basin, reports have it that rainfall has declined steadily in the last fifty years in the region. Consequently, it has shrunk significantly and cannot sustained livelihoods as in the past. Countries like Chad, Niger, Central African Republic and Nigeria are deeply affected as the ecosystem and economy of the Lake Chad Basin dwindle. The multiplier effect is that herdsmen in this region are migrating in search of greener pasture for their livelihood. As they move southwards, there is competition between them and crop farmers over land, water, vegetation, infrastructure, and other live-sustaining resources, resulting in violent clashes. In extreme cases, lives are lost.

This is a clarion call on government to rise up to task of ensuring that its policies and programmes are not biased but all-embracing so as deescalate tensions between farmers and herdsmen. Apart from demonstrating the political will, the need for data-driven decisions that overtime has been known to be non-prejudicial cannot be over-emphasized (Jeong and Lee, 2018).

Against the backdrop that insecurity in any part of the world should be the concern of all, farmers-herdsmen face-off in Nigeria has attracted global attention in recent times. This is particularly so as the country is grappling with the Boko Haram insurgency (Hamid and Baba, 2014). To this end, this article proffers a soft approach to tackling the menace of farmers-herders violence. The study proposes a socially inclusive and mutually beneficial institutional framework that promotes a sense of justice and peaceful coexistence among farmers and headers. To achieve this aim, public policies and programmes should be formulated based on antecedents rather than sentiments. Historical antecedents as reflected in data can be harnessed for eliciting information and knowledge which policy makers and service providers can base their decisions for optimal outcome. In this regard, the paper proposes a knowledge engineering system christened Farmers-Herdsmen Expert System (FHES) that uses deep neural network (DNN) to extract features and classify behaviours of farmers/pastoralists. Regression analysis and pattern recognition in the DNN culminate in an inference engine equipped with rules (knowledge) that guide ac-

curate prediction of disposition of farmers and herders. Such unbiased and non-prejudicial forecast can be used to consolidate on existing socially inclusive policies and initiate new ones so as to proactively tackle impending conflict.

On the contrary, Tubi and Feitelson (2016) posit that formulating policies based on political patronage and primordial sentiments can escalate social conflicts between subsistence farmers and the nomadic herdsmen particularly in developing economies where infrastructure for ranching and grazing reserves are less developed. This is evident in Nigeria where legislations such as Anti-Open Grazing Law and Open Grazing Prohibition and Ranches Establishment Law have resulted in escalated violence and deaths as some concerned parties feel that the legislations are socially exclusive and justice is not being served (Gwangwazo, 2018).

The remainder of the article is arranged as follows: Section 2 is a literature review and related work; the methodology is discussed in Section 3; in Section 4, the implication of the proposed system for social inclusion and peaceful coexistence of farmers and herdsmen is discussed; Section 5 focuses on further work; in Section 6, limitations of the study discussed and recommendations made; and the study is concluded in Section 7.

2. Background and Related Work

2.1. Climate Change and Farmers-Herdsmen Violence

The Sustainable Development Goal 13 (SDG 13) focuses on Climate Action with emphasis on the exigency of taking urgent action to tackle climate change and its impacts through the regulation of emissions and promotion of developments in renewable energy (Goal 13, 2015); Ndehedehe et al., 2016). Many nations have ratified, domesticated and are presently implementing SDG 13. Another reality is the inextricable link between development and climate. In this light, public sector is enjoined to initiate measures to minimize negative impacts on the environment (Kumara et al., 2018).

Nigeria is one of the countries that have domesticated and enforcing SDG 13. Prominent among government initiatives to tackle climate change and its adverse effects are the setting up of an Ecological Fund (Nwabughiogu, 2017) and the Nigerian Meteorological Agency (NIMET). However, the burden of corruption on the country has made the fund less effective in the attainment of set objectives (Galinatoa, and Galinato, 2013). But for corruption, hopes were high at the country's independence in 1960 that a highly industrialized nation would soon emerge given its abundant human and material resources. It is public knowledge that climate-resilience of developed countries have shielded their citizens from unpalatable consequences of climate change.

Among the many manifestations of the negative impacts of climate change on developing economies is the chronic desert encroachment in northern Nigeria. In its trail are socio-economic fallouts and humanitarian crisis occasioned by the raging farmers-herdsmen clashes that have left many dead. As the desert encroaches, green vegetation depletes, forcing the Fulani herdsmen to flee their traditional base in northern Nigeria to the southern parts with their cattle. As the herders approach southern Nigeria with predominantly subsistence farmers, there is competition for resources. As depicted in Figure 1, the farmer wants the land for his crop while the herdsman insists that his cattle must graze on same land. Crisis erupts and in extreme cases, lives have been lost (Gwangwazo, 2018).

Figure 1. Graphical illustration of the social tension between farmers and herdsmen in Nigeria (Source: This Day Newspaper, 2018).

Though governments at state and federal levels have been fashioning out ways to tackle the problem, military options have been largely used as a quick-fix and reactionary measure (Abubakar, 2017). There is room for more advances in research for diplomatic solutions, soft approaches and long term solutions. Part of policy measures taken so far by some state governments are legislations such as the Anti-Open Grazing Law in Taraba State and Open Grazing Prohibition and Ranches Establishment Law in Benue State (Nwachukwu, 2018). However, these legal frameworks have compounded the face-off between the pastoralists and crop farmers, aggravating existing humanitarian crisis. The reason is that some concerned parties, particularly the Fulani herdsmen feel these measures are not socially inclusive and mutually beneficial (Gwangwazo, 2018). In quick response, the Federal Government has suggested creation of cattle colonies across the states but this initiative has met resistance in some states. Since the Land Use Act of Nigeria concedes power over land to states, the federal government has its hands tied as it can only appeal to states for cooperation (Matemilola et al., 2018).

Table 1. Military operations across geo-political zones of Nigeria

SN	Military Operation Code	English Translation	Geopolitical Zone	States covered	Main Target	Main Motivation of Agitators
1.	Operation *Lafia Dole*	Operation Compulsory Peace	North-East Nigeria	Borno, Adamawa, Yobe	Boko Haram terrorists	To create an Islamic state in Nigeria
2.	Operation *Egwu Eke*	Operation Python Dance	South-East Nigeria	Enugu, Anambra, Imo, Abia, Ebonyi	IPOB (Indigenous People of Biafra)	Self-determination struggle to create Biafra Republic
3.	Operation Crocodile Smile	Operation Crocodile Smile	South-South Nigeria and South-West Nigeria	Akwa-Ibom, Cross-River, Rivers, Bayelsa, Lagos, Ondo, Edo, Delta	Niger Delta Militants, Kidnappers, and Pirates	Fight for resource control
4.	Operation *Harbin Kunama*	Operation Scorpion Sting	North-West Nigeria	Kaduna, Zamfara	Cattle rustlers, Farmers-Herdsmen,	Communal clash
5.	Operation *Ayem Akpatuma*	Operation Cat Race	North-Central Nigeria	Benue, Taraba, Kogi, Nasarawa, Kaduna, and Niger	Farmers- Herdsmen	Struggle for grazing land
6.	Operation *Ruwan Wuta*	Operation Rain of Fire	North-East Nigeria	Borno, Adamawa, Yobe	Boko Haram Terrorists	To create an Islamic state in Nigeria

2.2. Insecurity in Nigeria

The climate change-induced farmers-herdsmen clashes have continued to soar as researchers and policy makers are busy making frantic efforts to bring the situation under control. As part of a quick fix, military intervention such as Operation Ayem Akpatuma (Operation Cat Race) has become necessary in affected areas (Ugwuanyi, 2018). Insecurity in Nigeria is legendary with virtually all the six (6) geopolitical zones affected with one form of insecurity or the other. Table 1 contains details of military responses to the various security challenges across geo-political zones in Nigeria (Abubakar, 2017).

Though such use of brutal force to quell crisis is unavoidable in certain circumstances, there is need to increasingly explore and exploit soft approaches for proactively curbing insecurity. From Table 1, it can be inferred that the military makes conscious effort to domesticate its various operations and make them socially inclusive by code naming its operations using local dialects of respective operational zones. This deliberate policy of soliciting the support of the people is commendable though military option is only a reactionary and hard approach that is less fashioned. Overtime, dialogue and diplomacy have been known to be a viable alternative with great potentials for soothing nerves in a way that promotes justice and peaceful coexistence. As captured by SDG 16 (Peace, Justice, and Strong Institutions), sustainable peace between farmers and herdsmen can only be achieved if there is a pervasive feeling of justice among both parties (Goal 16, 2015). As far as the geopolitical space called Nigeria is concerned, both have a feeling that they have equal stakes in catering for their livelihoods (crop farming and cattle rearing). Hence, government policies and pronouncements based on sentiments rather than historical antecedents will create feelings of social exclusion and escalate existing tensions.

A soft approach that promises long term solution to the climate change-induced crisis is data analytics. Basing decisions such as legislations, policies, and programmes on credible and robust information elicited from farmers-herders' data would eliminate bias and prejudices and therefore promote peace and justice among the farmers and herdsmen.

2.3. Deep Neural Network in Agriculture

Enthusiasts in the agricultural sector are desirous of credible knowledge for informed decision making (Shena et al., 2018). Extracting knowledge from farmers-herdsmen historical data could be done using data science techniques such as statistics, data mining, knowledge discovery in databases (KDD), data warehouse, and machine learning (Ali et al., 2012). Deep Neural Network (DNN) is a high-end predictive data mining technique as well as machine learning tool that is reputed for accuracy in generating knowledge from agricultural data sets (Kamilaris and Prenafeta-Boldú, 2018). DNN relies on regression analysis (function approximation), classification (pattern recognition), and forecasting (predictive analytics) for availing policy makers and service providers in the agricultural sector with robust and credible information from observational data (Lu et al., 2017)**.** Applied to farmers-herdsmen data for example, it has capability for classifying behaviours of farmers and herdsmen as well as predicting their disposition to violence amid scarcity of productive resources such as land, water, and infrastructure. In this sense, historical antecedent can be harnessed for furnishing stakeholders in the agricultural sector

with unbiased and non-prejudicial information. Such credible information can be used for strategic interventionist measures and adaptive solutions in the form of socially inclusive and mutually beneficial policies, legislations and institutions. Therefore, designing a DNN-based learning system such as the Farmers-Herdsmen Expert System (FHES) as proposed in this study will go a long way in promoting peaceful coexistence between farmers and herdsmen given that stakeholders will muster the political will to implement it. Farmers and herdsmen will have a sense of social inclusion, justices and equity as a result of unbiased policies and pronouncements of government based on patterns learnt and information extracted by FHES from operational data. The process involves training FHES sufficiently to attain stability by the neural network prior to deploying it for predicting outcome from future farmers-herdsmen data inputs.

