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Long paper

Climate Change Adaptation and Mitigation using Information and Communication Technology

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Abstract

Purpose- This study aims to determine how ICT can be used to address climate change by enhancing adaptation and mitigation measures.

Methodology - The research looked at the existing literature on ICT use in climate change adaptation and mitigation. The findings of the literature review were divided into three categories: the role of ICT as an adaptive and mitigating factor, as well as a contributing factor to climate change; role of global ICT companies in combating climate change; and the course of action for increased adoption of ICT to fight climate change.

Findings - According to the study, technological advances driven by cutting-edge innovation in ICT have been recognized as effective means of combating climate change by revealing signals of changing climate, analyzing and modeling climate change, and implementing mitigation and adaptation measures that improve human resilience. The study also found that, while ICT has been hailed as a game-changer in combating climate change and its variability, a few limitations remain, as ICT may contribute to some extent to the ongoing climate change. The study also discovered that major ICT companies such as Google, IBM, and Microsoft have increased their efforts to reduce greenhouse gas emissions.

Conclusion - As an essential component of mitigating the effects of climate change, ICT provides new opportunities for knowledge discovery and real-time information exchange. The application of ICT in conjunction with appropriate laws and regulations has the

potential to drive the fundamental transformation required in the global fight against climate change.

Recommendation - The study recommends that Kenya and the rest of the world embrace and use ICT to mitigate and adapt to climate change to accelerate the achievement of SDGs and other national economic blueprints.

Keywords – Climate Change, Adaptation, Mitigation, Sustainability, Information Exchange

INTRODUCTION

Global resilience and sustainability hang precariously due to the substantial difficulties caused by climate change and variability. In just over 130 years (from 1880 and 2012) the average yearly global temperature rose to 0.85°C (Global Footprint Network, 2018; McGrath, 2019). As a result, weather-related events such as heatwaves, droughts, floods, wildfires, hurricanes, tropical cyclones, and heavy rain and snowfall have become more common and severe (Paris & Pierre-Henri, 2019; Balaji et al., 2007). This has significantly impacted the climate susceptible sectors of agriculture, water, ecosystem, energy, infrastructure, and human health. The situation is even dire in developing countries whose economy is mostly based on rainfed agriculture and tourism. This threatens the survivability of the people in these nations.

In Kenya, the challenge of climate change is becoming a reality. Some of the notable episodes were El Niño and La Niña which had severe consequences on the country's economy and infrastructure, caused deaths, and slowed down value-added agriculture growth (Government of Kenya, 2016). Like other nations, human activities which continue to exert pressure on natural resources environmental degradation, and depletion are to blame for Kenya's increasing climate variability (Kenya National Bureau of Statistics, 2020). Consequently, it is projected that temperatures in Kenya are expected to rise at an average of between 1.2 - 2.5°C per annum by the year 2050, while rainfall will become more intense and less predictable (USAID, 2018). Arid and Semi-Arid Lands (ASALs) in the north and east, the coast, and lake basin region would be particularly hard hit by the climate changes. Droughts, floods, and landslides will be more likely to occur in the Rift Valley region. The glacier melt in the mountains will further diminish future water availability in the lowlands. Coastal regions will be hit hard by flooding and saltwater intrusion caused by rising sea levels. Increasing interseasonal variability and declining rainfall in the main rainy season will significantly impact agricultural productivity thus threatening the population's food security and livelihoods. Models estimate that by 2030, climate change will cause losses equivalent to 2.6% of Kenya's GDP annually (USAID, 2018). Therefore, Kenya must adopt sound adaptive and mitigation measures across various sectors to address the challenge of climate change. These measures can be harnessed through the utilization of ICT.

