Chapter

Green Computing: A Machinery for Sustainable Development in the Post-Covid Era

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Abstract

Socio-economic sustainability has emerged the common song of the policy makers globally. It has been projected as a developmental strategy by international and regional agencies. There has been several campaigns and programs all of which are intended to promote sustainability. In developing countries, the masses have been bamboozled with often unrealistic bogus policies hypocritically crafted in a bid to deceive the uninformed who are undoubtedly helpless in the midst of the conundrum. However, the 2019 reports of the IPCC and OECD respectively on global warming, sustainability and climate change is not a phenomenon that should be swept under the carpet by any sensible government. Though in many jurisdictions, campaigns and policies have long assumed political undertone, it must be stressed that it is time for talking the walk. Governments must put up implementable strategies that are all encompassing across the various sociopolitical classes and the different industry levels. According to the said reports, global warming and climate change pose severe challenges to sustainability and this is attributed to social, and economic root causes. The social sources are conflicts and poor socio-political governance structures whereas the economic sources are connected to *industry, electricity, residential, agriculture, and transport. It is reported that 60% of greenhouse emissions globally emanate from the economic source.* The worst hit is the sub-Saharan Africa where the dumping of electronic wastes and uncontrolled deployment of unregulated hardware for industry operations have remained a major environmental menace in the last decade. Having regard to the foregoing, this paper seeks to provide a systematic inquiry into the green computing policies and legislations in a major economic hub in the sub-Saharan Africa. The essence of this investigation is to critically review the present status of existing policies, strategies, and legislation vis-à-vis their strengths, lapses, and the contributory effect of these on driving the sustainability programs in the general developmental outlook of the sub region.

Keywords: green computing, environmental computing, computer wastes, climate change, sustainability

1. Introduction

Green computing (GC) has remained an important aspect of vital discussions involving environmental protection, green energy, climate change and sustainable development, though several equivalent terms such as Green ICT (GICT), ICT sustainability, and perhaps in a broader terminology, 'environmental computing', one thing remains glaring that is, the common goal which, according to the global body on GICT, the International Federation of Global and Green Information Communication Technology (IFGICT), is to practice and achieve eco-friendly deployment and use of ICT in the society. Ordinarily, the green computing ideology is aimed at reducing the perilous component load during computing equipment manufacturing. It is also concerned with energy-efficient and eco-friendly computing as well as processes for marshaling out machineries that enhance the biodegradability of computer-based wastes [1]. Green computing cover the spectrum of large-scale computing environment such as data centres, and mobile systems [2, 3]. It has been noted that green computing is a major leap in mitigating environmental pollution, degradation, and the impacts of climate change [1]. Adopting the tenets of green computing does entail producing and using energy-efficient computing devices, developing cutting edge strategies and research towards reducing energy consumption, and the appropriate disposal of electronic waste arising therefrom. Abugabah and Abubaker proposed a 5-phase lifecycle strategy for green computing [4]. According to the said proposal, green computing encompasses green design, green production, green procurement, green operations, and green disposal. Whereas the proposition is apt, it must be noted that these technical phases are not naturally continuous as in a process cycle but could occur independently. Consequently, each phase may present unique concerns that are influenced and shaped by social and economic forces (e.g. policies, legislations, lifestyles, culture, etc.) hence must be factored in for an effective greener ICT ecosystem. With the ever-growing global population, the demands for computing and ICT devices may experience sustained increase and the consequence is enormous pressure on the manufacturers to either release new technologies or increase the volume of production of current brands [5]. There is no gainsaying that technology advancement has its downsides or side effects which include generation of e-wastes, pollution, health and environmental degradation. In this chapter, three key factors that promote these side effects have been identified. They are: Unregulated and indiscriminate deployment of heavy ICT infrastructure; rapid technology evolution; and socioeconomic inequities in developing countries.