2.4. Related Works

In (Kumara et al., 2018), the research addressed the problem of missed or swapped animals and false insurance claims by proposing deep neural network learning based approach. The approach identifies individual cattle using the image pattern of its nose (muzzle point). This feature extraction and classification initiative leveraged on the realization that animal biometrics is a frontline aspect of computer vision that can aid the registration, identification, and verification of livestock. Deep learning as an embodiment of pattern recognition and cognitive science has been able to recognize species or individual animal using visual features. This is in contrast with existing handcrafted texture feature extraction and the traditional appearance-based feature representation techniques that are incapable of recognizing animals in unconstrained environment. Even in constrained environment, the deep neural network approach outperformed traditional methods of animal identification. Though this study demonstrated the use of deep neural network in resolving identity crisis in animal husbandry, it fell short of mentioning how same technology could be applied to resolve emerging farmers-herdsmen crisis that has impacted adversely on livestock rearing and crop farming.

The work of (Sonawane and Choubey, 2017) focused on crop farming and demonstrated the use of neural networks for value addition in seed processing. The research used artificial neural network to grade soyabean seeds for sale in commercial quantity. The authors observed that the use of computer vision rather than human vision in the visual inspection of soyabean seeds will reduce time delay, minimize errors, and scale up accuracy in the process of grading soyabean seed. Hence their advocacy for a neural network-based automated system. The work further highlighted key parameters used as criteria for evaluating quality of soyabean seeds as well as summarized the use of various machine vision techniques for visual inspection and classification of grains. Despite using neural network to enhance agricultural programme through quality seed management, handling farmers-pastoralists face-off using same technology was not discussed, the main focus of this present study.

Tubi and Feitelson (2016) examined how climate change-induced conflicts between herdsmen and farmers in Isreal's northern Negrev were handled by state institutions. The study used archival data to x-ray conflictive and cooperative interactions between the pastoralists and farmers during the 1957-1963 drought, acclaimed to be the worst in the 20th century. The paper reiterated that climate change is increasingly a security problem that deserves attention of academics and political office holders. Strategic interventionist measures taken by state institutions to mitigate frictions and offer relief assistance were cardinal to the limited level of conflict even though it strengthened the power disparities between the groups. It was observed that the drought impacted conflict and cooperation though violence occurred when herders and farmers lacked previous familiarity. The all-embracing approach of the state institutions and the consequent peaceful coexistence between herders and farmers even in the face of severe drought and attendant limited resources underscores the significance of social inclusion to justice, peace and sustainable development. The paper however did not explore the use of artificial neural network for eliciting robust and unbiased information from farmers-herdsmen data for informed decisions.

The work of (Ukamaka et al., 2016**)** used 135 crop farmers and 72 herdsmen as subjects for conducting the study which focused on the roots and remedies of farmers-herders' conflicts. The farmers surveyed outline causes of conflict as destruction of harvested crops, uncontrolled grazing, destruction of farmland, pollution of water source of community and other unpleasant activities of herdsmen. On their part, the herdsmen identified animal rustling, commercialization of crop residue, inability to access water point, and other factors capable of undermining their livelihood. The authors classified the causes broadly as resource use and structural factors while outlining conflict management strategies adopted as rural institutions and social strategies. However, poor funding and institutional supports were fingered as constraints of successful conflict management. Other constraints are demographic, political, economic, social and cultural orientation. The study did not explore the possibility of harnessing historical farmers-herdsmen data using deep neural network for unbiased and informed decision making geared towards social inclusion of both farmers and pastoralists in policies for justice and peaceful coexistence.

Reuveny (2007) researched the impact of climate change on the environment and implications for migration. The study observed that environmental problems caused by climate change such as drought,

rising sea level, melting glaciers, and desert encroachment can stimulate residents to migrate. For those not yielding to migration, they try to adapt to the problems by staying in place without making efforts to ameliorate them. Yet others stay and make conscious and concerted efforts to mitigate the problems. The author opined that option chosen depends on mitigation capabilities and extent of environmental problems. The work further observed that people in lesser developed countries are more likely to choose the option of leaving affected areas which may result in conflict in receiving areas. Based on his findings, the author opined that there are policy implications for climate change. In spite of the fact that the study did not explore the use of machine learning for eliciting credible information for policy formulation for dealing with climate change-induced conflicts, the findings bear relevance to the Nigerian situation used as case study in this present research. The herdsmen from northern Nigeria are chased by desert encroachment and as they approach southern Nigeria, conflicts erupt between them and the subsistence farmers over agricultural resources.

3. Methodology

The study examined data on estimates of crop hectarage, yield and production made available by the Nigerian National Bureau of Statistics (National Bureau, 2011). These estimates are based on sample survey data gathered from farming households. Also examined is the dataset on livestock as contained in the annual inventory of livestock and estimates of livestock and poultry production. The livestock dataset was obtained from the National Bureau of Statistics and Livestock Department of Federal Ministry of Agriculture and Rural Development (FMARD). Both agencies of government prepared the data based on information gathered from farmers and agricultural sample surveys.

The above datasets are respectively sample sizes of crop farming data and livestock data. The population data for entire farming activities since 1914 when the geo-political entity called Nigeria was created to date is a high dimensional dataset that requires sophisticated and precision-conscious machine learning technique like deep neural networks for real-time data analysis and unlocking of useful information. Except in exceptional cases, patterns in both the crop dataset (Table 2) and livestock dataset (Table 3) indicate that there has been expansion in crop production and animal farming. This is attributable to the diversification drive of the government from a monolithic oil economy to non-oil exports. Agriculture is a key area that the diversification policy is focusing on. The growing farmers-herdmen clash could therefore be linked to competition for resources like land, water, vegetation and implements aggravated by climate change effects like desertification.

However, human vision may not be precise in unlocking potentials in the data for planning purposes. To process the data real-time and unveil hidden and useful information for policy making and project implementation, this paper proposes an ANN-based Farmers-Herdsmen Expert System (FHES) as an intelligent software system that offers advisory to critical and relevant stakeholders in peaceful coexistence of farmers and herdsmen for sustainable development. As a pilot scheme, this technology-driven social inclusion initiative harnesses Nigerian farmers-herdsmen data using ANN for generating robust and credible information and knowledge that guides decision making. This is against the backdrop that decisions based on sentiments rather than antecedents will promote social exclusion, aggravate violent clashes and deepen humanitarian crisis.

Conversely, socially inclusive policies, legal and institutional frameworks based on historical data will galvanize peace, justice and strong institutions as enshrined in SDG 16 (Goal 16, 2015). The ANN assists FHES in learning hidden and useful patterns in farmers-herdsmen data for the purpose of generating knowledge for decision making using regression analysis (function approximation), classification (pattern recognition), and forecasting (predictive analytics).

In modelling FHES, deep neural network (DNN) was used. DNN has input layer, hidden layer and output layer of nodes with the hidden layer made up of many layers of nodes for rigorous and elaborate training of the FHES for purposes of high accuracy in results (Kamilaris and Prenafeta-Boldú, 2018). DNN represents a new paradigm in machine learning and DNN-based FHES will be trained rather than programmed, accounting for high accuracy as programmer's errors and biases are eliminated (Lu et al., 2017).

Gathering and analysis of requirements as well as system design were done preparatory to actualizing FHES. The system was designed using Unified Modeling Language. However, implementation is pending.

3.1. Requirements for Farmers-Herdsmen Expert System (FHES)

Tackling the climate change-induced farmers-herdsmen clashes requires that a non-partisan approach be adopted for conflict prevention and control. Therefore, in formulating policies, implementing programmes, and managing projects that have direct bearing on land for crop farming and cattle rearing, both farmers and herdsmen must be integrated in a fashion that promotes a sense of justices and belongingness. All critical and relevant stakeholders in agriculture are therefore potential users of the proposed expert system christened Farmers-Herdsmen Expert System (FHES). The services that FHES renders to these stakeholders include Enquiries, Regression

Table 2. Estimated area planted with major crops in Nigeria, 2004/2005-2007/2008, source: National Bureau of Statistics

'000 Hectare

Crops	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009
Millet	3,835.58	4,428.18	4,270.00	3,827.61	3,749.60
Guinea corn/Sorghum	3,956.71	4,597.56	4,578.00	4,113.68	4,736.73
Groundnuts	2,152.96	2,265.30	1,666.00	2,336.40	2,636.31
Beans	2,153.51	2,153.49	3,098.00	2,364.89	2,524.58
Yams	2,060.80	2,165.75	1,696.00	2,651.03	2,776.01
Cotton	307.37	301.43	222.00	261.80	374.14
Maize	3,209.20	3,791.95	4,670.00	3,175.92	3,335.86
Cassava	2,570.25	2,790.00	2,659.00	2,983.60	3,126.51
Rice	1,454.57	1,590.37	1,526.00	1,680.76	1,788.20
Melon	532.52	530.65	200.00	503.91	454.24
Cocoyam	296.81	315.47	513.00	421.86	480.75

Table 3. Estimated population of domestic livestock in Nigeria, 2006-2010, source: Federal Livestock Department

Livestock	2006	2007	2008	2009	2010
Chicken (Poultry)	158,216,648	166,127,481	174,433,855	183,155,548	192,313,325
Cattle	16,013,382	16,152,698	16,293,226	16,434,978	16,577,962
Goats	51,208,022	25,488,222	53,800,428	5,677,901	56,524,075
Sheep	32,305,032	33,080,353	33,874,281	34,687,264	35,519,759
Pigs	6,386,866	6,642,341	6,908,034	7,184,356	7,471,730

Analysis Services, Classification Services, and Prediction Services as illustrated in the Use Case diagram in Figure 2.