Climate change mitigation reduces or eliminates greenhouse gas emissions by increasing the amount of activity that removes these gases from the atmosphere (Intergovernmental Panel on Climate Change, 2018). Energy, transportation, buildings, industry, waste management, agriculture, and forestry are the major sources of these gases. Mitigation involves adopting renewable sources of energy, efficient use of energy, adoption of efficient technologies, recycling and re-use of resources, waste reduction, afforestation, and smart mobility (Bekaroo et al., 2016). On the other hand, adaptation to climate change is a behavior adjustment aimed at reducing the susceptibility of natural and human systems to actual or imagined climate change consequences (IPCC, 2011). Adaptation can be realized by preparing for changing environmental and climatic conditions and building resilience of communities, target groups, environments, and ecosystems. Adaptation will help humankind to be more resilient to expected changes such as rise in sea levels, rise in temperature, unpredictable and erratic rainfall, increase in severity of dry spells and duration of heatwaves, landslides, flooding, melting of glaciers. This is because these changes are expected to have far-reaching consequences on the livelihoods of the populations. The mitigation and adaptation measures should be anchored on sound policies that promote the utilization of ICT to harness their realization. In this paper, we reviewed the literature on how ICT can be used to enhance climate change adaptation and mitigation for sustainable development. We provided our findings in the following section.

INFORMATION AND COMMUNICATION TECHNOLOGIES FOR CLIMATE CHANGE ADAPTATION AND MITIGATION

The International Telecommunication Union (ITU) has promoted ICT use as part of its commitment to help battle climate change (Maclean & Arnaud, 2008). This is because the use of ICT opens new channels for modeling and predicting climate change and aids the exchange of knowledge and information (Houghton, 2015). This notion is supported by the Global e-Sustainability Initiative (GeSI), which projects that ICT can help reduce energy consumption, and greenhouse gas emissions and improve resilience to climate change (GeSI, 2021). Further, a study by Houghton concluded that proper utilization of ICT in combating climate change can generate over USD 11 trillion in economic benefits and link an extra 2.5 billion people to the knowledge economy by 2030 (Houghton, 2015). According to (Upadhyay & Bijalwan, 2015), ICT reduces time lag, systemically transforms information, plays a critical role in supporting public outreach, creating awareness for climate change adaptation, and thus ensuring the well-being of biophysical entities. Similarly, Aleke & Nhamo (2016) research reflected how ICT intervention orchestrated changes in communication patterns geared toward reducing vulnerability and exposure to climate change. The study concluded that ICT intervention in the mining sector must be part of a larger and ongoing climate change adaptation agenda. The United Nations Primer Series has also championed the use of ICT to address climate change and promote green growth which will assure inclusive and sustainable development (Asian Disaster Preparedness Center, 2013).

ICTs have the potential to combat climate change in three ways, namely (i) the ICT sector itself can reduce emissions by using more energy-efficient equipment and networks such as the use of green computing, cloud computing technologies; (ii) ICT can reduce emissions and enable energy efficiency in other industries by substituting travel and physical mobility to electronic ones (dematerialization), for example, the use of emails (Gmail, Yahoo, etc), virtual meeting platform (Zoom, Teams, Google Meet, etc), smart mobility (electric cars, Uber, Lyft, Bolt) among others; and (iii) By assisting the global nation in dealing with the consequences of climate change through adoption of ICT-based systems to track meteorological and environmental conditions around the world including the use of:

a) Satellites to track the progress of hurricanes and typhoons;
b) Radars to track the progress of tornadoes, thunderstorms, and the effluent from volcanoes and major forest fires;
c) Radio-based meteorological aid systems that collect and process weather data, without which the current and planned accuracy of weather predictions would be seriously compromised;
d) Earth observation-satellite systems that obtain environmental information such as atmosphere composition (e.g. CO_2, vapor, ozone concentration), ocean parameters (temperature, surface-level change), soil moisture, vegetation including forest control, agricultural data, and many others;
e) Terrestrial and satellite broadcasting sound and television systems and different mobile radiocommunication systems that warn the public of dangerous weather events, and aircraft pilots of storms and turbulence;
f) Satellite and terrestrial systems are also used for the dissemination of information concerning different natural and man-made disasters (early warning), as well as in mitigating negative effects of disasters (disaster relief operations) e.g FAO"s Global Information and Early Warning System for food security (GIEWS).

The increasing move towards ICT adoption to address climate change is because of the realization of the significant role ICT plays in the transformation required to reach net zero. Studies show that some of the factors driving adoption include: the availability of low-carbon technology such as renewable electricity generation and battery manufacturing which have become much cheaper and more widely available; increased investment in research and development and innovation in ICT; use of supportive policies, processes and regulatory standards; availability of expertise; corporate commitment to net-zero and use of more concrete environmental, social, and governance goals; high demand for quality low-carbon products and services; and an increasing number of founders to tackle the climate challenge.