1.1 Unregulated deployment of energy-intensive ICT infrastructure

The unregulated deployment of heavy ICT infrastructure such as data centres and base stations for telecommunications, is a major contributor to environmental pollution and other environmental imbalances. Nwankwo and Ukhurebor noted that data centres have become indispensable in driving socioeconomic activities globally in recent times [6]. Data centres are not only run by technology service providers (TSPs) such as telecommunications and ICT service provisioning companies but are commonplace in the industry sector (cement factories, steel production factories, consumer goods production industries, automobile factories, finance and banking organizations, etc.) of every economy. These energy-intensive infrastructure are localized in many industrial zones in developing and developed countries. It has been noted that across all economic sectors including the public sector, modernization programs are not complete without ICT infrastructure [7–12]. Research has shown that data centres contribute significantly to greenhouse emissions, pollutions and eventually climate change [13–20]. In the post-COVID era, there is likely to be a surge in the deployment of data centres, mobile stations, and other sophisticated computing equipment as the pandemic is engendering an era wherein at least 80% of all economic activities are to run online. This has been christened the 'new normal' across different jurisdictions. With this predicted surge, Governments must put up implementable strategies and machineries that are all encompassing across the various sociopolitical classes and the different industry levels.

1.2 Rapid technology evolution and unfair competition

Rapid technology evolution and unfair competition globally, is a serious contributory factor to the menace of electronic dumping especially in Africa and other developing jurisdictions [21]. Over the years, Africa has emerged the targeted destination for sales of computing hardware from Europe, Asia, and America regardless of the product specifications in relation to standard, safety, and ecofriendliness [21, 22]. Atkin described this anomaly as an environmental injustice occasioned on the developing nations by the developed countries (Europe, United States, Japan, Korea, Australia, China, etc.) who intentionally transport tons of e-waste to vulnerable countries though with adequate knowledge that these poor countries do not have the resources to dispose these wastes [23].

Interestingly, despite Africa's economic prowess and abundant human and natural resources that would have promoted manufacturing or local assembly of computing equipment within the continent, it appears the continent is sabotaged by those countries with supposedly superior technical and technological endowments. This inequity suffered on a large scale by the continent across the global economic sphere, is one of the factors that occasioned the continued inflow of substandard and electronic wastes into the continent amid regional and national campaigns against electronic dumping.

As noted by [24] electronic dumping has remained one of the most worrisome environmental issue throughout the African continent. According to their study, second-hand and discarded electronic products from Europe, Asia and America is very predominant and has continued to create an uneasy atmosphere for the disposal machineries and strategies put in place by the various national governments. According to them the computer components that are popularly shipped to Africa are categorized into three: those that have reached end of life but bought by some Africans and other nationals that trade in second-grade goods; products phased out from mainstream distribution and support, by their manufacturers; and used products already discarded by their owners in foreign countries.

Several researchers have linked electronic dumping to advancement in technology and the increasing output in the production of computing and electronic devices in western countries and Asia [25, 26]. As more industries across different jurisdictions churn out new devices, the existing ones though had not reached their end-of-life may be discarded regardless of their utility values owing to the release and promotion of newly launched sophisticated models. A typical example is mobile phones and personal computers (PCs). These two devices are emerging part of everyday life in the socioeconomic ecosystem as technology rapidly becomes the vehicle for social and economic activities. The existing traditional and/or simple devices are being re-engineered using Artificial Intelligence (AI) and Internet of Things. Notice that these two pervasive technologies are rapidly evolving into full-fledged consumer-oriented technologies. The quest for intelligence in devices is exerting a tremendous effect on the development of new devices that would in no time replace the existing ones. In other words, the major concern would no longer be the end of life of the equipment per se but the utility value. Thus, where the utility of the device is found relatively lower vis-à-vis that of the emerging device, then it would be discarded in favor of the more sophisticated device thereby adding to the global e-waste burden. Currently, it has been observed that semiconductor devices and sensors are being added to products that were never before contemplated to have such components in them. For instance, the desire for wearable monitors, smart city, smart homes, smart agriculture, intelligent TV, etc. with embedded capabilities to exchange information with other devices, though laudable, also contributes immensely to the problem of electronic wastes.

It has also been observed that the newly produced devices often exhibit shorter life spans owing to the use of non-removable batteries. Typical examples are smart phones, tablets, consumer health monitoring devices, etc. A decade ago, almost every smart phone or tablet has a battery which could be easily replaced at will by the owner of the device once the battery's performance falls below a certain range. The trend is different nowadays. Currently, these devices come with non-removable batteries. The implication is that once the batteries malfunction or get exhausted, the devices themselves would be considered useless and would ultimately be discarded and new ones acquired.