The actor in the above diagram is generic and represents stakeholders such as government, researchers, and service providers who want to secure information from FHES for informed interventionist measures to tackle the ongoing farmers-herdsmen clashes. Towards achieving SDG 16 (Goal 16, 2015), learnt patterns in farmers-herdsmen experiential data should suggest quantity and quality of lands, vegetation, water and implements that satisfy the needs of farmers and herdsmen.

With the use case *Enquiries*, critical and relevant stakeholders in the agricultural sector shall be able to access real-time online information on government agricultural programmes and crisis prevention/mitigation interventions. For example, policy makers and service providers such as ranchers shall be able to inquire from FHES information on levels of availability of agricultural resources such as land, vegetation, water and implements in the various geopolitical zones and geo-agricultural belts of the country. The unbiased information can be used to guide efficient and effective policies on development of initiatives such as farm lands, ranches, grazing land, and cattle colonies in a way that promotes social inclusion and minimizes social tension.

The *Regression Analysis Services* will be used by stakeholders to model a machine learning function for real world farmers-herdsmen training data. Specifically, FHES shall show the relationship between availability of productive resources such as land, water, vegetation, implements and peaceful disposition of farmers/herdsmen. The essence is to ensure that ANN function sufficiently mimic the statistical function of the live data. This will ensure data fitting between machine representation and real-life statistical features of the historical data.

The classification of farmers and herdsmen and their behaviours is another initiative that can douse tension. The use case *Classification Services* can be invoked when the concern of agricultural stakeholders is to understand behavioural patterns of farmers and herdsmen. Sample question that could be asked here is what infuriates a farmer or herdsman and what appropriate steps should be taken to forestall such.

The use case *Predictive Analytics Services* will enable governments, researchers, and service providers to experiment with future input data with a view to forecasting possible outcomes. In the event that certain inputs indicate possible chaos between farmers and herdsmen, remediation measures can be initiated to forestall humanitarian crisis. This use case will only be functional after the ANN-based FHES has been sufficiently trained, stability attained, and enough confidence built that FHES' predictions will be accurate.

3.2. System and Software Design

Conflict management stakeholders shall rely on FHES to interrogate farmers-herdsmen data for credible information in order to proffer lasting solution to incessant farmers-herdsmen clashes. FHES as an intelligent framework for advisory on farmers-herdsmen peaceful coexistence is depicted in Figure 3 below. We anticipate that FHES will be able to suggest dynamically strategic interventionist measures that is all-inclusive based on patterns learnt from supplied farmers-herdsmen data. This way, the informed decision making process with respect to policies and legislations will galvanize a sense of belonging and fairness rather than social exclusion that fuels crisis.

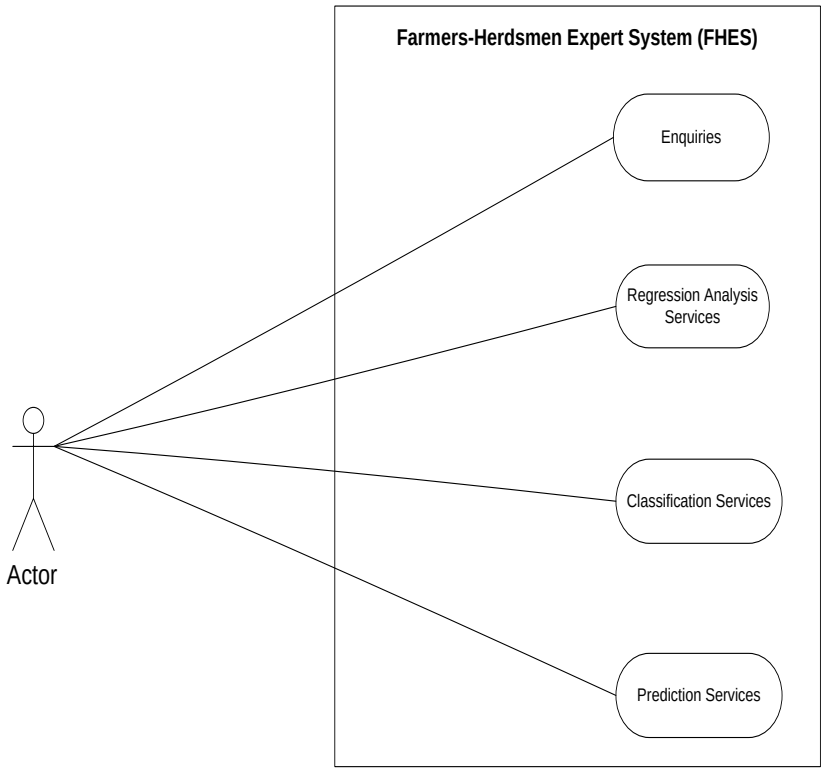

Figure 2. Farmers-Herdsmen Expert System (FHES) use case diagram

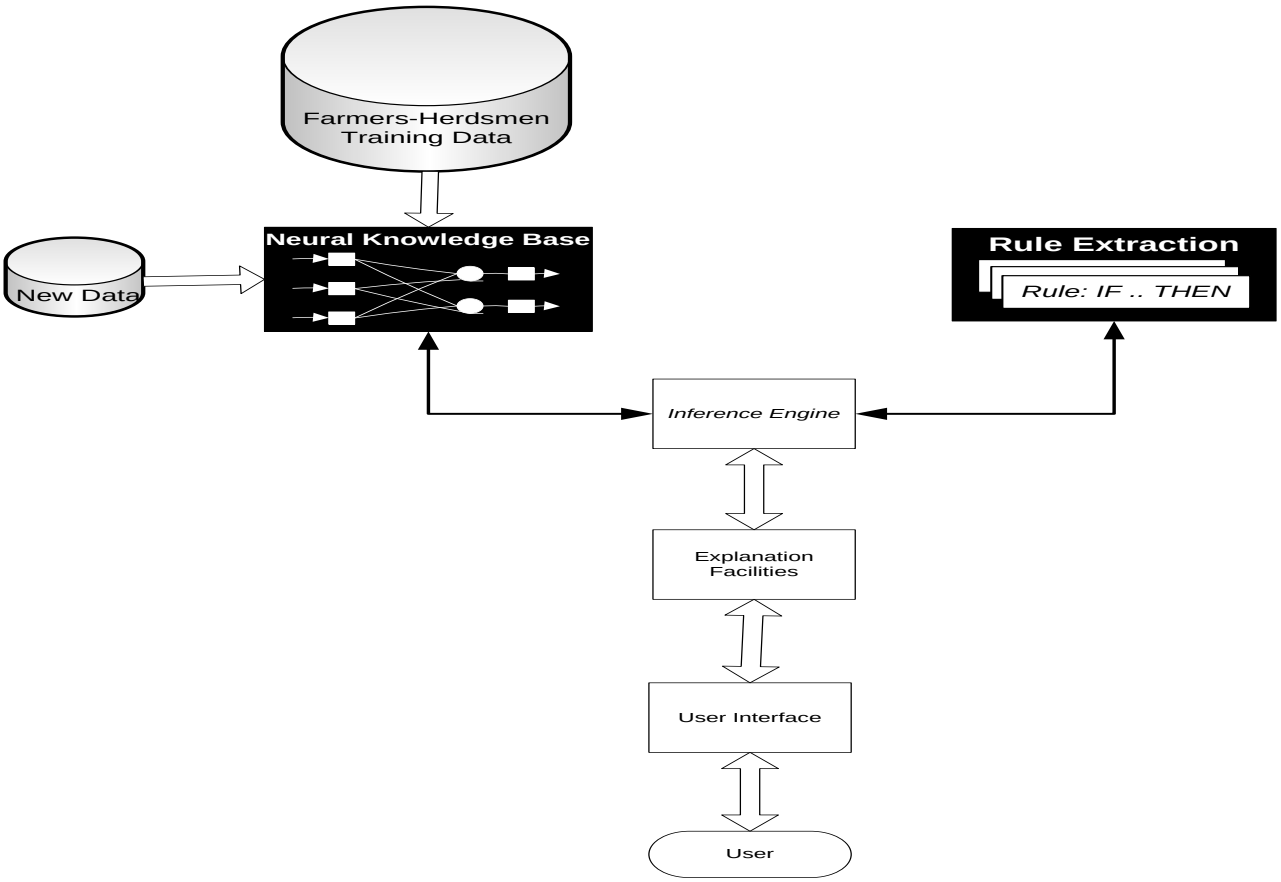

Figure 3. Farmers-Herdsmen Expert System (FHES) design

Table 4. Sample instances of resource distribution and impact on farmers-herdsmen disposition to violence.

Land (x_1)	Water (x_2)	Vegetation (x_3)	Implements (x_4)	Class: Farmers/herdsmen disposition (y)
Sufficient	Adequate	Lush	Available	Peaceful
Moderate	Adequate	Fair	Not available	Peaceful
Scarce	Inadequate	Poor	Not available	Violent

Table 5. Weighted farmers-herdsmen variables

Variables	Linguistic Variables	Weights
Land (x_1)	Sufficient	3
	Moderate	1
	Scarce	0
Water (x_2)	Adequate	1
	Inadequate	0
Vegetation (x_3)	Lush	3
	Fair	1
	Poor	0
Implements (x_4)	Available	1
	Not available	0

As shown above in Figure 3, FHES has both knowledge generation and usage components. The Neural Knowledge Base generates rules (knowledge) using supplied farmers-herdsmen training data and learning algorithm. The extraction and interpretation of rules for decision action is done in the Inference Engine. To foster understanding of system's actions, the Explanation Facilities are used. The User Interface is the channel through which users submit inputs and receive outputs.

Attempts to get coordinated and quantitative observational data on farmers-herdsmen activities from the National Bureau of Statistics of Nigeria for use in this work did not yield result as there is yet to be a coordinated set of data in Nigeria (News Agency, 2018). Hence, the study resorted to hypothetical data as shown in Table 4 which is reasonably representative of the farmers-herdsmen problem.

From Table 4, it can be inferred that the key variables that stimulate violent or peaceful disposition of farmers/herders are land, water, vegetation, and implements. Given that the above data set is used to sufficiently train the network, the proposed system can, based on patterns learnt, forecast the outcome of future tuples such as:

Land = Scarce, Water = Inadequate, Vegetation = Lush, Implements =Available, Farmers/herdsmen disposition = ?

This predictive information can be used by policy makers and service providers to formulate policies and implement programmes that will foster unity and engender peace.