ICT has massive potential in tackling the challenges of climate change and reorient humankind back to the path of sustainability through synergistic and symbiotic use of the natural ecosystem. In the long run, it will harness the realization of the United Nations Sustainable Development Goals, Africa Union Agenda 2063 and Kenya's Vision 2030, and the Big 4 Agenda.

Role of ICT in climate change adaptation and mitigation

The following section discusses some of the roles that ICT can play in climate change adaptation and mitigation:

a) Provision of information

Policymakers and the public can strengthen their resilience to climate change by using ICT to expand access to climate-based information. Adequate telecommunication networks and the proliferation of mobile telephony are critical in ensuring that communications reach people even in remote places. Approaches such as using renewable energy to power mobile base stations through the GreenPower for Mobiles initiative have led to an increase in the number of individuals who previously did not have access to electricity to get real-time climate-related information and alerts (IPCC, 2011). This helps environmental monitoring systems to reach a wider audience. Land-based weather stations also employ satellite or terrestrial communication networks to feed local forecasting stations with data to provide climate-based information to the local community. Google Earth and Microsoft Virtual Earth allow zooming in on satellite images for detailed mapping of the world, while Geographical Information Systems (GIS) provides an effective way to present environmental data for decision making. Multimedia programming and alerts are provided by radio and television networks to vulnerable communities. The use of the internet provides a source of reference information, databases, and strategies for tackling climate change. Information systems can also be used to analyze climate information for decision-making.

b) Analysis and modeling of climate change

Climate change research and decision-making face significant obstacles in characterizing and managing estimates of climate change, particularly at the local scale and for factors (such as precipitation and temperature) that are difficult to model (Ospina & Heeks, 2010). However, the use of advanced technologies such as grid computing through the emerging field of climate informatics has made it possible to accurately model climate and its variability. The current models in use include MITgcm developed by the Massachusetts Institute of Technology to study the atmosphere, ocean, and climate (Massachusetts Institute of Technology, 2021). To collect more data, the climate models are utilized in conjunction with meteorological and environmental sensors and communications networks. Climate models have been applied to forecast changes in regional and local weather as well as sea level for the benefit of local populations. As a result, governments have been able to better adapt their economic sectors to deal with the devastating effects of climate change and disasters.

c) Reduction of greenhouse gas emission

Digital technology can address climate change by lowering greenhouse gas emissions which are leading to global warming. This is possible by using ICT to automate and improve the efficiency of agricultural, transport, industrial, manufacturing, and business activities. For instance: sensors have been used to reduce energy wastage in buildings by controlling lighting and heating; smart mobility and the use of electric cars have led to a reduction in the use of motorized transport; use of virtual meetings and videoconferencing platforms have led to less traveling; advanced technologies such as flat and liquid crystal displays (LCD) consume less energy as compared to the traditional monitors. This, in totality, will lead to a substantial cut in the carbon footprint of ICT and allied sectors.

d) Protection of wildlife, forests, and forecast wildfires

The internet, social media, and mobile phone applications are empowering people to join the conservation cause. In Rwanda, an iPhone application has been used to track mountain gorillas. Kenya recently undertook a national wildlife census using technology to aid conservation and identify threats to its vast but threatened wildlife populations. Drones and Global Positioning System (GPS) have also been used to track endangered species such as black rhinos in Ol Pajeta conservancy in Kenya. Artificial intelligence (AI) applications such as Protection Assistant for Wildlife Security (PAWS) are helping to predict crimes such as poaching against wildlife and fisheries (Mills, 2017). Companies like Microsoft are assisting in the realization of this aim by providing access to their AI suite and cloud capabilities to organizations working on climate change (Roach, 2018). Forest management information systems have been used for advocacy and forest management to curb illegal logging, transportation, processing of timber, and illegal wildlife trade as well as monitor wildfires. Machine Learning and AI have also been used to model and forecast wildfires. Radio-frequency identification (RFID) has been used to control logging by ensuring that only mature trees are cut.