1.3 Socioeconomic inequities in developing countries

The quest for survival is the major promoter of the growing informal recycling business in developing countries. It is reported that the supposed boom in informal and unregulated recycling of failed and discarded computing equipment is associated with the ongoing massive shipping and dumping of these systems in developing countries. According to [22] these computer wastes are intentionally shipped to developing countries especially in Africa with the aim of selling them to users who may put them to use or recycling to recover some valuable elements (gold, copper, etc.) which may be sold thereafter to meet economic demands [27]. It is reported that these businesses thrive in countries such as China, Nigeria, Ghana, India, the Philippines, Thailand, Vietnam, etc. [28–31]. The downside of such businesses is the adoption of traditional methods of recycling that often release toxic and hazardous substances into the environment [32, 33]. Again, the massive production of these devices is connected to the rate at which they become obsolete. It is reported that in 2016 alone, about 49 million tons of electronic wastes were generated and the said report predicts an increase to 57 million metric tons of e-wastes in 2021 [34]. Another report states that the global e-waste burden stood at 5.8 kg per person in 2014 which rose to 6.3 kg per individual globally in 2017 [35]. According to the global e-waste monitor, 53.6 million tons of e-waste was generated globally in 2019 [36]. This report agrees perfectly with the projection made by Cho in 2018 [34]. On average, 40 million tons of electronic waste are generated globally every year [37]. According to a report, the United States alone disposes over 47.5 million computer systems and hundred (100) million cell phones among other electronic wastes each year [23]. It is estimated that proper disposal of a ton of e-waste would cost 2500 USD in a developed country [23]. Developing countries rarely have these resources for e-waste disposal. Despite this, these countries allow imports of e-wastes at 3 USD per tonne.

These findings call for urgent measures especially as human existence is increasingly confronted with more health challenges such as the Covid-19 pandemic.

The trend in e-waste generation has emerged a serious health and sustainability issue globally [37, 38]. For over two decades, there has been a continuous engagements of several global and regional organizations including the various agencies of the United Nations, African Union, European Union, national agencies for environmental protection, and non-governmental agencies. These efforts have been directed towards developing strategic interventions that would enable humanity deal with the peculiar and lasting challenges occasioned by e-waste. Some of the notable engagements include:

a. The Libreville Declaration on Health and Environment in Africa: this was held in 2008. It was the premier Inter-Ministerial Conference (IMC) to consolidate the pledges and declarations on environment, health, and safety [38];

b. The Busan Pledge for Action on Children's Environmental Health [37, 39]. This was an offshoot from the third conference on Children's health and the Environment by the World Health Organization (WHO) held in 2009 at Busan, Korea

c. The UN Decade on Ecosystem Restoration which adopts a 9-point strategy to restore the degrading global natural ecosystem [40]

d. United Nations Framework convention on Climate Change [41]

Amid the calls from different quarters in respect of climate change and environmental protection especially as it affects e-waste management it appears the ongoing programs and initiatives have adopted a collective approach in the sense that electronic wastes is a term that is all encompassing. Accordingly, some distinctions are important as not all electronic wastes emanate from computing devices and not only computer devices contribute to pollution and environmental degradation. It therefore follows that a particularized approach which would x-ray all the vital areas of computing deployments and applications taking into consideration the entire computing device forms and lifecycle (production, acquisition, deployment, use, withdrawal, and destruction/recycling) and their contributions to sustainability domains such as environmental protection, safety, and health. The destruction/recycling phase is a critical point in the lifecycle of electronic products generally. It is also the most demanding phase. Direct destruction through burning and deposition into landfills create sustainability problems. The by-products of burning are pollutants and usually toxic to humans and in some cases plants. Though recycling e-waste is promising, however, with the present poor recycling facilities across Africa, weak policies and regulations, and lack of recycling programs [38], the continent is in dire need of green ICT reforms. The aim of this chapter is to showcase the relevance of green computing on fostering sustainability through the design and entrenchment of mechanisms and approaches including policies and legislations that would forestall the impending danger that might be occasioned on humanity by the continuous accumulation of computer-based wastes, and the deployment of energy-intensive computing facilities.