Since deep neural network is purely a quantitative tool unlike other classification schemes such as Bayesian Network and Decision Tree that can process qualitative data, the above data were transformed to quantitative form by assigning weights to respective linguistic variables as indicated in Table 5. The weights were assigned based on their perceived relevance to livelihoods of farmers and pastoralists.

The network (machine) representation of the relationship between the input variables (land, water, vegetation, implements) and the output variable (disposition) is captured in the logistic regression diagram in Figure 4, where x_1 = land, x_2 = water, x_3 = vegetation, x_4 = implements and $\hat{y}$ is the network output.

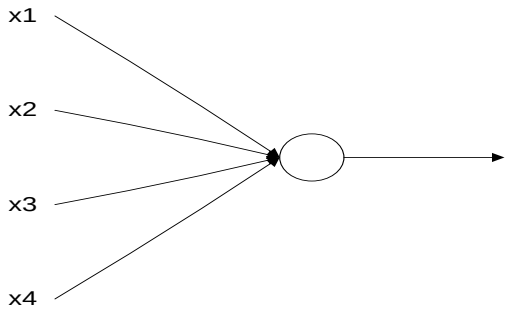

Figure 4. Logistic regression of farmers-herdsmen data

The learning process in the deep neural network commences with an activation function in the artificial neuron as shown in Figure 5.

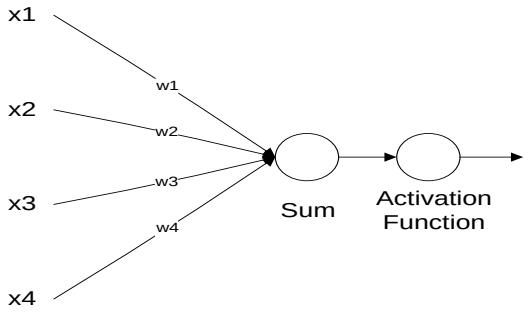

Figure 5. Artificial neuron structure showing learning process

The activation function enables the neuron to learn non-linearity in real world farmers-herdsmen data and also transforms real-valued inputs to probabilis-

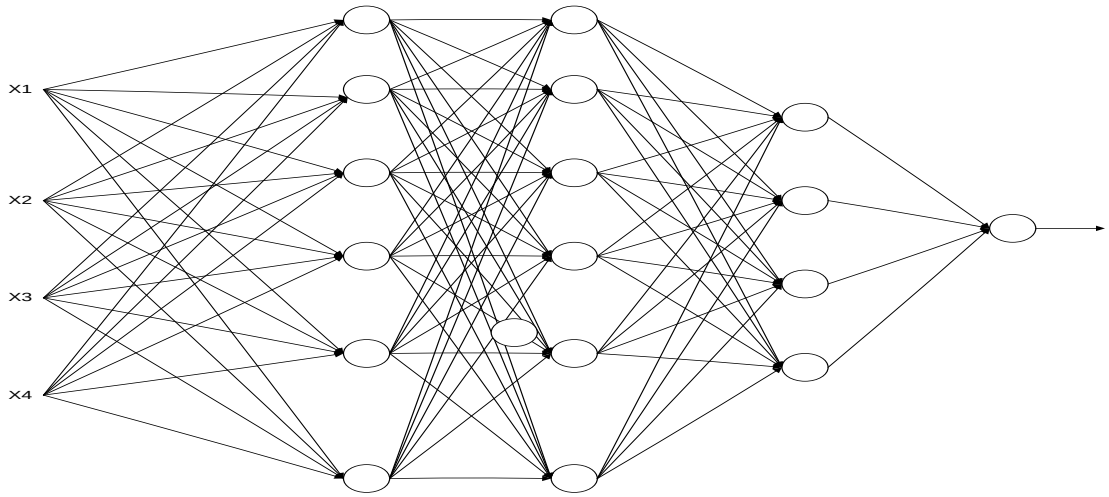

Figure 6. Deep learning of patterns in farmers-herdsmen data for a class of output

tic outputs. The machine learning process is mathematically depicted as follows:

Output of neuron ($\hat{y}$) = $x_1.w_1 + x_2.w_2 + x_3.w_3 + x_4.w_4$

In the event the network output ($\hat{y}$) is not equal to the data (desired or expected) output, an error (cost/loss) occurs. The deep neural network as a self-organizing system, adjusts parameters such as weights and learning rate in continuous iterative refinements until a zero error is achieved or an error size within a tolerable limit. The essence of this learning process, otherwise referred to as perceptron learning rule Dimililera K. and Kianib E. (2017). [25], is to train the proposed expert system, FHES, to correctly classify each instance of the farmers-herdsmen data and it is mathematically denoted below.

$W_{new} = W_{old} + \eta*\delta*X$

where

$\delta = Y - \hat{Y}$

Y = expected/desired output

$\hat{Y}$ = network/actual output

W_{new} = new weight

W_{old} = old weight

η = learning rate

δ = error (cost/loss function)

X = inputs (x_1, x_2, x_3, x_4)

The iterative refinement process of training FHES with successive update of weights is proportional to the derivative of the loss function otherwise referred to as gradient of the error function (Boukis et al., 2009). This is with respect to existing weight in each training iteration. Since the study considered n input variables ($x_1, x_2, x_3, .. x_n$) and m instances ($y_1, y_2, y_3,.., y_m$) for the farmers-herdsmen problem, the learning process can be expressed as a Jacobian matrix of derivatives of loss function as follows:

$$\frac{\partial y}{\partial x} = \begin{bmatrix} \frac{\partial y1}{\partial x1} & \frac{\partial y1}{\partial x2} & \frac{\partial y1}{\partial x3} & \cdots & \frac{\partial y1}{\partial xn} \\ \frac{\partial y2}{\partial x1} & \frac{\partial y2}{\partial x2} & \frac{\partial y2}{\partial x3} & \cdots & \frac{\partial y2}{\partial xn} \\ \frac{\partial ym}{\partial x1} & \frac{\partial ym}{\partial x2} & \frac{\partial ym}{\partial x3} & \cdots & \frac{\partial ym}{\partial xn} \end{bmatrix} = 0$$

When all instances of the farmers-herdsmen data have been correctly classified as depicted by $\partial y/\partial x=0$, FHES is said to have sufficiently learnt and the pattern recognition process concluded. The ANN-based system is then considered to be stable enough for predicting subsequent disposition of farmers/herdsmen from future inputs. Deep neural network modelling of the farmers-herdsmen problem showing vast nodes (neurons) in which the computations take place to correctly classify all instances in a particular category of output (Peaceful disposition or Violent disposition) is shown in Figure 6.

However, since the attitude, belief and behaviour of each farmer/herdsman must be analyzed for a comprehensive, representative and socially inclusive decision making, the mapping of all tuples to their respective classes of output is shown in the deep neural network in Figure 7.

This, in essence, is a comprehensive neural network model of the binary class farmers-herdsmen problem showing mappings from the input vector (X) to output vector (Y).

4. Implications of FHES for Farmers-Herdsmen Clashes

Though statistics of farmers-herdsmen clashes in Nigeria abound (Agbese, 2017), a comprehensive and coordinated database of herdsmen and farmers is lacking (News Agency, 2018). More disturbing is the realization that little efforts have been made towards harnessing such numbers for informed decision making. More often than not, stakeholders in conflict resolution and management base their decisions on mere conjecture, political patronage, primordial sentiments, or just rely on instinct which may not be productive. There is need for a paradigm shift for objective and socially inclusive policies to be formulated for peaceful coexistence of farmers and herdsmen. Proposed legislations such as National Grazing Reserve bill, Open Grazing bill, and Cattle Colony bill for environmental sustainability

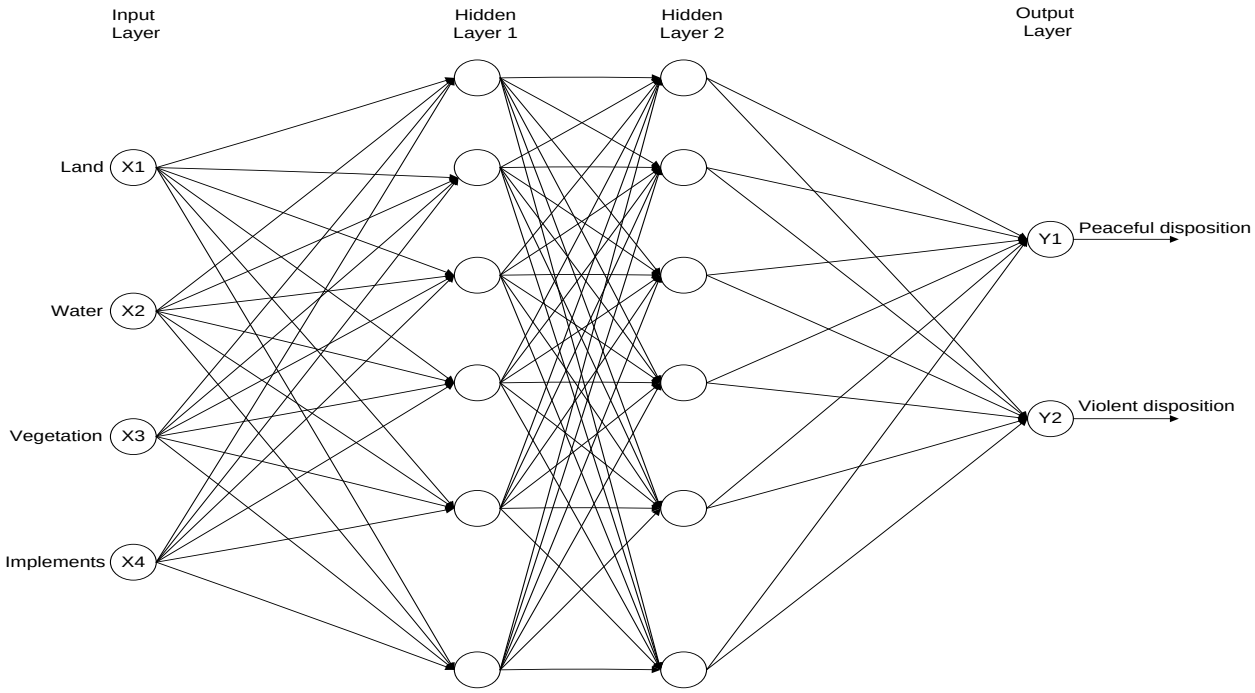

Figure 7. Deep neural network showing binary farmers-herdsmen problem

should be articulated based on historical data or antecedents. This is because there is a strong link between environmental sustainability and economic/national security (Okewu et al., 2018a; Okewu et al., 2018b).

