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Article

Influence of E-Waste Management in Green-Computing

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Abstract: Over the past two decades, extensive use of electronic devices and rapid urbanization have produced significant electronic waste that pollutes soil, water, and the environment. As a result, environmental activists and scientists around the world now prioritize pollution control and environmental safety above all. One of the by-products of urbanization, electronic waste disposal, has emerged as a foremost social issue. According to the Global E-Waste Monitor 2020, consumers worldwide disposed of 53.6 million tonnes worth of electronics in 2019, an increase of 20% over the previous five years. The gradual deposition of these electronic wastes results in the accumulation of different toxic and heavy metals like lead (Pb) and cadmium (Cd), among others, because these wastes are not biodegradable and contaminate groundwater and soil. In turn, groundwater contamination has an impact on animals, plants, and the entire living system, posing serious health risks and problems. As a result, proper disposal of these electronic wastes has emerged as an urgent need. The process of designing, manufacturing, utilizing, and managing products in an environmentally responsible manner is referred to as "green computing. "E-waste has arisen as a growing environmental issue. The environment and ecology face a problem that cannot be avoided: the use of e-waste. This paper aims to describe e-waste management to implement green computing. The reader of this paper is provided with information about e-waste management and green computing, as well as their potential interactions during the activation process. As a result, e-waste management is working as a green computing strategy.

Keywords: urbanization; e-waste; green computing; contamination; management

1. Introduction

In the 18th century, advancements in science and technology led to the industrial revolution, which marked the beginning of a new era in human civilization. The information and communication revolution of the 20th century has significantly impacted how we organize our lives, economies, industries, and institutions [1]. The colossal mechanical improvement in the 21st century enjoys many benefits. However, the development of new technologies necessitates a lot of energy and generates hazardous emissions and electronic waste. The exponential growth of technology contributes to increased climate change and global warming. The world is paying more attention to eco-friendly computing and e-waste management. Green communication and networking, green design and implementation, and green services and applications are currently the most exciting areas [2]. Green computing is the best way to use information technology to control an organization's progress toward sustainability. Green computing has the potential to be a well-balanced and long-term strategy for creating a safer, healthier, and greener environment without jeopardizing the technological requirements of the present and future generations. Green computing's primary objective is to achieve maximum energy

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efficiency over the product's lifetime. A brief discussion based on eco-friendly computing and e-waste management is presented in this section, and a discussion of related research in the field of putting green computing into practice follows this. Electronics that have reached the end of their "useful life" are referred to as "electric waste" or "e-waste." One of the waste streams that is growing the fastest around the world is e-waste. On average, it accounts for 1% of all solid waste in developed nations. E-waste is one of the fastest-growing waste streams due to its growing "market penetration" in developing nations, "replacement market" in developed nations, and "high obsolescence rate" [3] (Figure 1). We must ensure that the environment and natural resources are preserved for the benefit of future generations. Natural resources are conserved and hazardous disposal-related air and water pollution are avoided by recycling electronics' raw materials (United Nations Climate Change, 2020). Recycling computer equipment can diverge hazardous materials like lead and mercury from landfills. There are many ways to reuse. It could inventory dated equipment. Environmental sustainability entails monitoring the physical world, controlling the direct and indirect effects of large-scale human activities like agriculture, transportation, and manufacturing, and educating individuals about their consumption and behavior choices [4]. The management of e-waste is in a very bad state right now. The world will become greener and more eco-friendly if we all contribute to the management of electronic waste.