2. Implications of computer-based wastes and energy-intensive computing

2.1 Computer-based wastes

Ordinarily, computer-based wastes are often in the solid form as opposed to liquid and gaseous wastes from other sources (see **Figure 1**). Examples of such wastes include: Computers including PCs, high end server hardware, Telephones and smart phones, Network devices (routers, switches, gateways, radios, etc.), Chips, Base stations, Motherboards, Printers, Wireless devices, Fax and copiers, Cathode ray tubes and Monitors, and Transformers. However, due to the physicochemical complexity of the components that constitute these electronic products, the tendency to generate liquid and gas emissions are very high. Typically, materials used to produce computing hardware contain several reactive elements such as lead, silicon, silver, mercury, platinum, copper, cobalt, palladium, aluminum, cadmium, lithium, selenium, etc. According to a report by the environmental protection agency of the United States [23], while comparing the amount of certain elements contained in the e-wastes and that mined from raw ores indicated that it is estimated that the amount of gold in a ton of electronic circuit boards is 40–800 times more than that from the ore, and that the quantity of copper in one ton is 30–40 times more than the quantity of mined copper from a metric ton of raw ore. With these reactive elements in electronic dumps, the underlying health implications of these components are brought to bear.

Figure 1.
Computer-based e-wastes for sale in Ikeja Lagos Nigeria.

It is interesting to note that computer-based wastes like other e-wastes contain toxic heavy metals such as mercury, lead, cadmium, beryllium, plastic (polyvinyl chloride), and hazardous chemicals (e.g. brominated flame retardants) that are harmful to the health of individuals in particular and the environment generally. It has been observed that most of these wastes are shipped to developing countries for use and possible recycling [21, 42, 43]. These wastes produce gaseous emissions that pose health risks to the individuals within and around such e-wastes are dumped or recycled [42]. Having recognized the dangers associated with such wastes, countries such Nigeria has made necessary legislative provisions to guard against such hazardous or harmful wastes. Section 15 of the Harmful Wastes (Special Criminal Provisions etc.) Act, rightly provides that "harmful wastes depicts any injurious poisonous, toxic or noxious substance and, in particular, nuclear wastes emitting any radioactive substance … as to subject a person to the risk of death, fatal injury or incurable impairment of physical or mental health". The effect of this provision is that any waste whether or not electronic that could cause some harm is a harmful waste. There is no gainsaying that wastes from computing equipment could be hazardous enough to pollute the air, water, and soil. The contamination of these three environmental layers is akin to humankind intentionally creating a hazardous ecosystem antithetical to sustainable development and growth. These hazardous e-wastes could route toxic chemicals through the soil, air, water thereby providing the channel for generalized environmental degradation and pollution that promotes health anomalies and imbalances such as infections, respiratory stress, allergic reactions, visual impairment, poisoning, hematological problems, etc. (See **Table 1**). It has been reported that these wastes have strong nexus with adverse birth outcomes, thyroid dysfunction, behavioral changes, lung failure, and adverse cellular changes [30], Kidney failure, cancer, etc. **Table 1** shows some toxic metals and compounds from computer wastes and their health implications.

2.2 Energy-intensive computing (EC)

EC involves the deployment and utilization of energy-intensive computing equipment especially to drive socioeconomic activities. Data centres globally fall within the ranks of energy-intensive computing. They are not only common in developed countries but are also at the cornerstone of industry in developing countries. The intensive use of data centres and high capacity computing hardware are popular from the telecommunications subsector to banking and finance, manufacturing and production, agricultural and food processing, mining and extraction, and educational institutions. EC infrastructure popular in mission critical applications such as in manufacturing, production, mining, telecommunications, and the financial services subsectors. EC is a creator of both computer wastes and pollution. Despite

Metal/ Compound	State	Where used in computing hardware	Health implications	Route
Cadmium [44–46]	Solid. Its pyrolysis generates toxic fumes	Resistors, Nickel-cadmium batteries, Screens, lasers	Kidney, lung, bone damage, muscle pain, chills, fever, nausea, vomiting, decreased memory and cognition abilities, impaired neuro-motor skills	Inhalation, Ingestion
Lead [30, 37]	Solid. Lead oxide is formed when burnt/heated	CRT monitors, printed boards, polyvinyl chloride formulations	The mucous membranes within the lungs, skin, abdomen, easily absorb lead into the blood which may predispose the individual to lead poisoning, high blood pressure, liver and kidney damage, reduced nervous development and permanent nervous damage in children	Inhalation, ingestion
Mercury	Liquid/ Gaseous	Fluorescent tubes and flat screen monitors.	Whether alone or in methylated forms, this substance is harmful to the digestive, nervous and immune systems respectively. The lungs, kidneys and other internal organs are affected. Mercury salts are corrosive to the eyes, skin and the gastrointestinal tract	Inhalation Ingestion
Beryllium oxide	Solid/Liquid	Thermal grease for heat-sinks; Processor, power transistors, vacuum tubes.	Causes irritation skin, throat, nose, and lungs.	Inhalation Contact
Barium	Solid/Liquid	CRT monitors	Poisoning	Inhalation Ingestion, contact
Zinc [30]	Solid	CRTs, Metal coatings	Poisoning, vomiting, nausea, diarrhea, cramps	Inhalation, ingestion

