A multicriteria framework for selecting information communication technology alternatives for climate change adaptation

Adebisi John A.1, Babatunde Damilola E.2* and Babatunde Olubayo M.3

Abstract: The numerous consequences of climate change worldwide have precipitated research efforts to realise sustainable development goal 13 (SDG 13). SDG 13 has recommended mitigation and adaptation strategies to combat climate change, and many of these can be achieved using emerging technologies. Research has shown the efficacies of information communication technologies (ICTs) in mitigating and adapting to climate change. However, the selection and ranking of ICT tools for mitigating and adapting to climate change is a multicriteria problem. This paper presents a multicriteria framework that identifies and ranks the various ICT tools that can ensure climate change mitigation and adaptation. A fuzzy technique for order of preference by similarity to ideal solution method is used as the basis of this model and tested using information obtained from an expert. The results show that the most ideal ICT alternative is social media with a closeness coefficient of 0.62, while the least preferred alternative is the intelligent system with a closeness coefficient of 0.17. The proposed model can be used in the planning of climate change adaptation strategies in developing countries where finances are usually a major constraint in implementing climate change action.

Subjects: Environmental Studies; Climate Change; Information & Communication Technology; ICT; ICT

ABOUT THE AUTHORS
Adebisi John A. is a Ph.D. holder in Software Engineering at the Obafemi Awolowo University, Ile, Nigeria. He has over 15 years of industrial and academic experience with several professional certifications. He is a chartered Engineer in Nigeria and a member of the Association for Computing Machinery and IEEE.

Babatunde D. Elizabeth is a registered engineer with the council for the regulation of engineering in Nigeria and holds a Ph.D. in chemical engineering from Covenant University, Ota, Nigeria. Her research involves the application of artificial intelligence and state-of-the-art computer packages for solving environmental problems.

Babatunde O. Moses completed a doctoral degree in Electrical Engineering at the Tshwane University of Technology, South Africa. He has published over 70 articles in high-impact journals. He is a registered Engineer in Nigeria and a member of the American Energy Association.

PUBLIC INTEREST STATEMENT
According to research, cities are responsible for approximately 70% of the global CO₂ emissions—a gas which is the leading cause of climate change. For this reason, the United Nations included climate action as one of the goals to achieve sustainable development. To attain the targets of SDG 13 by 2030, research efforts have been increased with respect to urban climate change adaptation and mitigation strategies.
Keywords: information communication technology; fuzzy-TOPSIS; multicriteria; environment; climate change mitigation; climate change adaptation

1. Introduction

One of the major challenges of significant concern to the international community is climate change, albeit there is no intuitive approach to the problem; hence, the grasp of scientific knowledge and the basis of its impact on nature and society at large are important (Creutzig et al., 2022). Burning fossil fuels—such as oil, gas and coal—for transportation and power generation are the leading cause of climate change. Other human activities such as deforestation and farming also release greenhouse gases (GHGs) into the atmosphere (Rolnick et al., 2022). This causes the warming of the planet and climate destabilisation (Cook, 2022), which are felt by strange weather events. Climate change mitigation and adaptation require a multidisciplinary and deliberate approach. It requires actions by government, civil societies, youth, researchers, and business across the globe. The causes and prevention of climate change have been extensively analyzed and discussed in the literature (Davenport & Diffenbaugh, 2021; Matata & Adan, 2018; Ryley et al., 2020).

Various frameworks are continually being developed toward the enhancement of climate resilience, as seen in the works by A. P. Aizebeokhai (2009, 2011), Ede and Oshiga (2014) and Tunji-Olayeni et al. (2019). While many researchers and decision-makers agree that concentrating on mitigation and adaptation is essential for tackling climate change impacts, the application of various emerging technologies has the potential to contribute to climate resilience. The research underpinning this paper concerns sustainable development goal 13 (SDG13) and how information communication technology (ICT) can be used to address some of its challenges towards achieving this goal. No doubt, ICT tools are fast becoming a fast generic approach to addressing a lot of challenges towards achieving various SDGs; the vast relationship between ICT tools and climate change emphasizes the importance of this research. Multi-criteria ICT-based approach is needed to address some of the climate change challenges to combat its continuous disruption on economic growth for various countries and the world at large. Obviously, knowledge and information about climate change are unlikely to be enough to motivate most people to act; access to adequate and timely information by various parts of society remains a key concern of climate policy. Adaptation will thus be dependent on the technical and human capabilities to obtain and handle the required information flows in numerous scenarios.

There are various ICT alternatives such as Geographical Information System tools (GISTs) forecasting, Audio-Visual Platforms (AVPs) and Social Media Platforms (SMPs) for fast information dissemination, and Enterprise Application Deployment (EAD) for various ministries, agencies and departments for prompt response to unprecedented climate-driven events and occurrences, among others. Therefore, there exist many synergies between these alternative and various criteria to urgently mitigate the effect of climate change on citizens and economy at large. Many variables hamper responding to climate change in different regions, including persisting social and economic inequalities, uneven quality of human settlements, and chronic poverty in places also vulnerable to climatic dangers (Byrnes & Surmins, 2019). To this extent, it is imperative for ICT experts to defend livelihood from interference (internal and external) that springs up through climate change. In addition, an appropriate framework for checking the environmental situations of various habitations in real time should be explored. Climate information and characteristics could be monitored to offer respected intuitions on how best to mitigate changes at the least cost of ICT tools, among other criteria. Therefore, stakeholders could leverage this to design and harvest real-time data about climate-related activities at any given time, especially from remote locations. This study presented a multicriteria approach for addressing climate change adaptation and mitigation using various ICT alternatives.
1.1. Climate change mitigation and adaptation
Climate change management and mitigation should be well accomplished using cost-efficient and workable tactics. Most often, drought, sea-level rise, extreme weather events, and slow-onset processes can inflict losses and damage to human communities, infrastructures, and the natural environment. This is enough to concentrate more efforts on mitigating this fast-becoming deadly nature of the change in climate being experienced. Anthropogenic (human-caused) climate change and natural climate variability combine to produce these climatic impacts (Lse.ac.uk, 2021). Climate change, as one of the most complex issues facing humans today, is a global problem that involves many dimensions despite being around for many decades, hence adapting to this change through diverse methods is essential (Hinkel, J., & Bisaro, A. (2015). The adjustment to the actual or expected future climate to reduce our vulnerability to the dangerous effect of climate change, especially the sea-level encroachments and the intense weather, among others, is very important (Jiricka-Pürrer et al., 2020). Adapting ICT alternatives to help in building resilience and increase awareness in suburbs or city outskirts is a possibility (John et. al., 2017) and it is one of the central focus of this research (John et al., 2017). ICT tools’ capacity towards adapting to climate change will always improve and limit its effect and will likely require increased attention. In this context, several benefits of climate change mitigation and adaptation through ICT become relevant when planning the realization of the SDGs in this regard.