To make optimal use of the database of farmers-herdsmen conflicts, the application of a high-end predictive data mining technique and machine learning tool such as ANN is necessary. The ANN-based learning system, FHES, proposed in this paper is deliberately modelled as a deep neural network to vigorously and rigorously learn patterns in historical data of farmers and herdsmen with a view to offering informed advisory to stakeholders such as government, security agencies, farmers and herdsmen. This is particularly useful in Africa where climate change response system is very weak (Okewu et al., 2017).

If the advisory is heeded, policy formulation, programme implementation, project management, and public pronouncements would be devoured of bias and prejudice. This creates an atmosphere of justices and equity capable of promoting patriotism and sense of belonging thereby mitigating tendencies for violence and conflict. Such proactive crisis management strategy will reduce losses in terms of human and material resources and speed up development across all facets of the SDGs.

5. Further Work

ANN-based expert systems are known to suffer from open problems such as system quality issues, prolonged time of training neural networks, and huge memory requirements. Though advances in research have led to certain improvements, more efforts are required to fully harness the potentials of ANN for optimal decision making in preventing humanitarian crises like those occasioned by farmers-herders clashes. Another area researchers should intensify efforts is reducing the adverse effects of climate change on lives and livelihoods. As depicted in this study by the farmers-herders conflict in Nigeria, scarcity of opportunities (such as occasioned by climate change) and conflicts are inseparable.

6. Limitations of Study

The proposed expert system, FHES, is based on the assumption that adequate, reliable and coordinated data is available. While in developed economies availability and integrity of data are guaranteed, same cannot be said of developing economies such as Nigeria. This can impact negatively on outcomes of data-based studies such as this. Though the Nigerian statistical system has evolved since 1928 providing statistics for national transformation agenda (Olubusoye et al., 2015), obtaining complete dataset for crop and animal farming in Nigeria from 1914 to date is difficult. In any case, the sample data used in this study as obtained from the Nigerian national bureau of statistics offers opportunity for using real-life data for evidence-based policy formulation for tackling farmers-herdsmen conflicts.

Also, typical knowledge discovery in databases value chain requires that pre-processing and processing of data be carried out when knowledge engineering tools are deployed. Though the data used in this study were scrutinized for abnormalities that could impair outcome of the research, some other more advanced studies would have preferred a more

detailed and rigorous data preparation procedure. Nonetheless, the aim of this study is to demonstrate that ANN could be applied to farmers-herders' data to elicit unbiased and non-prejudicial information for policy formulation, programme implementation and project management. Since it has been demonstrated that the proposed ANN-based FHES can promote socially inclusive policies for peaceful coexistence of farmers and herdsmen based of real world sample data obtained from the Nigerian National Bureau of Statistics, it is considered that the aim of system modelling in this paper has been achieved.

Recommendations

1. Countries wishing to implement a scheme such as FHES should have a coordinated data in the form of national database. Presently, many countries, particularly the less developed, don't have such national asset for knowledge engineering.
2. Policy makers and service providers should demonstrate sufficient political will to use the robust and credible output (information/knowledge) from unbiased intelligent systems like FHES for informed and optimal decisions. In this sense, taxpayer resources can be optimally and judiciously utilized in an equitable and socially inclusive manner to promote justice, peaceful coexistence and sustainable development. Conversely, politicization of policies and programmes will breed social mistrust and violence.

7. Conclusion

The humanitarian crisis ignited by farmers-herdsmen clashes may not be peculiar to Nigeria as climate change-induced conditions are found in countries all over the world. However, this study used Nigeria as a case study to proffer a technology-based solution to an environmentally-linked humanitarian crisis. The proposed expert system (FHES) is trained rather than programmed using extracted features of farmers-herdsmen. Real-life farming-related data obtained from the Nigerian National Bureau of Statistics were used to explain the competition between crop farmers and herdsmen for agricultural resources which often results in clashes. A sufficiently trained ANN-based FHES is able to predict crisis-stimulating behaviour based on future inputs using rules in its inference engine. This way, unbiased information is made available to policy makers and service providers for proactive interventions and measures. As a result, socially inclusive policies, legislations, and pronouncements could be made to promote peace, justice, and sustainable development. If the proposed model is implemented, accurate and reliable information can be generated from national database of farmers-herdsmen attributes. An ANN-based expert system does not only classify behaviours of farmers and herdsmen, but is able to predict potentials dangers so that concerned authorities will take appropriate measures to avert the kind of humanitarian crisis frequently experienced in Nigeria.

References

1. QAZI et al., 2015, The artificial neural network for solar radiation prediction and designing solar systems: a systematic literature review, in: *Journal of Cleaner Production*, 104.
2. NDEHEDEHE C.E., AGUTU N.O., OKWUASHI O., FERREIRAD V.G., 2016, Spatio-temporal variability of droughts and terrestrial water storage over Lake Chad Basin using independent component analysis, in: *Journal of Hydrology*, 540, p. 106-128.
3. BUMA W., LEE S., 2016, Investigating the Changes within the Lake Chad Basin Using GRACE and LANDSAT Imageries, in: *Procedia Engineering*, 154, p. 403-405.
4. JEONG D.H., LEE J.M., 2018, Enhancement of modifier adaptation scheme via feedforward decision maker using historical disturbance data and deep machine learning, in: *Computers & Chemical Engineering*, 108, p. 31-46.
5. HAMID A.M., BABA I.M., 2014, Resolving Nigeria's 'Boko Haram' Insurgence: What Role for the Media?, in: *Procedia – Social and Behavioral Sciences*, 155, p. 14-20.
6. TUBI A., FEITELSON E., 2016, Drought and cooperation in a conflict prone area: Bedouin herders and Jewish farmers in Israel's northern Negev 1957-1963, in: *Political Geography*, 51, p. 30-42.
7. GWANGWAZO K.M., 2018, Only justice, fairness will stop Fulani herdsmen, farmers clashes, in: *The Vanguard*, 19 January.
8. GOAL 13: CLIMATE ACTION, 2015, in: *Sustainable Development Goals* (SDGs), United Nations Development Programme.
9. KUMARA S., PANDEY A., SATWIK K.S.R., KUMAR S., SINGH S.K., SINGH A.K., MOHAN A., 2018, Deep learning framework for recognition of cattle using muzzle point image pattern, in: *Measurement*, 116, p. 1-17.
10. NWABUGHIOGU L., 2017, Ecological Funds: NEC approves N2bn each for APC states, in: *Vanguard Newspaper*, May 26.
11. GALINATOA G.I. AND GALINATO S.P., 2013, The short-run and long-run effects of corruption control and political stability on forest cover, in: *Ecological Economics*, 89, p. 153-161.
12. ABUBAKAR I., 2017, Understanding Military Operations as Safeguard of State, in: *The Post*, November 28.
13. NWACHUKWU O., 2018, Umahi heads committee to dialogue with Miyetti Allah, others over Fulani herdsmen/farmers clash, in: *Bussiness Day Newspaper*, February 2.
14. MATEMILOLA S., ADEDEJI O.H., ENOGUANBHOR E.C., 2018, Land Use/Land Cover Change in Petroleum-Producing Regions of Nigeria, in: *The Political Ecology of Oil and*

Gas Activities in the Nigerian Aquatic Ecosystem, p. 257-276.
15. UGWUANYI S., 2018, Benue youths reveal what they fear about Exercise Ayem Akpatuma, in: *Daily Post*, February 21.
16. GOAL 16: PEACE, JUSTICE, AND STRONG INSTITUTIONS, 2015, in: *Sustainable Development Goals* (SDGs), United Nations Development Programme.
17. SHENA Y., ZHOUA H., LIA J., JIANB F., JAYASB D.S., 2018, Detection of stored-grain insects using deep learning, in: *Computers and Electronics in Agriculture*, 145, p. 319-325.
18. ALI L., HATALA M., GAŠEVIC D. JOVANOVIC J., 2012, A qualitative evaluation of evolution of a learning analytics tool, in*: Computers & Education* 58(1), p. 470-489.
19. KAMILARIS A., PRENAFETA-BOLDÚ F.X., 2018, Deep learning in agriculture: A survey, in: *Computers and Electronics in Agriculture*, 147, p. 70-90.
20. LU Y., YI S., ZENG N., LIU Y., ZHANG Y., 2017, Identification of rice diseases using deep convolutional neural networks, in: *Neurocomputing*, 267, p. 378-384.
21. SONAWANE S., CHOUBEY N.S., 2017, A Systematic Literature Review on Soybean Quality Assessment and Utility of Neural Network in Seed Classification, in: *International Journal of Current Research*, 9(05), p. 51160-51165.
22. UKAMAKA M., EDWARD D., SALIFU D., IGBOKWE E.M., 2016, Resource use conflict in agrarian communities, management and challenges: A case of farmer-herdsmen conflict in Kogi State, Nigeria, in: *Journal of Rural Studies*, 46, p. 147-154.
23. REUVENY R., 2007, Climate change-induced migration and violent conflict, in: *Political Geography*, 26(6), p. 656-673.
24. NEWS AGENCY OF NIGERIA, 2018, Umahi orders traditional rulers to compile data on herdsmen, in: *Vanguard Newspaper*, February 9.
25. DIMILILERA K., KIANIB E., 2017, Application of back propagation neural networks on maize plant detection, in: *Procedia Computer Science*, 120, p, 376-381.
26. BOUKIS C., MANDIC D.P., CONSTANTINIDES A.G., 2009, A class of stochastic gradient algorithms with exponentiated error cost functions, in: *Digital Signal Processing*, 19(2), p. 201-212.
27. AGBESE D., 2017, Fulani herdsmen? Here are the grim statistics, in: *The Guardian*, 03 November.
28. OKEWU E., MASKELIUNAS R., MISRA S.,DAMASEVICIUS R., FERNADEZ-SANZ L., 2018, An e-Environment System for Socio-economic Sustainability and National Security, in: *Problemy Ekorozwoju/ Problems of Sstainable Development*, 13(1), p. 121-132.
29. OKEWU E., MASKELIUNAS R., MISRA S., DAMASEVICIUS R., FERNADEZ-SANZ L., 2018, Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem, in: *Journal of Sustainability* 2017(9).
30. OKEWU E., MISRA S., OKEWU J., 2017, Model-Driven Engineering and Creative Arts Approach to Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria, in: *Problemy Ekorozwoju/ Problems of Sustainable Development*, 12(1), p. 101-116.
31. NATIONAL BUREAU OF STATISTICS, 2011, Annual Abstract of Statistics 2011, Federal Republic of Nigeria, http://www.nigerianstat.gov.ng (1.12.2018).
32. OLUBUSOYE O.E, KORTER G.O., KESHINRO O.A., 2015, *Nigerian Statistical System: The Evolution, Progress And Challenges, Research*, DOI: 10.13140/RG.2.1.3136.4569, https://www.Researchgate.Net/Publication/283715250 (1.12.2018).