Table 1.
Some health implications of computer/ICT wastes.

the economic importance of EC infrastructure in driving industrialization, they are noted as potential causes of greenhouse emissions (GHG), pollution, and agents of climate change [15–19]. The gases contribute to warmer climate can affect the ecosystems locally and globally [47]. For instance, extreme weather affects agricultural crop production and yield, livestock production, desertification, health challenges including epidemics, ocean acidification, heavy precipitation, flooding, food supply and security challenges, new diseases, and energy supply problems [27, 48, 49].

3. Challenges confronting green computing

Green computing is confronted with many challenges. These are categorized into: Manufacturer-induced bottlenecks, Economic challenges, Policy, Consumer attitude, and Social exploitation.

3.1 Manufacturer-induced bottlenecks

The manufacturer-induced bottlenecks are a major barrier to the adoption, implementation and enforcement of green computing practices and policies. The equipment manufacturer is a major player in the distribution and supply business chain. In the local parlance, the equipment manufacturer is tainted as having 'the fork and the knife' in the sense that the equipment manufacturer is technically the addition to influencing the life span of computing equipment, the manufacturers are in principle aware of how long a device would be supported or maintained. Generally, these manufacturers play a major role in determining when a device becomes obsolete. These they may do by intentionally modifying the design, embedded software, or even withdrawing their support for specific models of the device. They often project the benefits of the newly produced variant of the device in terms of cost and functionalities while at the same time hyping the costs of maintenance of the older models. Experience has shown that many of such claims do not reflect the reality rather the manufacturer's desire to maximize profits at the expense of the consumer and the environment. Another area of concern is the use of materials that are not ecofriendly in the synthesis and production of electronic goods. If green manufacturing is strictly adhered to, green computing challenges would be significantly reduced [50–53]. In the same vein, the power consumption requirements by devices may depend on the manufacturer's specifications and readiness to use ecofriendly and sustainable materials [52]. It therefore follows that manufacturers can drastically reduce power demands by carefully selecting and using materials that require less energy to operate. However, [52] note that manufacturers face challenges of incurring high cost and low returns in their bid to switch to greener technologies, green production and manufacturing processes, compared to the traditional methods. Their study also revealed that these companies encounter difficulties in generating the required energy by greener and/or renewable methods.

3.2 Economic challenges

Inequities in the distribution of resources is a major factor in the battle against electronic dumping and green technologies. As has been adumbrated by researchers, developing countries are grossly disadvantaged in the management of e-wastes. This may be connected to the poor economies, political will and leadership failure [54]. The developed countries often exploit these gaps while dealing with the developing nations. Due to indebtedness to the developed nations, many developing nations lack the willpower to reject such exploitation. As survival is the ultimate desire of every individual, small and medium scale businesses involving in buying and selling of second-grade electronic products is common. It is also not uncommon to see large businesses who are involved in the importation of these second-hand computing equipment and by extension e-waste. For instance, Alaba market located in the Ojo area of Lagos Nigeria is popularly known in the sub-Saharan Africa for its exploits in deals involving second-hand computing equipment from Europe and America. The same is true for the popular computer village in Lagos and Agbogbloshie in Accra Ghana [55]. In Lagos, these small and medium Majority of these thousands of businesses involving the importation of and trade in fairly used computing products reflect the inequities occasioned on the masses by the leadership and economic maladies. It is important to stress that despite the ban on the importation of some of those goods in developing countries such as Nigeria, such goods are either smuggled or concealed in other cargoes during shipping and inspection of those cargoes at the destination port is often fraught with a lot of irregularities including corruption currently owing to human intervention which has remained a major problem in the inspection and clearance processes at the ports [56–58]. With the rising spate of unemployment and no remedy in sight, it is believed that trade in contraband goods would always thrive despite the policies and regulations in place. There, the inflow of e-waste is very much likely going to abate in continental Africa till the various governments implement functional policies and machineries to reduce economic hardship and unemployment.