1.2. The role of ICT in climate change
It is important to note that a poorly managed ICT alternative selection procedure could have a negative impact on the effectiveness of mitigating climate change since thousands of citizens can feel its effect. Consequently, the presentation of a suitable technology and a detailed monitoring system provides a viable tool for the accuracy of climate change impact in terms of climate change parameter intensity measurements. The knowledge of ICT mechanisms is indispensable to mitigating flooding and other related changes in this context. ICT tool deployment entails durable, cost-effective and friendly-to-place equipment. In the past, the climate-monitoring activities were done using manual approaches, and the behaviour and measure pattern of the effects could not be captured expressively (Eakin et al., 2015; Worldbank.org, 2021). In recent years, researchers have resourcefully consumed the treasure of information technology to improve capable systems for checking the behaviour of climate change as an attempt to resolve this fundamental problem (Faghmous & Kumar, 2014). Toward this end, the deployment of sensors has become increasingly ubiquitous in the precision of climate, and several professionals have used wireless sensor network technology to monitor, detect, and measure climate change, especially in and around the human vicinity. Thus, data could be collected and sent automatically at a programmed time to an anticipated gateway for data harvesting and further dispensation to mitigate disasters (Fahad & Wang, 2020). The development of advanced technological solutions capable of protecting the climate from the effect of sensitive changes is undoubtedly one of the greatest needs of human-kind in recent times (Carbonbrief.org, 2021). Toward this end, this paper addresses the urgent need to use a multicriteria approach to mitigate climate change’s impact on our society. In addition, the various losses and damages identified at different levels, as indicated in Figure 1, are more than enough reason for all hands to be on deck for achieving success in this research path (Byrnes & Surminski, 2019). Access to dependable infrastructure and resources, social services, markets, information networks and possibilities for welfare enhancement all contribute to vulnerable conditions and hinder adaptability.

According to scientific consensus, human-induced activities increases the frequency and intensity of climate-related events in general, as well as compounding the effects of natural climate variability. These elements are causing more severe climatic impacts and increased losses and damage. However, ICT can be used to ensure mitigation and adaptation to these losses and damages. Although ICT implementation also comes with some level of emission, the advantages outweigh some of its shortcomings in climate change adaptation.
2. ICT alternatives for climate change

Various ICT alternatives that could be considered for climate change adaptation are discussed in this section. These include GISTs, AVPs, SMPs, EAD, Internet of Things (IoTs) and Intelligent Systems (IS). Various alternatives that are considered for climate change adaptation are indicated in Table 1.

GISTs: This is a great tool that plays an undisputable role in climate change adaptation, with the use of various data involved in GIS procedures, preparation and analysis through automation using python scripting; for various geographical data, python scripts have been written to automate tasks that could be shared with experts and team members via servers and other IT inclined tools towards addressing climate change problems; Esri’s ArcGIS server is one of the foremost GIS tools playing an undaunted role in climate change adaptation. In addition, GIS frameworks helped Bunn et al. (2005) gain a robust understanding of a truly global scale of informed decisions and sustainable management in climate change adaptation. Provision of valuable information has been tremendous with the use of GIS tools; Dangermond and Baker (2010), among other researchers, have proved the relevant impact of GIS tools through their developed ArcGIS server with the use of python programming language towards climate change mitigation. Through this innovative design, a shift from oil to renewable energy is considered based on robust evidence data analysis despite the vast hydrocarbon resources. GIS is an absolute critical tool that is imperative in managing the overall spatial information necessary for designing and building sophisticated visualization and navigation tool with the use of master plan data over time.

AVPs: Audio aids, radio, recorders, charts, black and white boards, maps, picture models, flash cards, and textbooks, among several other aids, are no doubt very impactful in general. However, their impacts are not left out of the subject under discussion regarding climate change adaptation. The massive transformation of most audio-visual aids to IT inclined platforms also brings its

| Table 1. ICT alternatives for climate change adaptation |
|-----------------------------------------------|
| **Information technology alternatives**        |
| Geographical Information System Tools (GISTs) (T₁) |
| Audio-Visual Platforms (AVPs) (T₂)              |
| Social Media Platforms (SMPs) (T₃)              |
| Enterprise Application Deployment (EADs) (T₄)   |
| Internet of Things (IoTs) (T₅)                 |
| Intelligent Systems (IS) (T₆)                   |
relevance to climate change adaptation. Most articles represent climate change challenges through this medium and also propagate its awareness through fast, reliable and timely information dissemination. Consequently, this leads to the usage of social awareness to the public. Audiovisual practices have been brought together at different levels of public and private individual initiatives worldwide with successful implementation as emerging solutions to mitigate climate change’s negative impact (Lopera-Márml & Jiménez-Morales, 2021).

**SMPs:** As an ICT alternative, social media has been praised and recognised for being multimedia and multi-textual, and even though climate change is a problem with considerable visual records, photos, videos, and other non-textual aspects have rarely been investigated (Wang & Moriarty, 2018). Its incredible role cannot be overlooked; social media impregnates virtually every aspect of our lives today. The effect of its frequently increasing global presence has no doubt paid its quota in climate change adaptation. Pearce et al. (2018) showcase the transformative approach of digital technology and its role in climate change adaptation and suggest new improvement channels. With three key findings, the use of Twitter, Facebook, and Instagram for professional communication and sharing of mainstream information is considered. No doubt, social media’s role in climate change adaptation interests motivation and still developing, primarily through research of this nature.

**EAD:** Various enterprise application-dependent innovations have been unleashed towards tackling the effects of climate change. Bill Gates, a foremost entrepreneur, American business magnate and enterprise software developer with Microsoft’s large software solution base, especially enterprise applications, made headlines in 2015 by announcing major initiatives to combat climate change (GADDY et al., 2015). It was planned to invest not less than $2 billion in collaboration with the government of 20 countries and a group of 28 billionaires to transform the clean energy landscape. Nevertheless, enterprise application development forms a formidable component of such innovation. To say the least, the development of huge enterprise applications with problem-solving components will continuously make a dramatic, sustainable change in climate change adaptation. Decarbonizing the world’s energy supply and the creation of new renewable capacity for first-time electrification require enterprise applications, to say the least. Other SDGs also require one enterprise application or another for justifiable actualization of their objectives in due time (GADDY et al., 2015). Defence science and technology has also set up parts of its operations to ensure that climate sustainability is backed up by scientific and analytical rigour and that stakeholders can quickly implement problem-solving solutions (Nugee & N, 2021). Various enterprises and stakeholders have continued developing emerging climate change adaptation technologies.

**IoTs and IS.** The interconnection via the internet of computing devices embedded in climate-related objects, enabling them to send and receive data, mitigates the effects of climate change through data mining approaches from various hardware tools and resources. Various energy innovation approaches, climate change time calculators, climate change time machines, emission data, temperature data, and fossil fuel extraction data, to mention a few, are being extracted with the enormous support of IS- and IoT-based systems (Babatunde et al., 2019). The data are not only being extracted with the support of these IS, but also high-level analysis has also been handled with the use of these technologies towards getting accurate data and information even from remote and high-risk environments. With this innovative approach, almost nothing is impossible to achieve once conceived. The IoT ecosystems are made up of web-enabled smart devices that gather, send, and act on data from their surroundings; this demonstration of embedded systems, sensors, and communication hardware is undoubtedly an addition to ICT’s role in climate change adaptation (Popoola et al., 2018).

**3. Literature review**

It is reported that cities all over the globe are responsible for approximately 70% of carbon dioxide (CO₂) emissions which is the major contributor to climate change (Sharifi, 2021). The contributions of cities to carbon emissions are predicted to increase in the coming decades due to continuous
urbanization and increasing city populations (Matthew et al., 2018). The pressures created by urbanization and population increase make cities more prone to and not spared from the negative effects of climate change and its activities. Admitting this, cities all over the world are developing frameworks that can aid urban climate change adaptation and mitigation so as to build resilience. While there is an agreement that concentrating on both adaptation and mitigation is essential for mitigating climate change impacts, various research has been proposed and conducted. For instance, Balogun et al. (2020) addressed the digitalization gap in climate change mitigation, especially in the area of reducing GHG emissions (Denwigwe et al., 2019). The authors analysed trends currently obtainable in the digital revolution with respect to the subject of discussion. They further examined some of the challenges that might spring up during digitalization. Their research adopted a desk research methodology with a major focus on digital techniques and emerging technologies. The research used scenarios across different locations in the world to assess the possibilities of digital approach to climate threats. The findings of the work are so effective only for early warnings and emergency response systems, especially when it comes to water and food security enhancement and improvement of infrastructures, among other methods to minimize the impacts of threats associated with climates. However, the work recommended selected pathways that could overcome associated risks and challenges and offer numerous opportunities but no record of alternatives or multicriteria concept. The authors did not present details on how ICT could be useful in the digitalization of climate change adaptation initiatives.