4.1 Summary of impact article 3

In this chapter, we propose integration of deep neural networks as a practical and cost-effective model for evaluating sustainable development goals. The failure of past global sustainable development plans like the MDGs (2000-2015) is partly blamed on the absence of an evaluation technique that detects and predicts patterns in historical data. As a result, past observations on socio-economic activities could not be harnessed by decision makers for policy formulation, programme implementation and project management. We propose that predictive analytics like deep learning neural networks (DLNN) be integrated in the evaluation of country-based sustainable development policies, programmes, and projects. Data explosion and revolution occasioned by use of smart phones, biometrics, closed circuit television, satellite images and drones have facilitated the availability of big data. Nonetheless, there is need learn hidden and useful patterns in the existing observations so that big data can be made more relevant to the evaluation process. Machine learning techniques such as DLNN uses multiple layers of computational neurons to map input data into output data, while learning existing patterns for the purpose of accurate classification and prediction of the outcome of future observations. We demonstrated in the series of experiment performed that image data, which now forms the bulk of sustainable development data, could be successfully analyzed using convolutional neural networks with accuracy of predictions of over 98%. This implies that stakeholders evaluating sustainable development plans can have 98% assurance that the predictions they make and proactive measures they take to handle emergencies would make impact on lives and livelihoods.

The result and discussion of the work we have done in this thesis would be provided in the next chapter. In particular, we summarize and discuss the works presented in chapters 2- 4.

CHAPTER

5 RELATED WORKS

5.1 Introduction

Our advocacy for the use of software models to spell out details of implementation in the various domains of socio-economic development is to enhance stakeholders' understanding of critical issues involved so as to empower them for the collective obligations of measuring, monitoring and evaluating sustainable development initiatives. So far in this thesis, we have shown that UML activity diagrams and neural networks could be used to demystify concepts and promote collaboration among implementation actors.

In furtherance of our proposal for the integration of software models and predictive analytics in the measurement, monitoring and evaluation of sustainable development efforts at national and sub-national levels, we have some articles that are closely related to the work in this thesis are currently being considered for publication. Also, there is a closely related article that has been published and it is included. Details are given below.

5.2 Articles Currently Being Considered for Publication

The related articles that are currently being considered for publications are outlined in Table 14.

SN	Title	Potential Publication Outlet	Impact Factor
1.	Predictive Modelling for Evaluating and Achieving the Sustainable Development Goals	Sustainability Journal	2.177
2.	A Deep Neural Network-based Advisory Framework for Attainment of Sustainable Development Goals 1-6 (SDGs 1-6)	Sustainability Journal	2.177
3.	A Software Engineering Approach to Implementation of SDG 6 in Adum-Aiona Community of Nigeria	ICCSA 2020 – Lecture Notes on Computer Science	
4.	Parameter Tuning using Adaptive Moment Estimation in Deep Learning Neural Networks	ICCSA 2020 – Lecture Notes on Computer Science	

Table 14.. Closely related articles currently being considered for publication

5.3 Published Article on Predictive Analytics

Despite the presence of many predictive analytics tools, deep neural networks (DNN) is in the vanguard because of its high accuracy in prediction (Kingma and Ba, 2015). The training of deep neural networks is done using stochastic optimizers such as adam, rmsprop, adadelta, adagrad and sgd. Though these stochastic gradient descent algorithms have improved the training of DNN to a large extent, there is room for improvement as researchers are seeking further improvement in training time and loss quality (Koushik and Hayashi, 2017).

In our paper titled *Experimental Comparison of Stochastic Optimizers in Deep Learning* published in *Lecture Notes of Computer Science*, we show outcomes of series of practical experiments using Python deep learning libraries (Tensorflow and Keras API). Convolutional Neural Networks is used for modeling and the dataset used is the database of images of handwritten digits otherwise referred to as Modified National Institute of Standards and Technology (MNIST) database. We aimed at empirically comparing the performances of the stochastic optimizers in terms of training time, loss function and accuracy so that existing and potential users of deep learning such as sustainable development stakeholders would be better informed on their efficacies.

CHAPTER

6 RESULTS AND DISCUSSION

6.1 Introduction

This thesis presents three key activities involved in the implementation of sustainable development plans. They are measurement, monitoring and evaluation. Implementation of sustainable development initiatives starts from measurement and this work aimed at improving measurement by integrating computational models. This is because computational models support specifying developmental activities in numbers. This enhances socio-economic growth and development as statistics form the basis of decision making rather than mere conjecture. It is also a known fact that plans stated in numbers and diagrams are better appreciated that textual plan. In line with the growing agitation for being scientific in handling developmental issues, we have used computational models to express sustainable development goals. We are further motivated by the fact that practical and comprehensive ICT strategies like software models and predictive analytics can galvanize effective and sincere collaboration among stakeholders for fulfilling their mandate of measuring, monitoring and evaluating sustainable development drives at national and sub-national levels. We discuss the outcome of our study in the following section.

Monitoring of sustainable development initiatives is another task that is critical in the implementation value chain. Stakeholders like international agencies, governments, non-state actors (non-government agencies), and public-spirited individuals are conscious of the way and manner public resources are expended. To effectively serve as watchdog, clear-cut presentation of initiatives and their cost-benefit analysis is significant. Our studies applied data and computational models for promoting understanding and eliciting corporation of all stakeholders. Though computational techniques may be technical, we offer adequate explanation alongside the models so that all stakeholders can comprehend. And we advocate the same for all those who would want to improve monitoring of developmental programmes using software models.

6.2 Discussion on the benefits of our models.

Research question 1: Can software models be used to promote understanding and collaboration among stakeholders for the purpose of measuring sustainable development activities?

Chapter 2: A breakdown of the impact of software models on the understanding of stakeholders for enhanced measurement of sustainable development activities.

The use of computational models like entity-relationship diagram, use cases and class diagram to explain domain concepts also enhances measurement which is useful in managing sustainable development goals. It is an established fact that what is not measured cannot be managed. At the heart of any sustainable development, the initiative is the optimal utilization of public resources for the maximum benefit of the citizenry. Though sustainable development stakeholders are aware of this fact, how to quantify sustainable development efforts for maximum output remains a challenge. Many times, the goals to be achieved are expressed in quality terms. As part of conscious efforts to inculcate numbers to improve the measurement of sustainable development goals, our studies deliberately used computational models and statistics to describe sustainable development activities. The quantification of development activities promotes transparency, probity, and accountability. Both government and the governed can easily question and investigate quantitative fact than qualitative facts. In this way, participatory governance is enhanced, and the leakage of public finances is reduced.

Research question 2: What are the constraints in harnessing data for monitoring of sustainable development plans and how can we use data pre-processing to tackle the constraints such that the monitoring process is acceptable to implementation actors?

Chapter 3: A software model for sustainable development monitoring

Our investigation revealed that data and data analytics services could empower stakeholders for effective and efficient monitoring of development projects across diverse climes. In general, the integration of ICT in sustainable development plans improves visibility and promotes transparency, probity, and accountability. The pilferage of public resources is known to be high in an atmosphere of secrecy. Increased monitoring efforts have led to the creation of regional peer review mechanisms such as the African Peer Review Mechanisms. At the national levels, we have seen

the strengthening of institutions for the purpose of monitoring sustainable developments efforts, large to curb corrupt activities that deny the masses the welfare and wellbeing they desire. Non-state actors have also made giant strides in curtailed excesses of public and private sector officials who mismanage commonwealth to satisfy personal desires. To scale up the monitoring efforts so that the SDGs can be attained by the set date (2030), stakeholders must be guided by data and data analytics. Unfortunately, data availability is an issue, especially in developing countries. Even when available, it is noisy and sometimes not organized for putting it into use. We propose data pre-processing models for obtaining clean data that would be useful for monitoring sustainable development programmes. Besides preparing clean data, there is need for data exploratory services that put data in the proper context so that users of data like sustainable development stakeholders can better appreciate the role of data in sustenance and sustainability. Adding value to data by removing aberrations and organizing it into useful formats can enhance the monitoring of sustainable development initiatives.

Research question 3: How can data analytics be harnessed for addressing the challenge of inadequate evaluation of sustainable development plans?

Chapter 4: A cost effective and practical model for detecting and predicting patterns in data.

Evaluation of sustainable development initiatives can be subjected to bias and political consideration, especially in developing economies where opportunities are limited. Hence getting insight from observations (data) rather than seeking opinions could be efficient, given that the data is not adulterated. We propose a predictive analytics model for the evaluation of development plans. Evaluation of development plans entails benchmarking national sustainable development plans with global sustainable development plan such as the SDGs. For objective evaluation devoid of sentiments, there is a need for quality data to be generated in the process of formulating policies, implementing programmes, and managing projects that have a direct bearing on the lives of citizens.

The essence of evaluating sustainable plans on the national basis is because each nation has its unique developmental challenges. In our studies, we collected data and modelled the same using deep learning neural networks. We aimed at using artificial neural networks for detecting patterns

in data and evaluating how well neural network maps input to output. The machine learning model learns patterns directly from the data without the need for programming, thus avoiding programmer-introduced error which could mar the evaluation outcome.