e) Early warning alerts and disaster management programs

Heatwaves and droughts brought on by climate change have wreaked havoc on human life. It has led to the loss of life, famine, and reduction in agricultural productivity. Other effects of climate change include more frequent and powerful storms, higher wind speeds, and more rain. As the frequency and severity of extreme weather occurrences have increased, humans need timely, predictable, and effective information. Examples of how ICTs can help are:

i. Famine Early Warning Systems Network (FEWS NET) was developed by the United States Agency for International Development (USAID) to provide early warning and analysis of food insecurity to governments and relief agencies that plan for and respond to humanitarian crises.
ii. Distant Early Warning System for Tsunami (DEWS) which was funded under the 6th Framework Programme of the European Union to create cutting edge integrated early warning systems specifically on tsunamis caused by earthquakes
iii. PreventionWeb is managed by the United Nations for collaborative knowledge sharing for disaster risk reduction.
iv. The Arid Lands Information Network (ALIN) aims to provide the information required by the target communities and build the capacities of the communities to access information through community-based “Maarifa” centers
v. The Open Knowledge Network (OKN) and openeNRICH used to provide spatial decision support technologies
vi. Google Person Finder Haiti and Chile were used for communication and coordination in regions affected by earthquakes and other natural disasters and emergencies.

f) Enhancing agricultural productivity for improved food security

As a result of the changing climate, agriculture and agro-pastoral industries suffer because old techniques and tools no longer support farming. Human actions and increasingly frequent and severe weather events have altered the ecosystem, necessitating new solutions and improved information delivery to farmers (Kadi et al., 2011; Food and Agriculture Organization, 2017). ICTs play a crucial role in this. The most widely used adaptation strategies for exchanging climate information are based on mobile technology since mobile services are used to send information to populations that do not use smartphones or have internet access. Overall, ICT can help in facilitating decision making at a farm level and through the cropping system using models such as World Food Studies (WOFOST), Agricultural Production Systems Simulator (APSIM), Crop Management Expert, an expert system (COMAX), Decision Support System for Agrotechnology Transfer (DSSAT) and Model of Agricultural Adaptation to Climatic Variation (MAACV) (Magawata, 2014; Sala, 2011). These technologies would enhance agricultural productivity and thus improve the food security and livelihoods of the people.

g) Using ICTs to respond to climate-related humanitarian action on refugee issues

Extreme weather events like cyclones, storm surges, and other calamities linked to a warming climate, as well as the long-term effects of sea-level rise and glacial melt, have displaced an increasing number of people. As a result, climate-related migrants and refugees have become a common phenomenon. Therefore, through ICT, especially mobile telephony and internet connectivity, refugees and humanitarian organizations can leverage these technologies as shown below:

i. **ICT for Education:** ICT has been applied to solve the unmet education needs within refugee settings (Lewis & Thacker, 2016). This is because ICT can provide educational information at a cheap cost nearly anywhere and provide a curriculum and records system that can follow children as they move from location to location, reaching those who are unable to attend school. It can also be used to link digital content to the national curricula of students' home country or their country of refuge (World Bank & UNHCR, 2021; Lewis & Thacker, 2016; United Nations Educational, Scientific and Cultural Organization, 2018)

ii. **Information exchange:** Through the internet, refugees can access pre-migration information and during the journeys appropriate routes to follow, and the information to facilitate re-settling in the destination country after arrival (McAuliffe et al., 2018). Internet and mobile banking have also facilitated financial remittances and allowed migrants to access their own or family financial resources. SMS (messaging), voice and video calls, and social media applications have made it possible for migrants to continue linkages with families and networks in their country of origin.

iii. **Border surveillance:** Continuous border scanning has been accomplished using cameras and radar surveillance equipment mounted on drones, blimps, helicopters, or satellites, as well as towers and other static platforms. Underground sensors can also be used to detect movement along borders. Further, unmanned mobile robots in the aerial, water surface, underwater, and ground vehicles, capable of functioning both as standalone and in swarms are also used in border surveillance (Latonero & Kift, 2018)

iv. **Management of migrants:** Blockchain technology has been utilized to generate legal digital identities for migrants (Morrow et al., n.d.). It is also used to enhance the financial inclusion of migrants and refugees and manage public expenditures on migrants. Blockchain also enables safe and private transmission of remittances

v. **Migration management:** ICT has been used to manage the migration of refugees in terms of registration, issuance of identification details, and security (Latonero & Kift, 2018). For instance: UNHCR's proGres Refugee Registration Platform is used to process asylum claims and to provide food and medical supplies to more than 300 refugee camps in 75 countries; the EU's Eurodac database stores fingerprints of asylum-seekers across all member states; Germany's Asyl Online project integrate all national databases containing migrant and refugee information; Foreign Workers Centralized Management System (FWCMS) has been developed to link migrant workers' 'compliance, security, health and welfare' across both origin and destination countries.