Shaffril et al. (2020) presented a systematic review on the impact of climate change adaptation among indigenous people in the Asia Pacific regions. The authors integrated Reporting Standards for Systematic Evidence Syntheses (ROSES) using selected leading databases (Scopus, Web of Science and Google Scholar) and varieties of multiple research designs based on thematic analysis. The review of their research was based on publication standards. The findings were categorized under 7 major themes and 20 other sub-themes, including technology, traditional knowledge, livelihood, support from organisations, physical infrastructures, etc. The authors only explained the importance of integration on policies and strategies of adaptation. The research does not have any evidence of emphasis on technology-driven approaches to mitigate climate change as it is in this research. However, the author’s findings are instrumental to this research from a technology-assisted perspective. The authors recommended studies on the investigation of climate change’s negative impact, emphasising a technology-assisted approach in addition to other subthemes considered. An illustrative example of technology reliance and devices to adapt to changes with financial implications with little or no reliance on the government was established. Furthermore, the creation of passive responses in the community against climate extremes was a part of their focus. Overall, positive and negative perspectives of adaptation approaches might offer a comprehensive understanding based on the scholarly results. Although the research presented suggested that technology-assisted climate change mitigation and adaptation approaches are essential in mitigating climate change, the authors were unable to explore the use of ICT as one of the essential technological alternatives.

Daniere and Garschagen (2019) bring together Southeast Asia’s secondary cities in their primary research to give readers a better understanding of themes such as resilience in climate. The authors suggested possible next steps with documents indicating inhabitants of cities who are affected by the change in the climate. Participation of such inhabitants in developing climate adaptation policies is important for effectiveness. To understand citizens’ sensitivity to change in climate, both systems and approaches centred around people were explored. Illustration of Dawei’s urban systems and services of infrastructure plays a part in sensitising people and how it affects their daily lives. This peculiarity of their approach to addressing issues related to climate change is unique from various questions’ perspective but not technology based. It is, however, important to note that climate resilience can be aided through the use of various ICT tools which are closer to the residents in the city.
Di Silvestre et al. (2018) considered an overview of what they described as the most disruptive phenomena of our day and weighed against the evolution of power systems. Particularly, decarbonization, digitalization and decentralization were considered as the main agents for big transformations with respect to climate change adaptation. China, the United States, and Europe were described as appearing with very different development paradigms and planning capacities. This work particularly emphasized more on renewable and sustainable energy reviews using digital transformation as a strong impact on power system evolution during climate change. Although the authors acknowledged that the influence of digitalization on utilities and market model development appears to be larger based on their reviews, the role that ICT plays in the digital transformation of the power system network during climate change was not acknowledged.

Globally, the high susceptibility climate change impact is exacerbated by cities’ limited ability to adjust; therefore, the basis of effective and efficient climate change adaptation measure execution is excellent governance (Leal Filho et al., 2018). A work that focused on “Strengthening climate change adaptation capacity in Africa” was presented by Leal Filho et al. (2018). The authors used six major African cities as case studies examining the implications of policies on climate change adaptation. Their findings showed that there is a strong relationship between policy development, governance, and climate change development. As a result, it is critical to comprehend the socio-economic drivers of climate change-related dangers. As African cities expand, the authors emphasized that city officials must combine the present and future city development plans with climate change mitigation and adaptation methods, as well as strengthen the adaptive capacity of vulnerable urban populations. It is obvious that the sustenance of future cities is deeply rooted in the application of various ICT tools which were not the focus of the authors’ research. Africa is one of the most vulnerable regions with respect to climate change (Yengoh et al., 2017). As the African continent struggles to adapt to climate change, a variety of solutions are being pursued in several African towns to reduce the resulting stresses on people, property, and livelihoods. The work illustrated that adaptation to climate change in Africa is not as dismal as many people believe and that there are some hopeful alternatives. Hence, the need for strong ICT alternatives to mitigate climate change is explored in this research.

Simon and Leck (2015) addressed the implications and possible unforeseen challenges of climate change in a revolutionary approach. Various behaviours of planners, political leaders, urban managers, organisations, residents, and other stakeholders were examined. The study further tried to understand the adequacy of meeting climate change’s numerous challenges through ongoing urbanisation trends across Africa. Further opportunities in the context of pressing concerns towards reducing the impact of climate change were presented. The research method centres around critical assessment of changes and transformations with agendas and actions situated in the context of conceptual and comparative literature. An in-depth analysis was carried out around three major areas, namely analytical conceptual approaches, the environment of research, and challenges faced during implementation. Albeit no record of implementation was found in their work, but in terms of gendered understandings, approaches to environmental valuation, and climate and environmental justice, the research reviewed and represented a special issue that demonstrates major gaps and inadequacies that reflect diverse mixtures of local priorities and international trends with some time lag. The findings are completely theoretical with little or no relevance of ICT as the focus of the subject under discussion. However, a generally informed assessment of existing situation or interventions was already undertaken, and recommendations derived from analysis will be of a great input to the technologically inclined approach in this work. The authors acknowledged the potential impact of socio-ecological and technological revolutions as largely unexplored, and if the adaptation difficulties are to be met, a sea change in attitudes and attention is required. As like preceding authors, a gap in the use of ICT as a technological tool for climate change mitigation and adaptation is evident in this study.

Karanja Ng’ang’a et al. (2016) emphasized that climate change may threaten the livelihoods of farmers and herders in Africa and semi-arid lands. While there are a variety of solutions available
to limit family exposure to weather risk, adoption is still low. As an improvement on this understanding, the elements that encourage or hinder adoption have been a research priority. The work relied on an empirical approach that suggests how family ties, membership and risk sharing may affect migration in northern Kenya. Their findings show that, at least for pastoral households in northern Kenya’s semiarid areas, migration and local innovation are complimentary rather than substitutive strategies of self-protection. Remittances may also alter the dynamics of local capital markets by increasing cash availability in origin areas and encouraging local investments in various types of capital (Karanja Ng’ang’a et al. 2016). Therefore, a need for the study that will focus on probing some of the complicated interrelations between capital and labour, which are mediated through family membership and other local institutions, is long overdue according to the authors. Some of these concerns can be addressed with the aid of technology and other ICT tools. Faghmous and Kumar (2014) used a data science perspective to approach issues associated with climate change. First, they identified the interacting parts of the global climate system, which range from micrometer-sized particles and aerosols to large-scale changes in the land surface. Measures were then put in place to constantly monitor the evolving planetary processes for proper understanding of the interactive drivers and how they change if the climate continues to warm. To be specific, in addition to attribute-value data as input to most learning models, the research relied on traditional data science and machine learning methods. The authors do not just introduce data science as a technological view of climate change but further mine large climate datasets to address the challenges and opportunities therein, with emphasis on differences between traditional big data approaches and climate data mining methods. The objective of the research was fulfilled using climate science application. More importantly, the research highlights difficulties that must be addressed without being solely relying on findings but rather propose a theory-related data science paradigm that makes use of both big data techniques and interpretation of results and processes for accurate insight into climate data. Furthermore, the study reveals the tremendous space for technology such as big data and other IT-related tools for research since the advent of climate change. The work acknowledged that big data analytics alone are not enough to explore climate data insightfully and accurately. Climate data is very important for climate change mitigation if not the driver of its adaptation.