3.3 Policy challenges

Like developing countries, majority of developing countries have policies, legislation, guidelines, etc. associated with environmental protection [6]. Often, the problem in developing countries may not be the legislation or policy per se but the machinery to realize the provisions contained by the policy. Where these machineries are not properly harnessed gaps would continue to widen [6]. Several pitfalls connected to the operations of these machineries have been noted ranging from poor and crude infrastructure, incoherent initiatives of government operatives, poor maintenance culture, corruption, nepotism, social stratification with the emergence of the 'untouchables' that include individuals and organizations which are covertly above the law, poor enforcement, to negligence and abdication of responsibilities on the part of the personnel manning the public agencies. Two major problems confronting majority of policies including legislations and guidelines for driving GC ideals are noncompliance and weak enforcement [6, 59, 60]. Noncompliance and weak enforcement had linked to sociopolitical and economic problems [47, 61, 62].

3.4 Consumer attitude

Consumer attitude is a major factor in the supply and demand chain. In developing countries, the demand trend especially for electronic products such as smartphones and other mobile computing devices does not often reflect the true status of the economies. Consumers regardless of their social statuses often desire to have sophisticated devices. It is common to see a student in a secondary school with two or more smart phones. In recent times ownership of such devices has become a denominator for social class differentiation and imposition among people. Consequently the drive to upgrade to latest technologies is a common behavioral disposition among the young and the old. There is need for a public re-orientation if this problem is to be nipped in the bud otherwise it would continue to promote energy overload and environmental menace as more devices are discarded on a daily basis.

3.5 Social exploitation

Social exploitation involves taking advantage of the lapses in the policies, rules, guidelines, and legislations as well as customer's ignorance and demand, by manufacturers and importers of computing devices. For instance, in societies where there are no clear laws applicable to enforcement of green computing ideals, importers and manufacturers are bound to exploit this gaps in shipping all manner of products without recourse to anything.

4. Solutions to green computing challenges

Going forward, the following points are stated as steps towards resolving the challenges confronting green computing globally.

a. International and National Policies on Green Computing including trans-border movement restrictions and enforcement which would necessitate mutual understanding between countries within a region. Adoption of regional taskforces to police the movement of computer-based products regardless of their condition. Review of trans-border customs guidelines and entrenchment of stricter inspection at border posts, airports, and sea ports. Initiating a global ban on the export and import of second-hand computing devices would be an ultimate global policy to control the menace of electronic waste movements generally.

b. Strict regulation on manufacturers: Computing device manufacturers are the biggest player in the fight against dumping. Policies on the use of eco-friendly and biodegradable materials in the manufacturing process cannot be overemphasized.

c. Creation of vibrant machinery for consumer awareness programs, consumer protection and enforcement of consumer rights including the right to repair, disassemble and replace parts of malfunctioned equipment. This would relieve the manufacturers the pressure of providing support for its equipment over a long period.

d. Establishment of global grants for the development of electronic recycling industry subsector. E-waste disposal is somewhat a difficult enterprise. Recycling is plausible means of generating economically viable products from the wastes, reducing environmental pollution and promoting healthy environment. However, in the last decade, informal recycling is predominant in developing countries.

e. Continued advocacy for the adoption of green production and manufacturing practices i.e. the use of environmentally friendly and sustainable materials

f. Design and Standards advocacy: Green computing should be developed as a standalone international standard and maintained by the international organization for standardization (ISO) just like other plethora of standards it defines and sustains. Once internationalized, governments can domesticate and adopt them into their mainstream economic policies, guidelines, and regulations.

g. Promotion of circular economy [63, 64]. A circular economy has the potentials of mitigating against the challenges posed by dumping and poor manufacturing practices. Entrenching a circular economy implies that there would be no waste in the lifecycle of the computing equipment. In other words, appropriate machineries and policies are put in place to ensure compliance across board. Every product produced by a manufacturer would be recyclable once it reaches its end of life or ungracefully discarded. The producers and other recycling facilities are readily accessible to consumers. Thus collection, dismantling, refurbishing, re-use, and recycling of e-waste are formally implemented in the producer-consumer experience cycle.

h. Adoption of technology-driven architecture that would employ a resource planning system to support collective and collaborative management of risks associated with computer wastes and the adoption of multi-platform waste management systems including bioremediation, biomining, etc. [65, 66]. The proposed architecture would extend any existing practices through the deployment of intelligent computerized approaches that includes risk and hazard profiling of various industry subsectors, industry operators, location of operation, environmental impact etc.