h) Reducing traffic congestion

Large cities have a lot of challenges caused by traffic congestion due to the increased number of vehicles on the road. According to BBC, an estimated 1.3 billion motor vehicles were on the world's roads in 2015 and this is expected to rise to over 2 billion by 2040 further worsening the congestion situation (Baker, 2018). This congestion contributes to air pollution, greenhouse gas emissions, increased energy use, and loss of valuable manpower, all of which negatively affect human and environmental health. The traffic in cities is expected to rise due to rapid rural-urban migration. Therefore, one of the most effective strategies to arrest the situation is to reduce the number of vehicles on the road (ITU, 2018). Consequently, the adoption of ICTs for smart mobility systems can help control traffic flows more efficiently. Also, the rising use of advanced technology such as internet telephony and video conferencing platforms such as Google Meet, Zoom, and Teams have created alternative options for enterprises and society to reduce commuting, reducing greenhouse gas emissions associated with motorized transportation. Smart cameras strategically mounted at crossroads can also automatically identify different road users, allowing the traffic management system to adapt according to their needs (BBC News, 2021)

i) Reducing energy usage and speeding up the adoption of renewable energy and smart grid technology

Sustainable generation and the use of available energy resources are significant ways of enhancing environmental sustainability. To save the environment, researchers are developing innovative technologies for energy generation, supply, and storage. These technologies include the generation of clean electricity from renewable resources like the sun, wind, and the tides; deployment of low-cost, efficient energy storage solutions like fuel cells, lithium-air batteries, hydrogen energy storage, and thermal energy collectors;

use of smart grids to assist in moving the generated electricity over distributed and energy network grids based on a flexible infrastructure and globally accepted standards for real-time monitoring of every consumer (Hossain et al., 2016). The grid also uses the internet of things, big data, and machine learning technologies to allow bi-directionally redirection of energy to wherever it is most needed, in real-time. The increased use of these technologies has cut down expenditure on energy and reduce dependence on nonrenewable energy such as fossil fuels like coal, petroleum, and natural gas.

j) E-Waste Reduction

According to ITU, the global generation of e-waste since 2014 has grown by 21% to 9.2 million metric tonnes (ITU, 2020). The fate of much of this waste is not known. However, through the Connect 2030 Agenda, ITU has set a 2023 target for e-waste recycling rate to 30%, the percentage of countries with e-waste legislation to increase to 50%, and reducing the volume of redundant e-waste by 50% (ITU, 2020). To realize this target, the adoption of advanced technologies such as the Internet of Things which integrates sensors to keep track of the life cycle of products and alert users when damaged or outdated models can be fixed or reconditioned are currently being used (Organization for Economic Co-operation and Development, 2020). Also, when a product is no longer useful or is thrown away, the sensors can notify the producers of the parts that can be repurposed and reused. This will contribute to saving the environment from toxic wastes such as mercury and the net effect on the economy.

k) Facilitating climate change and environmental observation

ICTs can improve countries' ability to collect climatic data (such as temperature, humidity, rainfall, and snowfall) and sea-level information. The information is critical in explaining the climatic and sea-level changes in the region. Data gathered through automated techniques can be coupled with historical records and traditional data collection methods, then machine learning algorithms can help predict climate change and issue early warning signs (Hsu et al., 2020). Using remote sensing techniques and sensor-based networks, scientists can keep updated on environmental changes, human activity, and natural processes over extended periods. This aids scientists and planners in developing models that simulate observable trends and monitor climate, weather, and water levels.

l) Facilitating Adaptive Learning

ICTs could improve public awareness, build capacity, and revolutionize the way enterprises provide goods and services to better prepare for the future. Climate change adaptation and mitigation courses, learning and sharing networks, and free materials are all readily available on the internet, enhancing people's ability to cope with the effects of the changing climate. ICT can also be utilized to model efficient items that operate better in severe weather conditions. Through the Global Virtual University Consortium in Education for Sustainable Development, in partnership with the United Nations University, online programs have been developed to facilitate access to educational and scientific resources on climate change. This will help in creating a critical mass of people with the expertise to protect the environment.

m) Making informed adaptation decisions

To support all adaptation efforts, effective stakeholder engagement and knowledge management are essential. The use of ICT is critical for climate change monitoring and adaptation decision-making. ICT tools can also be used to identify climate change-related requirements and priorities and to identify resources and capacities available to respond to climatic opportunities and dangers. Hazard mapping and monitoring, as well as risk reduction in formats that are simply understood by all levels of stakeholders, could inspire all citizens to work together on climate change responses.