Fertner et al. (2019), in their research, established how a growing number of governments are creating computerized spatial plan registers. The digitization of planning data and the emergence of Geographical Information System (GIS) software with graphical user interfaces gave it a boost. The review of the article is important due to its relevance to technology, especially when it comes to profound digitalization in all areas which climate change is not an exception. The authors established a public spatial planning database for online distribution of digital planning and workflows to increase transparency of technology usefulness, just as in many European countries where geodatabases are effective for local development plans. Not less than 34,000 datasets were used by the researchers to inform about various technology planning practices and their associated outcomes. Although its efficacy was not comprehensively considered in this study, the study acknowledged that GIS is a very good alternative to climate change adaptation. Information can be fed into the artificial intelligence framework; this suggests that cities will receive a certain quantity of rain or specific temperature conditions, and it will calculate where the most likely disease outbreaks will occur (Leonie, 2019). This is a unique and insightful work that considers digital dashboards, which allows users to be forward-thinking and forecast 10-20 days of risk tendencies through artificial intelligence approach to weather trends. The hotspot in this work reveals the future of ICT dimension to climate change mitigation. With various ICT alternatives available, it becomes a challenge for stakeholders to select the most appropriate one based on economic, technical and other factors; this was not considered by the research conducted by Leonie (2019).

Wang and Moriarty (2018) presented a practical framework for big data application, cloud, pervasive and complex systems as a sustainable way out for urban environmental challenges. This is a good contribution in a technology-inclined direction to climate change adaptation and
was carefully examined for review purpose for this study. The authors covered various technologies, potential, and possible big data impact on energy efficiency and the urban environment. A pragmatic methodology was used including samples of open-source firmware, cloud services, mobile technologies, operating system design methods, networking and even middleware. A detailed framework in design and architectural principles were explored and the results produced form key components of developing energy systems that support sustainable urban environments. A case study and beneficial pathway improvement such as urban-transport demonstration of how to design energy-efficient next-generation transport systems with substantial leverage on cloud dataset and user behaviour is a boom. The research is pivotal in nature with rapid global urbanisation along the path to sustainable future. Imam et al. (2017) investigated possible applications ICT as adaptation tools and difficulties, with a focus on agricultural adaptation and catastrophe risk reduction from a community standpoint. The study was conducted among climate-vulnerable riverine island (char land) residents in four villages in Bangladesh’s Sirajganj District. As has already been said, ICT is critical for socio-economic development as well as solving important concerns such as climate change and sustainable development. The authors illustrated how people are using ICTs to adapt to the effects of climate change and concluded that there are significant untapped potentials for utilizing ICTs in climate change adaptation and recommend a better governance framework.

Based on the preceding literature (Table 2), it is evident that many interesting works have been carried out on issues of climate change mitigation and adaptation and ICT; however, the majority of the studies did not investigate the selection and ranking of ICT alternatives in climate change mitigation and adaptation. This research proposes a multicriteria approach that can be used in the ranking of various ICT alternatives that can be deployed in climate change mitigation and adaptation.

4. Contributions

The main contributions of this paper include the following:

• The study identified various ICT alternatives that can be used in climate change mitigation and adaptation, and this was done through an extensive literature survey.
• The selection and ranking of the identified ICT technologies involve the comparison of their technical, economic and policy features; hence, it presents itself as a multicriteria problem. In this study, important technical, economic and policy criteria and attributes that are important in the ranking of ICT alternatives used in climate change mitigation and adaptation were identified from the literature.
• The study also proposed a unique multicriteria framework for the ranking and selection of the ICT alternatives based on the identified criteria and attributes. This was tested using expert opinion from Lagos state in Nigeria. This framework can be modified and used in other locations with similar features as Lagos State.

5. Materials and method

This section provides a description of the methods adopted in this study. Also discussed in this section is the proposed framework and its implementation.

5.1. Proposed framework

In this study, the advantage of fuzzy set in capturing real-life physical situations is combined with the decision-making proficiencies of TOPSIS to evaluate and rank ICT technologies that have adaptation and mitigation capabilities with respect to climate change. Figure 2 presents the framework deployed in this study. The first step involved conducting a thorough literature search. From this survey, GISTS, AVPs, SMPs, EAD, IoTs, and IS were found to be ICT alternatives with the capability of climate change mitigation and adaptation. Furthermore, the literature is surveyed to identify the relevant criteria and attributes that could be used in the ranking of the identified technologies. A questionnaire that probes the relationship between the ICT technologies and the
| Reference                          | Location of study     | Aim                                                                 | Method/tool                                                                                                        | Shortcoming                                                                                      |
|-----------------------------------|-----------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Bologun et al. (2020)             | Amsterdam             | To address digitalization gap in climate change mitigation, especially in the area of reducing greenhouse gas (GHG) emissions. | Desk research methodology with major focus on core digitalization techniques and concepts towards the fourth industrial revolution (IR 4.0). | Only selected pathways that could overcome associated risks and challenges were offered and no record of alternatives or multicriteria concept. |
| Shaffri et al. (2020)             | Asia-Pacific region   | Presented the systematic review of literatures on the impact of climate change adaptation among indigenous people in the Asia-Pacific regions. | Integrated Reporting Standards for Systematic Evidence Syntheses (ROSES) using selected leading databases (Scopus, Web of Science and Google Scholar) and varieties of multiple research designs based on thematic analysis. | Although provided an illustrative example of technology reliance and devices to adapt changes but with little or no reliance on the government. No comprehensive understanding based on the scholarly results. |
| Daniere and Garschagen (2019)     | Southeast Asia        | Give better understanding of themes such as vulnerability, governance, and climate resilience. | Uses both system- and people-centered approaches to understand citizens’ sensitivity to climate change consequences as well as other non-climatic stresses. | Their approach to addressing issues related to climate change is unique, but it is not technology based. |
| Di Silvestre et al. (2018)        | Portugal              | An overview of what they described as the most disruptive phenomena of our day and weighed against the evolution of power systems. | Used decentralization and regulatory frameworks that promote or hinder the transfer of responsibilities and roles, as well as the development and implementation of related technology. | Emphasized more on renewable and sustainable energy reviews, and the benchmark of the work is not technology inclined. |
| (Leal Filho et al., 2018)         | Douala, Lagos City, Dar-es-Salaam, Accra, Addis Ababa and Mombasa | To establish the cornerstone of effective and efficient climate change adaptation measure execution is excellent governance. | Policy initiatives that may be implemented to improve African cities | Limited ability to adjust. |
| (Yengah et al., 2017)             | Douala metropolis     | To present climate change mitigation and adaptation methods.         | Socio-economic drivers                                                                                            | Result of the research is vulnerable in urban settings.                                         |
| Simon and Leck (2015)             | London                | Addressed the implications and possible unforeseen challenges of climate change in a sort of revolutionary approach | Method centres around critical assessment of changes and transformations with agendas and actions situated in the context of conceptual and comparative literature. | A great input to the technologically inclined approach, but the adaptation techniques are difficult to meet. |
| Karanja Ng’ang’a et al. (2016)    | Kenya                 | Migration and self-protection against climate change                 | Technology and other ICT tools                                                                                   | Complicated interrelations between capital and labour, which are mediated through family membership and other local institutions. |

(Continued)
identified criteria and quantification of the importance of the criteria as developed for expert opinion. Linguistic terms were used to capture the opinion of the experts. The responses of the experts are then subjected to the selected MCDM method based on the selected criteria. Based on the results, decision-makers make informed judgements.