Increasingly, data continues to get diversified inform – textual, voice, and image. This is particularly evident with prevalence in ICT technologies such as biometric devices, close circuit television (CCTV), smartphones, satellite images, and drone. For confidence in data, image data is growing in relevance compared with textual data. In our series of experiments to validate the use of predictive analytics in evaluating SDGs, we applied convolutional neural networks to image data. The outcome of the series of the test indicates that deep learning offers a high sense of prediction accuracy.

Based on the above experimental result, we are confident that the use of predictive analytics in the evaluation of the current SDGs and subsequent future global sustainable development plans has gains over existing evaluation methods. With greater attention being paid to image data such as biometrics and satellite images as a means of measuring developmental activities, our findings have both present and future relevance. Specifically, our proposed model of integrating predictive analytics in the evaluation process could result in better implementation of sustainable development initiatives for the future we desire.

6.3 Conclusion

In this chapter, we summarized the outcome of the main work as presented earlier in chapters 2, 3 and 4. In the first instance, our study investigated the measurement process of sustainable development plans in various nations and concluded that computational modelling of the process will promote understanding and collaboration of stakeholders. Secondly, we validated the monitoring process and sought to improve on it using data gathering and data pre-processing. Finally, we proposed and experimented with predictive analytics as a model that could improve the evaluation of sustainable development plans. We discussed how we practically collected our data and conducted experiments using standard software engineering procedures. Our predictive analytic model was experimentally tested using industry-acknowledged deep-learning processes and tools.

6.4 Summary

In this chapter, we discussed the gains of our proposed predictive analytics model in the cardinal activities of measuring, monitoring and evaluation the SDGs. In the following chapter, we provide a synopsis of the entire thesis work just as we discuss its prospects. In addition, we will discuss viable areas where more works are needed to improve the implementation of sustainable development plans.

CHAPTER

7 CONCLUSIONS AND FUTURE WORK

7.1 Introduction

In our series of research and publications that culminated in this thesis, we had emphasized that countries, particularly developing economies, need to grow by certain appreciable percentage before they can meet SDGs goals. This coupled with leakages in public finance underscores the need to develop systems to promote transparency for efficient and effective measurement, monitoring and evaluation of sustainable development drives. There is a gap in the strategic engagement of stakeholders for the role of measuring, monitoring and evaluating sustainable development initiatives at national and sub-national levels. This is occasioned by the non-transparency nature of the application of public resources. Using model-driven engineering and predictive analysis, we developed strategies to restore confidence in government and governance. This work seeks to close the existing gap by putting in place a transparent online real-time stakeholders' participatory platform. This thesis examined sustainable development from the three perspectives of measuring, monitoring and evaluation using sample goals of the global SDGs. Each SDG has targets and indicators which national sustainable development plans are designed to measure up to. To make the attainment of the SDGs possible by the target year 2030, harnessing existing data using predictive analytics is advocated. We gathered data in selected SDG areas and modelled the data using activity diagrams, use cases and neural networks. The activities of modelling and experimentation showed that sustainable development stakeholders could be better empowered with reliable information for decision- making and policy formulation. Also, the data gathering and data analytics performed in the various works compiled in this thesis have support our advocacy for data-based implementation of sustainable development programmes as they greatly enhance the core activities of measuring, monitoring and evaluation of the SDGs. The summaries of the definitive outcomes of these studies are given in the next section.

7.2 Conclusions

1. Sustainable development is an age-long concept that focuses on improving the standard of living of human beings by executing policies, programmes and projects that are people-oriented. Various global sustainable development plans have been launched towards this end, notably the MDGs (2000-2015) and the present SDGs (2015-2030). Various nations have their national sustainable developments which are tailored towards achieving the global sustainable development plans. With the growing spate of data explosion and increased awareness that harnessing data is key to a successful implementation of sustainable development initiatives, integration data ICT in general and data analytics into sustainable development drives is being given priority attention. This is to enhance measurement, monitoring and evaluation of sustainable developments objectives.
2. We have shown that computational models can be used to empower stakeholders for measuring SDGs. The precise and concise nature of the models helps SDG implementation actors to understand the impact of policies, programmes and projects designed and implemented to touch the lives of people. Data collected from the execution of developmental programmes and initiatives in various nations can be compared with metrics set in the targets and indicators of the SDGs. Software models that use activity diagrams, use cases and neural networks to represent development-related data promotes understanding of stakeholders, hence eliciting maximum support and collaboration in the implementation of policies, programmes and projects.
3. Monitoring of sustainable development initiatives in various countries to ensure compliance with targets in the SDGs is another key activity that is better achieved with the aid of reliable data and data analytics. From data collection through pre-processing, modelling, to forecasting, our works emphasized the need for quality data input so that prediction outcomes could be most helpful to policy makers and decision-makers. We propose in our works that monitoring should not be driven by mere conjecture or political aggrandizement but should be based on the generation, modelling and analysis of data for a solid basis for comparing actual developmental strides in different countries with expected developmental benchmarks captured in the SDGs. The high volume and variety of data generated in the era of SDGs (2015 -2030) entails that sophisticated data handling technologies such as NoSQL should be used as traditional data handling technologies cannot handle unstructured data (Pavlo et al., 2009).

Today, development-related data captured at the source includes both structured and unstructured data, given the prevalence of smartphones, satellite images, drone usage, among other data-generating devices in use today.

4. Our use of predictive analytics to facilitate the implementation of the SDGs is novel. Though researchers in the area of sustainable development have hinted that ICT could drive sustainable development, to the best of our knowledge, known as integrated deep learning neural networks in the evaluation of the SDGs. The MDGs failed partly because of the dearth of in-depth analysis of available data for insight that guides the decision-making process. Though the volume and variety of data available during the MDGs era (2000 – 2015) cannot be compared with what obtains in the SDGs era (2015 -2030), MDGs proponents needed techniques that could detect patterns in existing data and predict the outcome of future data as a way of managing emergencies proactively. We have decided to set the pace by practically demonstrating the application of machine learning in sustainable development drives. We specifically applied deep learning neural networks to historical data. We used artificial neural networks to model the data, train the networks and used the same to make predictions. The outcome of our experiments showed that neural networks exhibit high prediction accuracy, making it attractive for decision making involving scarce public resources. It also makes evaluation, a critical component of sustainable development, to be devoid of sentiments as the machine learning process is devoid of the biases from human intervention.

In conclusion, we specifically developed new protocols for empowering stakeholders for improved measurement, monitoring and evaluation of sustainable development efforts at national and sub-national levels using model-driven engineering and predictive analytics. The protocols involve enhancing the understanding of stakeholders in various development domains using software models to simplify concepts, promote transparency and elicit co-operation. The protocols also cover using data analytics to make online real-time information available to the implementation actors for informed decision making. The series of experiments conducted in our studies have proven that predictive analytics offers high prediction accuracy based on patterns learnt in existing development-related data.

We specifically modelled image data using convolutional neural networks to test how neural networks map an input to output and its prediction accuracy. The outcome of about above 98% prediction accuracy implies that sustainable development decision-makers and policymakers

relying on predictive analytics to forecast events for proactive and strategic interventionist measures have a decision-making tool to rely on. We conclude that with quality data input, predictive analytics using deep learning neural networks should be an integral component of the measurement, monitoring and evaluation of the SDGs in order to attain appreciable implementation for sustainable development by the target year 2030.

7.3 Future work

Successful implementation of sustainable development goals rest on putting in place the right stakeholders' engagement the structure that promotes transparency and ensures efficiency and effectiveness in the measurement, monitoring and evaluation. To achieve this, big data must be properly managed (Marr, 2015), concepts well defined using models, intelligent online real-time systems designed and implemented, and data analytics used to generate hidden and useful patterns in historical data for informed decision making. Hence, the integration of ICT in sustainable development cannot be limited to the use of deep neural network-based predictive analytics. Rather, a holistic approach is required, and we suggest the following future works:

1. Examine existing sustainable development evaluation frameworks to see the extent to which data and data analytics are prioritized. We aim at ensuring that sustainable development in the era of the SDGs (2015 – 2030) does not suffer the same fate as during the era of the MDGs (2000 – 2015) as a result of inadequate attention paid to data collection and its in-depth analysis for informed decision-making.
2. Integration of effective data handling technologies. With the growth in volume and diversity in structure of data, big data generated and used for measuring, monitoring, and evaluating sustainable development in the present era of SDGs cannot be handled by traditional data handling technologies like Oracle and SQL. Attention must shift to No-SQL technologies that effectively and efficiently handle unstructured data.
3. Reporting of the outcome of predictive analytics must be made easy for sustainable development stakeholders who may not necessarily be data scientists or machine learning enthusiasts. We aim at encouraging the use of deep learning libraries that incorporates graphs and statistics tools for simplifying presentations to policymakers and other stakeholders.
4. A good machine learning outcome is based on quality data input. Efforts must be scaled up on vigorous data cleaning using the data pre-processing stage. Incomplete data, missing data,

duplicated data, and all other aberrations that adversely impact on the accuracy of predictions are to be properly managed.

5. Improvement of deep learning algorithms to improve on neural network training time and loss quality. Although our series of experiments revealed that existing neural network algorithms like Adam, RMSprop, Adadelta, and Adagrad perform well, there is room for improvement (Koushik and Hayashi, 2017). Prolonged training time can discourage sustainable development stakeholders from using deep learning neural networks as a tool for enhancing decision just as loss quality can impair prediction accuracy (Glorot and Bengio, 2010).
6. Since this technological response to implementing sustainable development is heavily software-based, free and open-source platforms should be used to reduce the cost of software borne (Asiegbu and Ahaiwe, 2011; Asiegbu and Ahaiwe, 1981) so as to free resources for other initiatives.

REFERENCES

Aaronson, S.A., Data Is a Development Issue, Centre for International Governance Innovation (CIGI), CIGI Papers No. 23 – July 2019.

Aggarwal, K. K. and Singh, Y., Software Engineering, New Age International Publishers, 2008

Ahmed, I.K., Olajide, O.E., and Jeje, E. S. A., History of Corruption and National Development: The Case of Nigeria, Historical Research Letter, Vol.35, 2016, ISSN 2224-3178 (Paper) ISSN 2225-0964 (Online)Asiegbu, B. C. and Ahaiwe, J., Software Cost Drivers and Cost Estimation in Nigeria. Interdisciplinary Journal of Contemporary Research in Business. 8(8):12-14, 2011.