ICT as a contributing factor to climate change: threats and opportunities

Even though ICT has been touted as a game-changer in tackling climate change and its variability, a few limitations still abound since ICT could also contribute to some extent to the ongoing climate change. However, through global initiatives, activism, and awareness, many of these limitations could be alleviated. Some of the ways that ICT can contribute to climate change include:

a) Redundancy and unsustainable technology use

The economic models of digital technologies typically incorporate characteristics of redundancy and unreliability. This is because user requirements are constantly changing, and consumer preferences drive quick technological improvements. As a result, to keep current, users routinely upgrade their technology whenever new models are available or new designs are offered. This is due to the emphasis on innovation to entice clients to buy the latest technology rather than developing technology that can be reused. This is especially true for mobile phones, where it is estimated that each one generates 55 kilograms of carbon emissions during manufacturing; hence, the more phones created, the higher the carbon emissions (Ercan, 2013; Zhang & Liu, 2015). This constraint is now being addressed by a return policy that allows customers to return outdated devices for repurposing, recycling, or refurbishment or to replace them with newer ones at subsidized rates.

Due to incompatibility challenges, the hardware-software development cycle regularly mandates system updates for end-users in some circumstances. As digital technology advances, it is getting increasingly difficult to execute older software on newer machines. New software (particularly operating systems) needs the usage of more recent hardware. As a result, there is a massive number of obsolete equipment. This problem can be solved by enabling forward and backward compatibility on hardware, allowing newer software to be installed.

Despite ongoing attempts to recycle digital technology, electronic waste (e-Waste) is a persistent concern, particularly in developing countries. Dumping e-waste, which contains large amounts of potentially hazardous products, has major environmental repercussions. This difficulty can be addressed by implementing the Connect 2030 Agenda, which is now being championed by the ITU (ITU, 2020). Institutions should also develop and implement waste management and disposal policies, rules, and laws. Furthermore, institutions should offer incentives for people who properly dispose of e-waste. Toxic minerals such as mercury should not be used to manufacture electronic equipment.

b) Technology is driving electricity demand

Electricity is required to power digital technology, and as society and industry become increasingly reliant on it for production, exchange, and consumption, its demand will rise. Because coal-fired power stations generate the vast majority of the world's electricity, this practice has a compounding effect on climate change (International Energy Agency, 2021). There will be little reduction in carbon emissions if gasoline and diesel vehicles are replaced with electric vehicles unless the power is generated from renewable sources, but shifting to renewable production will significantly impact the environment through the construction of wind turbines and solar farms. This limitation can be overcome by requiring environmental impact assessments before the construction of wind turbines and solar farms. Incentives such as tax breaks should be provided by governments to encourage investment in renewable energy systems(World Economic Forum, 2017).

This limitation can be overcome by adopting and utilizing renewable energies such as wind, solar, and biogas. Smart grids will help ensure that energy is routed to where it is needed, reducing waste. Integration of intelligence in the system can help with self-audits of application performance and putting to sleep less often used programs to eliminate background processes that consume more energy. New technologies are also being used to produce battery systems that can store power for a longer period. Energy-efficient solutions that use less energy are also being produced. All of these elements will ensure that energy is used efficiently in ICT manufacturing and related sectors.

c) Environmental exploitation of technology

Numerous rare minerals are currently being extracted at an environmentally damaging and morally questionable rate. This is because most digital technologies rely on rare elements, which are becoming increasingly scarce. Rare earth elements like cobalt, gallium, indium, and tungsten are in high demand, and as a result, their prices have skyrocketed (Williams, 2011). Companies must deal with mine waste leaks, open-cast mining operations, and mine tailings. There is also a lot of violence and conflict over who gets to exploit the minerals, and many mining procedures are hazardous to one's health. The plight of children exploited in the extraction of minerals essential for modern digital technologies is also frequently raised. This constraint can be overcome by employing modern technologies to extract minerals while causing minimal environmental damage. Governments and institutions should also develop sound regulations to manage mineral extraction and marketing.