After the data have been generated based on the questionnaires sent to the experts, a fuzzy-TOPSIS approach is used to analyse the responses of the experts. In the first step, a fuzzy scale is defined between the fuzzy numbers and importance is assigned to the connection between the ICT substitutes and the identified benchmarks. The information obtained from the experts is also used to evaluate the fuzzy weights for the criteria and the aggregated fuzzy scores for the ICT options. Next, the fuzzy normalized decision matrix and the weighted normalized decision matrix are obtained. To obtain the order of preference of the ICT alternatives based on the expert judgements, the closeness coefficient for each alternative must be calculated; this can be obtained by first calculating the fuzzy positive and negative ideal solutions and the distance from each alternative from these solutions.
5.2. Formulation of multicriteria problem

Many decision-making problems involve the selection of the most preferred alternatives considering various attributes associated with them. In providing solutions to such challenges, experts are confronted with what are known as the multicriteria problems. The selection and ranking of the most preferred information and communication alternatives for climate change adaptation consist of evaluating each alternative based on a set of metrics. The concomitant assessment of these metrics usually forms the basis for the ranking of the alternatives. Typically, the task of ranking and selecting the best information and communication technology for climate change adaptation can be expressed in the form of a decision matrix as shown in Equation (1).

\[
C(T_i) = \begin{pmatrix}
C_{1}(T_i) & \ldots & C_{1}(T_m) \\
\ldots & \ldots & \ldots \\
C_{n}(T_i) & \ldots & C_{1}(T_m)
\end{pmatrix} : T_i \in T; (i = 1, 2, \ldots, m ; j = 1, 2, \ldots, n),
\]

where \(C(T_i)\) is the vector criterion of quality of the \(i\) – th alternative; \(C_j(T_i)\) is the \(j\) – th component of the vector criterion of quality \(C(T_i)\). The assessment of the \(i\) – th alternative for the \(j\) – th criterion \(C_j(T_i)\) has a well-constructed evaluation scale which is usually based on simulation results, results from experimental research, and expert experience (Krapivina et al., 2019). The solution to this type of problem starts with the creation of an initial problem with a vector criterion to an optimization problem with a scalar criterion, and this is solved to identify the most preferred alternative \(T^*\) which is defined as:
\[ T^* = \text{Arg} \max_{i=1,2,...,m} \langle C(T_i) \rangle, T_i \in T; i = 1,2,...,n \] (2)

5.3. Fuzzy set

In describing practical problems, there usually exists a certain level of inexactness that may make decision and assessment difficult and complex; this is because of the great level of fuzziness attributed to real-world conditions. To deal with this issue in the field of decision-making, Zadeh proposed the application of fuzzy set theory to quantify the characteristic fuzziness that is inherent in many of the physical situations in decision-making (Ighravwe & Oke, 2019b; Zadeh, 1965). Fuzziness is a kind of level of inaccuracy which may be linked with sets where there the boundary between transiting from membership to non-membership overlaps (Bellman & Zadeh, 1970). To rank and select \( m \) alternatives from \( T_1, T_2, \ldots T_m \), based on \( n \) attributes or criteria \( C_1, C_2, \ldots C_n \), decision-makers may find it challenging to assign specific numbers or values, especially when the attribute is qualitative rather than quantitative. In such a case, crisp MCDM approaches would not be able to capture the fuzziness of the data, thus the need for fuzzy set. The advantage of adopting a fuzzy approach in such case is to express the comparative importance of the criteria and the alternatives with fuzzy numbers rather than crisp values. In practice, fuzzy numbers may be trapezoidal or triangular (Triantaphyllou, 2000).

6. Definition 1 (Dzitac, 2015)

A fuzzy number is a fuzzy set in \( R \), namely a mapping \( x: R \rightarrow [0,1] \), with the following characteristics:

- \( x(t) \geq \min (x(s), x(r)), \text{ for } s \leq t \leq r; (x \text{ is convex}) \)
- \( \exists t_0 \in R : x(t_0) = 1; (x \text{ is normal}) \)
- \( \forall \in R, (\forall \alpha \in (0,1) : x(t) < \alpha, (\exists \delta > 0 \text{ such that } |s-t| < \delta \Rightarrow x(s) < \alpha \) (\text{x is upper semicontinuous})

6.1. Triangular fuzzy numbers

Definition 2 (Dubois & Prade, 1980):

A fuzzy number \( M \) on \( R \in (-\infty, +\infty) \) is defined to be a fuzzy triangular number if its membership function \( \mu_m : R \rightarrow [0,1] \) is equal to:

\[
\mu_m(x) = \begin{cases} 
\frac{x}{m} & \text{if } x \in [l,m] \\
\frac{1}{m-l} x - \frac{l}{m-l} & \text{if } x \in [m,u] \\
0 & \text{otherwise}
\end{cases}
\] (3)

In Equation (3), \( l \leq m \leq u \), and \( u \) is the upper value, \( m \) is the modal value and \( l \) is the lower value of the support fuzzy number \( M \). Hence, the fuzzy triangular number defined by Equation (3) can be written as \((l,m,u)\).

Remark 1: The elementary operations of fuzzy triangular numbers include addition, multiplication, negation, division, natural logarithm, and exponential (Equation (4)).

Addition : \( \bar{n}_1 \oplus \bar{n}_2 = (n_1l + n_2l, n_1m + n_2m, n_1u + n_2u) \)

Multiplication : \( \bar{n}_1 \odot \bar{n}_2 = (n_1l \times n_2l, n_1m \times n_2m, n_1u \times n_2u) \)

Negation : \( \ominus \bar{n}_1 = (-n_1l, -n_1m, -n_1u) \)

Division : \( 1/\bar{n}_1 \cong (1/n_1u, 1/n_1m, 1/n_1l) \)

Natural Logarithm : \( \ln(n_1) \cong (\ln(n_1l), \ln(n_1m), \ln(n_1u)) \)

Exponential : \( \exp(n_1) \cong (\exp(n_1l), \exp(n_1m), \exp(n_1u)) \)
6.2. Linguistic terms

In fuzzy MCDM, it is essential to attach weight and degree of importance to the identified criteria. Linguistic terms are defined in terms of variables which consist of natural language or phrase or words to which values are defined. In this study, the importance of the selected criteria and the performance of the selected alternatives were based on a 10-point linguistic term fuzzy scale (Table 3), which were converted into their equivalent triangular fuzzy numbers.

6.3. Fuzzy TOPSIS

Technique for order performance by similarity to ideal solution (TOPSIS), which was formulated by Hwang and Yoon, is a widely used MCDM approach that has found application in numerous fields (Hwang & Masud, 2012). This MCDM approach is founded on the idea that the most preferred alternative must have the least distance to Positive Ideal Solution (PIS), while the alternative with the farthest distance to Negative Ideal Solution (NIS) is the least preferred. As an extension, of the TOPSIS method, Chen proposed a vertex technique to compute the distance between two triangular fuzzy numbers (Chen, 2000) as defined in Equation (5).

\[ d(\tilde{x}, \tilde{y}) := \frac{1}{3} \sqrt{(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2} \]  

(5)

The steps in the implementation of the TOPSIS method include:

1. **Step 1:** Assign importance to the relationship between the alternatives and their attributes. Assuming a response is obtained from P number of experts, then the fuzzy score of the Pth expert about an alternative A_i with respect to criterion C_j is given a \( \tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \), while the weight attached to the criterion \( C_j \) is given as \( \tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}) \).