5. SD and GC in the post-covid era

SD is connected to GC and greener ICT. The post-covid period is an era of uncertainties especially in public health and safety ecosystem [67, 68]. This calls for a review of and the strengthening of the existing measures, policies, legislations, guidelines and controls on SD. As noted by [68], in the post-covid era, environmental degradation and climate change have higher tendency of causing more terrifying ecological catastrophes. According to [69] social inclusion, environmental sustainability and economic growth are the major objectives of SD. GC is a major driver of SD because its ideals, practices, and principles focus on a cleaner, safer, and sustainable environment that promote the total wellbeing of all members in the natural ecosystem. **Table 2** summarizes the relationship between green computing and SD. The 17 SD goals are presented I sequence with the projected contribution of green computing practices stated against each goal.

S/N	SD goal	Contributions of GC practices
1	No poverty	GC would ensure cleaner environment in the workplace which would guarantee the productivity, health, and safety of the average worker.
2	Zero hunger	GC would reduce soil pollution and contamination thereby promoting better crop yields and food security
3	Good health and Well-being	Green houses gases from computing devices and e-waste threaten the health and wellbeing of humans. If such threats are eliminated, there would be improvement in the social wellbeing of the people.
4	Quality education	Learning, research, and teaching are all affected positively by a clean and safe environment. Education under such circumstances produces knowledgeable experts who would contribute to national and global development
5	Gender equality	GC would eliminate water, air and soil contamination as well as good health. With cleaner environment and water women and girls would be relieved of the roles they play in homes such as searching for water and cleaning of the environment
6	Clean water and sanitation	Proper disposal of e-wastes and control of carbon load from large computing environments would prevent leaches that pollute underground water
7	Affordable and clean energy	GC advocates renewable and clean energy for computing equipment and allied devices
8	Decent work and economic growth	Safer and cleaner work environment motivate workers and this would boost productivity and by extension economic growth.
9	Industry, innovation and infrastructure	GC is an innovative ideology that promotes pollution-free industrial environment and harmony. It advocates for the development of sustainable devices and infrastructure
10	Reducing inequality	Pollution governance and actions can ensure that no group or community bears a disproportionate share of the harmful effects of pollution.
11	Sustainable cities and communities	Safe, clean and non-toxic environment promote sustainable production and economic activities in local and urban areas
12	Responsible consumption and production	GC drives sustainable consumption and manufacturing activities by encouraging the adoption of greener manufacturing and production processes by manufacturers which would reduce the incessant demand of newer devices by consumers owing to the fall in the utility value of existing devices
13	Climate action	GC promotes use of renewable energy devoid of high carbon loads; and the clean disposal of computer-based wastes which could pollute the environment thereby adding to the climate change burden
14	Life below water	Toxic wastes from electronic dumps contaminate underground waters leading to the death of essential aquatic organisms. GC advocates for proper e-waste disposal

S/N	SD goal	Contributions of GC practices
15	Life on land	One of the main goals of GC is safe, healthy and clean environment at all times
16	Peace, justice and strong institutions	Enforcement of GC policies and regulations without prejudice would promote peace and safety across all socioeconomic spheres thereby attracting confidence and trust for public institutions
17	Partnerships for the goals	GC ideal and policies should operate at national, regional and international levels. Such collaborations would engender unity of purpose and maximum impact as to the control of electronic dumping as well as the enforcement of greener production practices. The result would affect all spheres of the ecosystem

Table 2.
How GC practices promotes SD goals.

6. Conclusions

This chapter examines the green computing domain and articulates the implications of advances in the development and deployment of computing and ICT infrastructure globally laying emphasis on the growing spate of electronic dumping in the sub-Saharan Africa where countries like Nigeria and Ghana are greatly affected. It identifies some of the health and environmental problems which GC is intended to eliminate or reduce. Though it makes case for the adoption of the green computing ideals to ensure the realization of SDGs [69] in the post-covid era, however, it contemplates various barriers and challenges to the adoption of green computing ideals and proffers various feasible solutions that could help eliminate these challenges. In conclusion, it is established that GC is a viable machinery for sustainable development through a one-to-one mapping of SD goals to the goals of green computing.

Conflict of interest

There is no conflict of interest in this work.

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