d) Improvements in the construction of physical infrastructure

The massive number of additional cell towers and antennae required for 5G networks, as well as the structures that house server farms and data centers, have a significant environmental impact (Restart, 2021). In addition to the electrical demands for cooling, the sheer size of data farms has a significant physical impact on the environment. The average data center is approximately 100,000 square feet in size. Furthermore, scientists are concerned about the health implications of emerging 5G networks, particularly the higher frequency wavelengths employed in the 5G roll-out in densely populated urban areas (Siddik et al., 2021). This constraint can be overcome by encouraging the use of shared services provided by smart data centers that support the on-demand application deployment models such as the Internet of Things, cloud, platform-as-a-service, software-as-a-service, and infrastructure-as-a-service. This will lessen the need for each enterprise to build its data centers and cell towers.

e) Growth in the number of satellite systems

The environmental impact of rockets used to launch satellites into orbit had largely gone unnoticed until recently. However, it has been noticed that this is becoming exceedingly dangerous since any moderately large fragment of a disintegrating satellite has the potential to damage another satellite. According to the European Space Agency, there are currently 34,000 objects in orbit that are larger than ten centimeters, 900,000 objects that are smaller than ten centimeters but larger than one centimeter, and 128 million objects that are smaller than one centimeter but larger than one millimeter (European Space Agency, 2021). Organizations should decrease the quantity of mission-related debris (e.g., clamps, covers for lenses or sensors, de-spin devices, pyrotechnic release hardware, wraparound cables) released during spacecraft deployment and operations to reduce the debris threat in orbit. This can be accomplished by constructing autonomous spacecraft and rockets capable of deorbiting or accelerating orbital decay at the end of their functioning lifetimes, as well as orbiting their bodies into disposal orbits to reduce debris hazards in their initial orbit (National Academy of Science, 1995).

f) Digital challenges

Despite the potential use of ICT to overcome the alarming situation of climate change, its use in Kenya and other developing countries still faces many challenges, including lack of adequate ICT infrastructure, lack of capacity to use ICT, negative attitude toward technology adoption, poor government regulation policies, and difficulty in incorporating ICTs into adaptation and mitigation planning processes (Upadhyay & Bijalwan, 2015; Kimani, 2017). These challenges could be addressed by implementing a public-private partnership approach that allows the private sector to take the lead in enhancing the use of ICT in climate change adaptation and mitigation while the government provides the necessary legislative framework and support for the sector to thrive

Corporate commitments to net-zero emissions

Major ICT firms have more than doubled their resolve to decrease greenhouse gas emissions arising from their activities and decarbonize the entire global economy. The following sections provide an overview of some of the initiatives being performed by tech companies.

a) Safaricom has partnered with the Carbon Trust to take a strategic approach to achieve its commitments to becoming a net-zero company by 2050 through the use of clean and renewable energy, efficient use of energy efficiency, and carbon offset.