2. **Step 2:** Obtain the fuzzy weights for the criteria and the aggregated fuzzy scores for alternatives. To obtain the aggregate of the fuzzy score \( \tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \) of the Pth alternative in relation to jth criterion is calculated as:

\[ a_{ij} = \min_p (c_{ij}^p), b_{ij} = \frac{1}{P} \sum_{p=1}^{P} b_{ij}^p, c_{ij} = \max_p (c_{ij}^p) \]  

(6)

To obtain the aggregate of the fuzzy weight \( \tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}) \) of the criterion \( C_j \) is calculated as:

\[ w_{j1} = \min_p (w_{j1}^p), w_{j2} = \frac{1}{P} \sum_{p=1}^{P} w_{j2}^p, w_{j3} = \max_p (w_{j3}^p) \]  

(7)

3. **Step 3:** Obtain the normalized fuzzy decision matrix. The normalized fuzzy decision matrix is given as:

\[ \tilde{R} = [\tilde{r}_{ij}] \]  

(8)

But,

\[ \tilde{r}_{ij} = \left( \frac{a_{ij}}{c_{ij}}, \frac{b_{ij}}{c_{ij}}, \frac{c_{ij}}{c_{ij}} \right) \text{ and } c_j = \max_i (c_{ij}) \text{ (beneficial)} \]  

(9)

Or
\[ r^* = \left( \frac{a^*}{c^*}, \frac{b^*}{c^*}, \frac{a^*}{c^*} \right) \text{ and } a^* = \min_{i} a_{ij} \{ \text{non \ - \ beneficial} \} \] (10)

Step 4: Obtain the weight of the normalized decision matrix \( \check{V} \):

\[ \check{V} = (\check{v}_1, \check{v}_2, \ldots, \check{v}_n) = r^* \times w_j \] (11)

Step 5: Obtain the fuzzy PIS and Fuzzy NIS using:

\[ A^* = (\check{v}_1, \check{v}_2, \ldots, \check{v}_n), \text{ where } \check{v}_j^* = \max_{i} \{ v_{ij} \}; \] (12)

\[ A^- = (\check{v}_1, \check{v}_2, \ldots, \check{v}_n), \text{ where } \check{v}_j^- = \min_{i} \{ v_{ij} \}; \] (13)

Step 6: Obtain the distance from each alternative to the fuzzy PIS and fuzzy NIS. Equations (14a) and (14b) are the distance from each alternative \( A_i \) to the fuzzy PIS and to the fuzzy NIS, respectively.

\[ d_i^+ = \sum_{j=1}^{n} d(\check{v}_j, \check{v}_j^*), \] (14a)

\[ d_i^- = \sum_{j=1}^{n} d(\check{v}_j, \check{v}_j^-), \] (14b)

Step 7: Calculate the closeness coefficient for each alternative using Equation (15).

\[ CC_i = \frac{d_i^-}{d_i^- + d_i^+} \]

Step 8: The alternative with the highest closeness coefficient is the most preferred alternative, while the alternative with the smallest closeness coefficient is the least preferred.

### 6.4. Illustrative example

Nigeria is a prominent regional actor in West Africa and accounts for over two hundred (200) million people with one of the world’s largest young populations. It is Africa’s top oil exporter and
possesses the continent’s largest natural gas reserves, thanks to its abundant natural resources. According to (Eakin et al., 2015), Nigeria is suffering from the effects of climate change. Extreme heat is impacting the many millions of people who do not have access to air conditioning or power, and fluctuations in precipitation are threatening Nigeria’s predominantly rain-fed agricultural industry. Climate change, according to some, might exacerbate the danger of war in the country’s north. In the southern part of Nigeria especially Lagos, flooding has become a night mere for most of the residents during raining season.

Based on the existing setup of climate change management structures and administrative measures, Lagos state, Nigeria, is one of West Africa’s key economic hubs and one of the world’s fastest expanding cities (Figure 3). It is located in a low-lying coastal plain with waterbodies and marshes covering more than 40% of the land area (RESOURCES, M. O. E. A. W, 2020). More than half of Lagos’ 21 million population live in informal settlements, making them particularly exposed to climate change’s effects. One of the major effects of climate change affected by these areas is the rising level of the Atlantic Ocean, thereby causing serious flooding annually, especially towards the end of raining season (Oloke et al., 2013). The negative impact of this terrible yearly experience usually lead to lots of damages causing food insecurity, loss of properties and great decline in economic activities of the state during this period of the year. Lagos is carefully chosen as an illustrative example for this research due to its commercial hub popularity. Other varieties of climate change impact in Lagos include heat-related health issues, and damages to ecosystems and infrastructure. Several categories of climate change effects have affected Lagos state as revealed in the Lagos State five-year climate Action Plan released in 2020 (RESOURCES, M. O. E. A. W, 2020).

As part of the mitigation plan, a five-year action plan contains climate change adaptation strategies based on specific sectors, policies, programmes, and measures. The objective of this plan is to reduce the impacts of climate change through adaptation measures at the federal, state, and local levels. Some of the key sectors identified by the adaptation components are agriculture, communications, commerce, energy, forests, industry, and transportation. All these plans can produce better results if the best ICT alternative is also being considered as proposed in this research. Although not clearly indicated, but with the inclusion of communication, ICT’s role in climate change adaptation, sensitivity reduction, and risk mitigation resilience building cannot be overemphasized. Choosing the best ICT alternative will help alleviate failure of chances to adapt to current and future climate concerns and its disastrous effects for Lagos’ population, economy, infrastructure, natural resources, and political stability. However, due to the budget constraint and other attributes of these technologies (as discussed in the previous section), the government would not be able to implement everything simultaneously. The selection of the most preferred ICT alternative for the mitigation and adaptation of climate change then becomes a multicriteria problem.

In establishing the sustainability of the framework proposed, the model is reformed to climate change mitigation and adaptation in Lagos. Six ICT alternatives with climate change mitigation and adaptation capabilities were appraised based on six measures. The consideration of ICT
alternatives in this regard includes GISTs ($T_1$), AVPs ($T_2$), SMPs ($T_3$), EAD ($T_4$), IoTs ($T_5$), and IS ($T_6$). For ease, the alternatives are denoted by the set $T = \{T_1, T_2, T_3, T_4, T_5, T_6\}$, respectively. Using the six criteria $C = \{C_1, C_2, C_3, C_4, C_5, C_6\}$ designated in Table 4, the choices were classified in order of penchant. Based on the linguistic scale presented in Table 3, and the preference rating and judgment obtained from the selected experts, the fuzzy decision matrices $R$ are formed.

In this illustrative example, a total of 10 experts ($E$) from the industry and the academia with a sound knowledge on the issue of climate change and ICT were contacted for their knowledge and expertise on the subject. Because the quality of this research is based on the experience of the respondents, only experts with more than 10 years experience in the academic and industry were contacted. Previous studies on multicriteria have proven that five experts are enough to obtain valid and informative results (Aikhuele, 2020; Ighravwe & Oke, 2019a). As such, responses from five experts spanning across academics (40%) and industry (60%) were used. Sixty percent of the experts are Ph.D. holders, while the remaining 40% are Masters holders: All experts are practicing in the area of ICT with sound knowledge of climate change activities. Experts attained a minimum of 6–10 and up to 20 years of experience with Masters in IT-related field, while those with Ph.D. possess no less than 11-20 years of experience in industry and academics, respectively. They all acknowledged that they are aware of climate change, and they also agreed that weather pattern is changing dramatically in terms of rainfall seasons, rising and falling temperatures, and flooding among other observations. Furthermore, they all agreed that various climate changes will affect human ways of life and that IT tools could be used to tackle numerous challenges that come with climate change. Table 5 presents the details of some of the questions and their responses.