Bahrini, R. and Qaffas, A.A., Impact of Information and Communication Technology on Economic Growth: Evidence from Developing Countries, Economies 2019, 7, 21; MDPI Journal.

Bamberger, M., Segone, M. and Tateossian, F. (2017), Evaluating the Sustainable Development Goals, UN Women, Americas and the Caribbean, 2017.

Bamberger, M., Integrating big data into the monitoring and evaluation of development programmes, UN Global Pulse (scheduled for publication in October 2016) for an introduction to the application of smart data analytics in the evaluation of development programmes, 2016.

Boehm, B., Software Engineering Economics, Englewood Cliffs, NJ: Prentice-Hall, 1981, ISBN 0-13-822122-7, 1981.

Glorot, X. and Bengio, Y., Understanding the difficulty of training deep feedforward neural networks, DIRO, Universit´e de Montr´eal, Montr´eal, Qu´ebec, Canada, 2010.

Gorton, I., Essential Software Architecture, Second Edition, Springer, 2011. Guterres, A., The Sustainable Development Goals Report 2019, United Nations, New York, 2019.
Elgendy, Nada, and Ahmed Elragal, Big Data Analytics in Support of the Decision-Making Process, Procedia Computer Science 100: 1071–84, 2016. [CrossRef]

Kale, Y., Nigeria: Sustainable Development Goals (SDGs) Indicators Baseline Report 2016, 2017.

Kingma, D. and Ba, J., Adam: A method for stochastic optimization, Published as a conference paper at International Conference on Learning Representation (ICLR) 2015. Koushik, J. and Hayashi, H., Improving Stochastic Gradient Descent With Feedback, Conference paper at International Conference on Learning Representation (ICLR 2017).

Kyarem, R.N. and Ogwuche, D.D., Nigeria's Economic Recovery & Growth Plan: Tackling the Macroeconomic Downside Risks, International Journal of Advanced Studies in Economics and Public Sector Management | IJASEPSM, Volume 5, Number 3, December 2017

Lawrence, A.W., Towards Better Performance in Achieving Sustainable Development Goals in Nigeria, International Journal of Developing and Economic Sustainability Vol.6, No.3, pp. 27-34, June 2018.

Marr, B., Big Data: Using Smart Big Data Analytics and Metrics to Make Better Decisions and Improve Performance, Wiley, 2015.

Maendeleo Policy Forum, Corruption, an Impediment to SDG Achievement: What Must Africa Do?, 2017.

Meadows, D.H., Indicators and information systems for sustainable development, The Sustainability Institute, 1998.

Meier, P., Digital Humanitarians: How Big Data is Changing the Face of Humanitarian Response, CRC Press, 2015.

National Bureau of Statistics, National Corruption Survey: Corruption in Nigeria - Bribery as Experienced by the Population, Vol. 2, 2017.

Okewu, E., Misra,S., Okewu, J., Damasevicius, R., and Maskeliunas, R., An Intelligent Advisory System to Support Managerial Decisions for A Social Safety Net, Adm. Sci. 2019, 9, 55; doi:10.3390/admsci9030055

Okewu, E., Misra,S., and Fernandez-Sanz, L., Deep Neural Networks for Curbing Climate Change-Induced Farmers-Herdsmen Clashes in a Sustainable Social Inclusion, Journal of The Problems of Sustainable Development, Vol. 14 No. 2 2019, European Academy of Science and Arts, Salzburg, Poland.

Okewu, E. and Adewole, P., Artificial Neural Network-Based Learning Analytics Technique for Employability and Self-Sustenance, The Journal of Computer Science and its Applications (JCSA) Vol.25 No.2., 2018.

Okewu, E., Maskeliunas, R., Misra, S., Damasevicius, R., and Fernandez-Sanz, L., An e-Environment System for Socio-economic Sustainability and National Security, Journal of The Problems of Sustainable Development, Vol. 13 No. 1 2018, European Academy of Science and Arts, Salzburg, Poland.

Okewu, E., Maskeliunas, R., Misra, S., Damasevicius, R., and Fernandez-Sanz, L., Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem, October 2018, Journal of Sustainability 2018(9).

Okewu, E., Misra S., and Okewu, J., Model-Driven Engineering and Creative Arts Approach to Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria, Journal of The Problems of Sustainable Development, Vol. 12 No. 1 2017, European Academy of Science and Arts, Salzburg.

Okewu, E., and Daramola,O., Design of a Learning Analytics System for Academic Advising in Nigerian Universities, IEEE Xplore Digital Library 2017.

Okewu E., and Misra, S., Resolving the Recruitment and Selection Problem as NP-Hard Problem, Indian Journal of Science and Technology, Vol 9(22), DOI:10.17485/ijst/2016/v9i22/95255, June 2016. ISSN (Print): 0974-6846, ISSN(Online): 0974-5645.

Okewu, E., Incorporating Biometric and Mobile Systems in Social Safety Nets in Sub-Saharan Africa, Covenant Journal of Informatics and Communication Technology (CJICT) Vol. 3 No. 1, June, 2015.

Okewu, E., and Daramola, O., Component-based Software Engineering Approach to Development of a University e-Administration System, IEEE 6th International Conference on Adaptive Science and Technology (ICAST). IEEE Explore Digital Library, 2014.

Okolo, P.O. and Raymond, A.O., Corruption in Nigeria: The Possible Way Out, Global Journal of HUMAN-SOCIAL SCIENCE: F Political Science Volume 14 Issue 7 Version 1.0 Year 2014.

Oleribe, O.O. and Taylor-Robinson, S.D., Before Sustainable Development Goals (SDG): why Nigeria failed to achieve the Millennium Development Goals (MDGs), The Pan African Medical Journal. 2016; 24:156.

Pandey, P., Demystifying Neural Networks: A Mathematical Approach (Part 2), 2018.

Pavlo et al., A., A Comparison of Approaches to Large-Scale Data Analysis, In Proceedings of the 2009 ACM SIGMOD International Conference (Providence, RI. June 29 - July 2). ACM Press, New York, 2009. Pressman, R.S., Software Engineering: A Practitioner's Approach, 7th ed., 2009.

Prusa, V. and Kilanko, A., Impact of insecurity and corruption in the Nigerian security sector on the implementation of the 2030 Agenda for Sustainable Development, Civil Society Legislative Advocacy Centre/ Transparency International Nigeria, 73rd UN General Assembly, New York, USA, Side Event, September 2018.

Siegel, E., Predictive Analytics: The Power to Predict Who Will Click, Buy, Lie or Die, Wiley, 2013.

Solomon, B. A., and Fidelis, M. A., An Appraisal of the Nigeria Economic Recovery and Growth Plan, 2017-2020", African Research Review, AFRREV VOL.12 (3), S/NO 51, July, 2018.

Sommerville, I., Software Engineering, Ninth edition, 2011.

Sustainable Development Solutions Network, How Information & Communication Technology can help achieve the Sustainable Development Goals, 2015.

Sustainable Development Solutions Network, How Information & Communication Technology can help achieve the Sustainable Development Goals, 2015.

Torres, J., Convolutional Neural Networks for Beginners, Practical Guide with Python and Keras, 2018.

Ugaz, J., No sustainable development without tackling corruption: the importance of tracking SDG 16, Transparency International, Civil society, 17 July 2017.

United Nations, Digital Economy Report 2019, Value Creation and Capture: Implications for Developing Countries, United Nations Conference on Trade and Development, 2019

UNODC, Corruption, United Nations Office on Drug and Crime (UNODC), 2019.

Vaessen, J. and D'Errico, S., Evaluation, and the Sustainable Development Goals: Unpacking the Issues, A structured overview of some of the key evaluative issues and questions around this topic April 10, 2018, Independent Evaluation Group, World Bank Group, 2018.

Verhulst, S.G. and Young, A., Open Data in Developing Economies: Toward Building an Evidence Base on What Works and How, The GovLab, July 2017.

Walia, A.S., Types of Optimization Algorithms used in Neural Networks and Ways to Optimize Gradient Descent, 2017.

World Bank, Open Data for Economic Growth, Transport & ICT Global Practice, June 25, 2014.
Yalçın, O.G., "Image Classification in 10 Minutes with MNIST Dataset", 2018.

LIST OF PUBLICATIONS (RELATED TO THE WORK OF THESIS)

Web of Science-ISI/JCR/SCI/SCIE Indexed Journals

1. E. Okewu, S. Misra, J. Okewu, R. Damasevicius and R. Maskeliunas, 'An Intelligent Advisory System to Support Managerial Decisions for A Social Safety Net', Adm. Sci. 2019, 9, 55; doi:10.3390/admsci9030055
2. E. Okewu, S. Misra and L. Fernandez-Sanz, 'Deep Neural Networks for Curbing Climate Change-Induced Farmers-Herdsmen Clashes in a Sustainable Social Inclusion', Journal of The Problems of Sustainable Development, Vol. 14 No. 2 2019, European Academy of Science and Arts, Salzburg, Poland.
3. E. Okewu, R. Maskeliunas, S. Misra, R. Damasevicius, and L. Fernandez-Sanz, 'Optimizing Green Computing Awareness for Environmental Sustainability and Economic Security as a Stochastic Optimization Problem", October 2017, Journal of Sustainability 2017(9).
4. E. Okewu, S. Misra and J. Okewu, 'Model-Driven Engineering and Creative Arts Approach to Designing Climate Change Response System for Rural Africa: A Case Study of Adum-Aiona Community in Nigeria', Journal of The Problems of Sustainable Development, Vol. 12 No. 1 2017, European Academy of Science and Arts, Salzburg.

BIOGRAPHY OF EMMANUEL OKEWU

Emmanuel Okewu is a Deputy Director at the University of Lagos. He manages ICT operations. He holds a Bachelor of Science (B.Sc.) in Computer Science, Master of Science (M.Sc.) in Computer Science, and Master of Business Administration (MBA). His research interests include Artificial Intelligence, Software Engineering, and Data Mining.

Among others, his project management experience includes: (1) Project Manager, University of Lagos e-Administration project (2012-2016); (2) Project Manager, Nigerian Army Turnkey Project (2008 – 2010), Co-ordinator, Pension Enrolment Schemes (2007 -2008).

He has published papers in various journals and conference proceedings.