b) The Climate Pledge, launched in 2019 by Amazon and Global Optimism, aims toward net-zero carbon emissions by 2040. Companies, organizations, or people can sign on, committing to measuring and reporting greenhouse gas emissions regularly; implementing methods to eliminate carbon emissions; and neutralizing remaining emissions with verifiable carbon offsets(Consumer Technology Association, 2021).
c) AT&T has committed to becoming carbon neutral across its global operations by 2035 by implementing initiatives such as virtualization of many network functions, transitioning to a low-emissions fleet, accelerating energy efficiency and network optimization efforts, expanding sustainable feature film and television production, supporting renewable energy marketplace, and investing in carbon offsets (Consumer Technology Association, 2021).
d) Bosch company has already reached its aim of having all 400 of its global locations be carbon neutral by 2020. The company's goal is to cut emissions by 15% across its whole value chain by 2030, including purchases of goods and services, transportation logistics, and product use.
e) Dell has declared a moonshot goal for sustainability by 2030, which includes reusing or recycling an equivalent product for every product purchased by a customer, making all packaging from recycled or renewable material, and making more than half of product content from recycled or renewable material.
f) Facebook has committed to achieving net-zero greenhouse gas emissions for its value chain by 2030, in addition to retaining its promise of net-zero greenhouse gas emissions for global operators and running on 100 percent renewable energy. To that end, Facebook is evaluating materials with lower carbon footprints; designing products to be repairable and recyclable; extending the lifespan of hardware; ensuring responsible product disposal at the end of its lifecycle, and collaborating with key suppliers to help them set and meet their emission targets.
g) Google's ambition for the feature is a carbon-free one. Google declared in 2020 that it has erased its carbon footprint by acquiring carbon offsets. Its next environmental aim is to run Google's operations entirely on carbon-free energy, beginning with data centers and campuses. Outside of its operations, Google is working to achieve its carbon-free vision through a variety of initiatives, including enabling 5 GW of new carbon-free energy through investment by 2030; more than 500 cities reducing 1 gigatonne of carbon emissions annually by 2030; partners and organizations reducing their carbon usage and removing carbon from the atmosphere; and 1 billion people making more sustainable choices through tools and information by 2022 (Consumer Technology Association, 2021).
h) General Motors (GM) has started an ambitious program to become carbon neutral in its owned goods and operations by 2040 and sign the Science Based Targets initiative's Business Ambition Pledge for 1.50C. To achieve this target, GM intends to decarbonize its portfolio by transitioning to zero-emission cars, such as battery electric vehicles; sourcing renewable energy; and utilizing minimum carbon offsets or credits (Consumer Technology Association, 2021).
i) IBM has committed to achieving net-zero greenhouse gas emissions by 2030 across all of its facilities in more than 175 countries. IBM aims to minimize greenhouse gas emissions across its activities, use renewable energy for 90% of its energy usage, and eliminate carbon emissions equal to or greater than IBM's residual emissions from the environment (Consumer Technology Association, 2021).

j) Intel aims to improve the sustainability of its worldwide manufacturing methods while increasing manufacturing capacity. Intel has established a multi-pronged 2030 goal that includes net positive water consumption, 100 percent renewable energy, zero landfill trash, and significant absolute carbon emissions reductions (Consumer Technology Association, 2021).
k) Microsoft's goal is to be carbon negative by 2030 and to have removed from the environment all of the carbon the corporation has emitted since its inception by 2050 (Consumer Technology Association, 2021).
l) Adobe has committed to running its whole business on renewable electricity by the year 2035.
m) RE100, a global project that brings together organizations dedicated to using 100% renewable energy, includes Microsoft, Deutsch Telecom, and Lyft as members.
n) Firms such as Salesforce have joined the B Team's Net-Zero by2050 team. This is a group of CEOs and business executives who have agreed to produce a plan outlining how they would reduce their Scope 1, 2, and 3 emissions to minimize global warming to 1.5°C or less by the year 2050. Companies like Salesforce have committed to accelerating the transition to net-zero GHG emissions by 2050 by joining the Net-Zero by 2050 initiative.
o) A Terrafuse-Microsoft partnership has created advanced climate-related wildfire risk models built on Azure, Microsoft's cloud computing service. Wildfire danger may be predicted at the local level using historical fire data, current physical simulations, and live satellite observations.
p) Using Microsoft Azure's satellite imagery and machine learning, SilviaTerra is increasing the accuracy of its forest inventories while reducing the amount of manual labor required. Their data can assist conservationists and landowners in better managing and understanding forests, including how climate change affects them, how to improve species habitats, and how to encourage sustainable harvesting practices.

CONCLUSION AND RECOMMENDATION

Climate change has significantly impacted the attainment of global sustainability given its disruptive nature. It has resulted in the worst natural calamities triggered by extreme weather conditions, severely affecting people's lives and livelihoods. Consequently, productivity in climate-vulnerable sectors such as health, infrastructure, agriculture, and water availability has deteriorated. As a result, the people's livelihoods are jeopardized. However, the use of ICT combined with suitable laws and regulations has the potential to drive the fundamental transformation required in the global fight to combat climate change. It enables earth observation, information exchange for decision making, early warning/alerts, weather monitoring, change prediction, disaster management, and other critical indicators of climate mitigation and adaptation. Therefore, it is recommended that Kenya and the global community embrace and use ICT to mitigate and adapt to climate change to accelerate the achievement of sustainable development goals and other national economic blueprints.

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