The opinions of the experts were collected with the aid of a well-structured questionnaire that points toward the importance of the criteria and the relationship between the alternatives and the

| Table 4. Considered criteria in the study |
|-----------------------------------------|
| **Factor**                             | **Criteria**                                      | **Description**                                                                 |
| Policy                                 | Climate change policy sustainability ($C_1$)     | Use of ICT to drive policies that reduce climate change impact on daily living and the environment through publicity, automated adoption practice sustainable resources. |
|                                        | Research activities engagement ($C_2$)           | Continuous research activities and ICT expert engagements on innovative solutions that will enhance climate change policy implementation. |
| Economic                               | Implementation cost ($C_3$)                      | Cost of deployment and implementation of ICT tools in line with global practices and standards. |
|                                        | Maintenance cost ($C_4$)                         | Cost of continuous update of features and components as the change is evolving including upgrade and replacement costs where necessary. |
| Technical                              | Simplicity ($C_5$)                               | Simple, friendly, and interactive ICT solutions that are usable by citizen of different categories and specializations towards climate change adaptation. |
|                                        | Durability ($C_6$)                               | ICT Solutions that are flexible with easy upgrade features in case of change. Modifiable technical components as climate change evolves. |
criteria that were selected. The responses of the experts were given equal weights. The linguistic results obtained from the six experts are presented in Table 6 and later converted into their respective TIFN. Based on the algorithm of the proposed method, the fuzzy decision matrices $R = [r_{ij}]$ of each expert’s judgment are aggregated using the elementary operators of the fuzzy triangular numbers defined under the Remark 1 subsection such that the overall opinion and preference rating $\langle OP_i \rangle (i = 1, 2, 3, \ldots, K)$ are extracted for the various ICT alternatives to form a matrix similar to that presented by Equation (1) (Table 7). The same procedure is followed to obtain the weights of the criteria from the preferences provided by the experts before conversion to crisp values. The combined results of the weights of the criteria are presented in Table 8.

Next is the construction of the weighted normalized fuzzy decision matrix, and this is done by combining the results of the aggregated decision matrix and the results obtained from the aggregate weights of the criteria. The result of the weighted normalized fuzzy decision matrix is presented in Table 9. By combining Equations (5) and (12–14), the distance from each alternative to the fuzzy PIS and fuzzy NIS is evaluated and documented as shown in Table 10. Furthermore, the closeness coefficient for each alternative is calculated and used in the ranking of the ICT alternatives. From Table 11, the alternative with the highest closeness coefficient is the SMPs ($T_3$), and this is followed by the (GISTS ($T_1$), IoTs ($T_5$), EAD ($T_4$), AVPs ($T_2$) and IS ($T_6$) in descending order of preference. This means that the SMP is the most preferred ICT alternative for climate change mitigation and adaptation, while IS is the least preferred alternative.

7. Results and discussions
The use of SMPs as an ICT tool to mitigate climate change is no doubt the most effective tool used through spreading of information, awareness of new changes as they occur and information on how some of these changes could also be mitigated and be very effective through various SMPs such as Twitter, Facebook Channels, and Instagram, among others. Users’ ability to take pictures of events from different locations and time zones on the current effect of climate change allows speedy penetration of information to the society.
Table 6. Expert opinion on the ICT alternatives

|    | E1          | E2          |    | E4          |
|----|-------------|-------------|----|-------------|
|    | C1 | C2 | C3 | C4 | C5 | C6 | C1 | C2 | C3 | C4 | C5 | C6 |
| T1 | VH | AA | VH | L  | A  | VH | T1 | VH | EH | VH | EH | VH | EH |
| T2 | L  | EH | VH | A  | H  | H  | T2 | H  | H  | VH | VH | VH | EH |
| T3 | H  | H  | AA | VL | A  | H  | T3 | AA | H  | EH | VH | VH | VH |
| T4 | VH | H  | VH | A  | H  | AA | T4 | EH | VH | H  | VH | AA | VH |
| T5 | H  | H  | H  | A  | A  | AA | T5 | VH | VH | EH | EH | VH | VH |
| T6 | VH | H  | VH | AA | AA | AA | T6 | H  | H  | VH | AA | H  | H  |

Table 7. The combined results of the fuzzy decision matrices

|    | C1          | C2          | C3          | C4          | C5          | C6          |
|----|-------------|-------------|-------------|-------------|-------------|-------------|
| T1 | (6, 8, 4, 10)| (5, 7, 10)  | (6, 8, 10)  | (1, 6.8, 10)| (4, 6.6, 10)| (7, 8.4, 10)|
| T2 | (2, 6.8, 10)| (5, 7.8, 10)| (7, 8.4, 10)| (4, 7.4, 10)| (4, 7.4, 10)| (6, 8.2, 10)|
| T3 | (4, 7.2, 10)| (4, 6.6, 10)| (2, 6.4, 10)| (1, 5.8, 10)| (4, 7, 10)  | (4, 7.2, 10)|
| T4 | (6, 8.6, 10)| (5, 7.2, 9) | (6, 8, 10)  | (4, 7.6, 10)| (5, 7.4, 10)| (5, 8, 10)  |
| T5 | (6, 7.4, 9) | (6, 8.6, 10)| (5, 7.8, 10)| (4, 7.6, 10)| (4, 7, 9)   | (5, 8, 10)  |
| T6 | (6, 7.6, 10)| (6, 7.2, 9) | (5, 7.4, 10)| (5, 6.8, 9) | (5, 6.8, 9) | (5, 7, 9)   |

The fast information spreading capability of SMP is no doubt one of the features of its ranking as the best and most suitable ICT tool for adapting climate change. When information moves fast, it gets to experts for necessary and required responses for note and immediate actions where necessary. Climate experts and various climate change adaptation agents could embrace this channel more as could foster the spread of information all over the world in creating supplementary awareness in this regard. In addition, SMPs could also play a great role in sorting for public opinions when there are diverse mitigation options. These opinions and feedbacks could get back to the expert seamlessly within a very short period, based on human feelings, geographical locations and cultural diversity on possible causes, effects and proposed solutions.
Table 8. The aggregated weights of the criteria

| Criteria | Weight of the selection index | Combined weight |
|----------|-------------------------------|-----------------|
| C1       | E1  | E2  | E3  | E4  | E5  |   |
| C2       | E1  | E2  | E3  | E4  | E5  |   |
| C3       | E1  | E2  | E3  | E4  | E5  |   |
| C4       | E1  | E2  | E3  | E4  | E5  |   |
| C5       | E1  | E2  | E3  | E4  | E5  |   |
| C6       | E1  | E2  | E3  | E4  | E5  |   |

Table 9. Weighted normalized fuzzy decision matrix

|        | C1            | C2            | C3            | C4            | C5            | C6            |
|--------|---------------|---------------|---------------|---------------|---------------|---------------|
| T1     | (1.20, 5.21, 9.00) | (2.50, 6.20, 10.00) | (1.00, 2.00, 3.33) | (0.50, 1.21, 10.00) | (2.00, 5.28, 10.00) | (4.90, 5.88, 10.00) |
| T2     | (0.40, 4.22, 9.00) | (2.50, 6.71, 10.00) | (1.00, 1.90, 2.86) | (0.50, 1.11, 2.50) | (2.00, 5.92, 10.00) | (4.20, 5.74, 10.00) |
| T3     | (0.80, 4.46, 9.00) | (2.00, 5.68, 10.00) | (1.00, 2.50, 3.33) | (0.50, 1.410, 10.00) | (2.00, 5.60, 10.00) | (2.80, 5.04, 10.00) |
| T4     | (1.20, 5.33, 9.00) | (2.50, 6.19, 10.00) | (1.00, 2.00, 3.33) | (0.50, 1.08, 2.50) | (2.50, 5.92, 10.00) | (3.50, 5.60, 10.00) |
| T5     | (1.20, 4.59, 8.10) | (3.00, 7.4, 10.00) | (1.00, 2.05, 4.00) | (0.50, 1.08, 2.50) | (2.00, 5.60, 9.00) | (3.50, 5.60, 10.00) |
| T6     | (1.20, 4.71, 9.00) | (3.00, 6.19, 10.00) | (1.00, 2.16, 4.00) | (0.56, 1.21, 2.00) | (2.50, 5.44, 9.00) | (3.50, 4.90, 9.00) |
| A*     | (1.20, 5.33, 9.00) | (3.00, 7.40, 10.00) | (1.00, 2.40, 10.00) | (0.56, 1.41, 10.00) | (2.50, 5.92, 9.00) | (4.90, 5.88, 10.00) |
| A-     | (0.40, 4.22, 8.10) | (2.00, 5.68, 9.00) | (1.00, 1.90, 2.86) | (0.50, 1.08, 2.00) | (2.00, 5.28, 9.00) | (2.80, 4.90, 9.00) |

Table 10. Distance from each alternative to the fuzzy PIS and fuzzy NIS

|        | Distance from FPIS |        | Distance from FNIS |        |
|--------|--------------------|--------|--------------------|--------|
| T1     | 0.07 0.85 3.86 0.12 0.47 3.83 |        | 0.90 0.68 0.28 4.62 0.58 1.46 |
| T2     | 0.79 0.49 4.14 4.33 0.29 4.14 |        | 0.52 0.88 0.00 0.29 0.69 1.11 |
| T3     | 0.55 1.15 0.00 0.03 0.34 4.79 |        | 0.59 0.58 4.14 4.62 0.61 0.58 |
| T4     | 0.00 0.95 3.86 4.33 0.00 4.46 |        | 0.95 0.41 0.28 0.29 0.74 0.81 |
| T5     | 0.67 0.00 3.47 4.33 0.67 4.46 |        | 0.51 1.29 0.67 0.29 0.18 0.81 |
| T6     | 0.36 0.90 3.47 4.62 0.64 4.16 |        | 0.75 0.65 0.68 0.08 0.30 0.40 |
Table 11. Final ranking

| ICT alternative | di* | di- | Cci |
|-----------------|-----|-----|-----|
| T1              | 9.20| 8.51| 0.48|
| T2              | 14.18| 3.48| 0.20|
| T3              | 6.87| 11.11| 0.62|
| T4              | 13.60| 3.49| 0.20|
| T5              | 13.62| 3.75| 0.22|
| T6              | 14.15| 2.87| 0.17|

In line with the ranking are GISTs; these tools enhance large amount of data from various climate change activities and its effect. It further could investigate cause of such changes and can be used as an active ICT tool towards achieving climate change mitigation. Its ability to analyze and map spatial data, temperature rising, snow and rainfall patterns from various locations are a plus for this tool towards realising climate change adaptation. This is with respect to the thirdly ranked ICT tool (IoT); with this ICT tool, most of the data used by the GIST are dependent on one hardware device or the other; some of these devices are becoming more sophisticated through Internet connection to record live information, nowadays; they can be connected remotely to send data for analyses and broadcast through cloud services to allow stakeholders take actions almost immediately when necessary to avoid disaster. Since climate change effect could sometimes be sudden and many times we might not be prepared, ICT could play more significant roles as revealed by multiple criteria through various integration possibilities, and the dependent properties of GIST on IoT justify the ranking as the second and third most important ICT tool that could help adapt climate change.

Next in the ranking is EAD; while social media spreads information to stakeholders on happenings and event occurrences, GIST and IoT centers around gathering climate change-related information, while applications are required to manage this information at the enterprise level. It is less coincidental that enterprise application is ranked fourth most important ICT tool that could fit in this purpose. Deployment of solutions to address challenges in all facets of life is fast becoming popular. This is more effective for professional stakeholders to automate process that could be involved business process automation and creation of standard approaches, and
availability of reusable software solutions for most climate change enterprise (governmental and non-governmental organisations) becomes a very important ICT measure in the journey. The data gathered by the top ranked tools will then be used as an input into the EAD either by integration or by a simple data entry approach. The numerous capabilities of software that provides effective business logic modelling to improve productivity and efficiency of climate change activities cannot be less or more important as ranked (Figure 4).

EAD rank is based on the fact that it receives input from other highly ranked ICT tools and subsequently provides corresponding outputs. The output from this stage can be made available through AVPs such as television programmes, YouTube channels, newspaper publications, radio program sponsorships, and new book publications to mention a few. Some of the components of AVP are EAD usability instructions, usage procedures, update and maintenance information and feedbacks on user experience. Although AVPs and SMPs are closely related but play a clear different role in climate change adaptation, while the SMP ranking concentrates more on input data from society and spreading life-changing information for onward processing, AVP is more of corporate awareness and information on adaptive approaches following data gathering and the developed/deployed systems. IS, least ranked ICT tool as they are still evolving, advanced machines that would be able to respond to environmental changes intelligently, analyse data and even suggest solutions, are still in progress. Most of which can be seen as currently in the development stage, albeit some inherit smart technology feature reactive machines, theory of mind and self-awareness. When finally incorporated into climate change activities and adaptation, there could be a total turnaround of ICT impact on climate change adaptation because every activity might become seamless from start to finish. With domain knowledge, sophisticated decision-making processes, and the ability to explain actions, IS are fast becoming popular and applied as a form of artificial intelligence that could be tailored towards different areas including climate change. Its ability to effectively engage with humans to teach or help sophisticated information processing is its most significant feature, which is still upcoming in the area of climate change and its adaptation.

8. Conclusions
City planners and decision-makers have acknowledged the contribution of ICT across many sustainable developmental goals, and its role in addressing key challenges in climate change adaptation has been understudied. More specifically, the sustainability aspects of ICTs in climate change adaptation are a subject that has not been comprehensively captured in the literature. Based on this reason, this study presented a discussion and a framework for the selection and ranking of ICT alternatives that can be used in climate change mitigation and adaptation. Just like any other selection and ranking problem (Ashraf et al., 2020), the selection and ranking of ICT alternative applicable in climate change mitigation and adaptation is a multicriteria problem. Literature review shows that no research has been conducted to identify or prioritize ICT technologies that can be used in climate change mitigation and adaptation. This novel study proposed a Fuzzy-TOPSIS framework for the ranking of ICT alternatives that are targeted at climate action. The originality of the work is embedded in the fact that the study first identified ICT alternatives that can be used to either mitigate or encourage adaptation to climate change and then the important criteria and attributes related to them. Six ICT alternatives, which include GISTs (T₁), AVPs (T₂), SMPs (T₃), EAD (T₄), IoTs (T₅), and IS (T₆), were identified to be useful in climate mitigation and adaptation. Also, climate change policy sustainability, research activity engagement, implementation cost, maintenance cost, simplicity and durability were the attributes found to be vital to the selection and ranking of the ICT alternatives. These attributes were categorized as either policy criteria, economic criteria or technical criteria. Based on information supplied by the experts about the ICT alternatives and the associated attributes, a multicriteria analysis was performed to identify the most and least preferred ICT alternatives using Lagos State, Nigeria, as a case study. Experts’ opinion suggests that the most preferred ICT alternative that be used for climate action is the SMPs, while the least preferred is the IS. This framework can be used in selecting which ICT alternative stage holders should invest in based on financial, technical and available policy
constraints. It can serve as a model for identifying the most preferred ICT alternative that
government and other stakeholders can fund in the future.

To improve the robustness of the current research, further studies would be dedicated to the
comparative analysis of the application of other MCDM tools to the same subject. Also, researchers
can direct research efforts to the sensitivity analysis of the weights of the criteria to the results of
the ranking. In this study, equal weights were allocated to the experts; further studies could
explore the effects of allocating varying weight to the experts.

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Author details
Adebisi John A. 1
Babatunde Damilola E. 2
E-mail: damilola.babatunde@covenantuniversity.edu.ng
Babatunde Olubayo M. 3
1 Electronic Communications Engineering
Department, University of Namibia, Windhoek, Namibia.
2 Department of Chemical Engineering, Covenant
University, Ota, Nigeria.
3 Department of Electrical Engineering, Tshwane
University of Technology, Pretoria, South Africa.

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All authors discussed and conceived the study and wrote
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