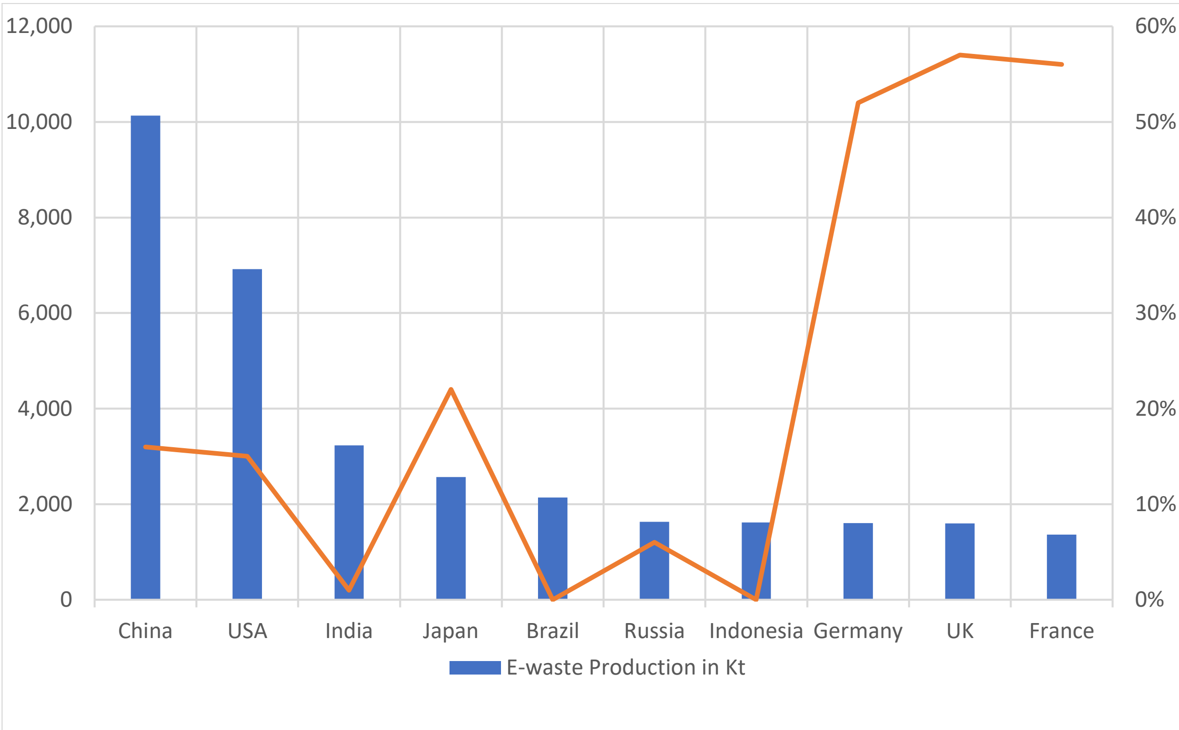

Figure 1. E-waste generation per capita in developed and developing countries.

The study explains in detail how green computing can benefit from e-waste management, the steps involved, and how effective it will be to work on e-waste management as a green computing strategy. The foundation studies and a few existing deals with green registering are introduced in the forthcoming segments. The paper concludes with a description of the best E-Waste Management solutions for implementing green computing, a review analysis, and the scope of future research.

2. Problems

Electronic waste is a problem for both manufacturers and consumers. More e-waste is produced as improved models based on new technology hit the market [5]. Additionally, manufacturers fail to take responsibility for their products after they are sold, making disposal a hassle for customers. The current state of management of this electronic waste is extremely poor whereas the majority is recycled; the remainder ends up in garbage dumps. Electronic waste, which contaminates groundwater, accounts for 70% of the heavy metals found in landfills, according to a report [6]. If these wastes are burned rather than buried or dumped, they cause air pollution and unhealthy emissions.

Even though computer design has progressed well and surprisingly quickly in terms of performance, the work is still in its infancy, from a green perspective. Lead, cadmium, mercury, and other toxic substances are commonly used in computer manufacturing [7]. Green experts claim that a computer alone contains 4 to 8 pounds of lead and contributes two-fifths of all lead in landfills, along with other electronic devices. Computers pose a significant threat to society not only in terms of the generation of hazardous waste but also in terms of power consumption and heat generation [8]. “Data centers servers use 50 times the energy per square foot as an office”, claims PG&E’s principal program manager, Mark Bramfitt. Energy consumption is mostly caused by data centers, and many businesses spend more on energy than they do on hardware like servers. Energy costs, which currently account for approximately 10% of the average IT budget, are anticipated to rise to 50% in the recent year. Faster processors consume more power and produce waste heat, which raises the temperature and contributes to reliability issues like disk crashes and device failures, among other things [9]. Air conditioners are used to solve these problems, but they also use a lot of electricity and give off a lot of heat to the outside world, creating a vicious cycle of waste heat and high-power consumption. Additionally, the release of chlorofluorocarbon (CFC), which has the potential to deplete the ozone layer, poses the greatest threat to the environment from an air conditioner. There is a need to look for an eco-friendly computer to counter all these growing threats to the pollution that are occurring all over the world as a result of the increasing use of electronic devices in general and computers.

3. Current Scenario of E-Waste Generation

The infrastructure and facilities required to maintain technology grew alongside the technology’s ever-increasing development. The amount of information, as well as the infrastructure and equipment needed to generate, process, store, and use it, is rapidly increasing The efficient use of computing resources is frequently used to describe green computing. It is the movement’s name, and it stands for a more environmentally friendly method of computing that uses less power [3].

Green computing is a responsible approach to addressing global warming. Green computing can help people save money on energy and paper while also making a positive contribution to environmental sustainability. The U.S. Environment Protection Agency introduced the Energy Star Program in the 1990s, which gave rise to the concept of “green computing”. In 1992, the agency introduced the Energy Star rating for monitors and other electronic devices [10,11].

Green registering incorporates key regions represented in Figure 2 and made sense of as follows [10,12,13]:

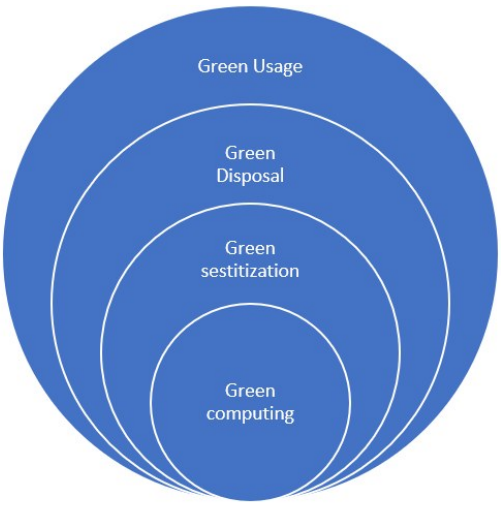

Figure 2. Key regions of Green computing.

E-Waste Management

Waste is any material that is thrown away. It is an important raw material that has been misplaced. Many of the wastes that are currently being used in a wasteful way or not used at all pose significant threats to the human environment [3]. Electronic products that are near the end of their “useful life” are referred to as “e-waste.”

Computers, televisions, VCRs, stereos, copiers, and fax machines are examples of electronic waste [14]. The following are some of the reasons why e-waste is a problem:

- There is an ever-increasing amount of electronic waste.
- Electronic waste has an impact on the environment.
- Tons of electronic waste are shipped overseas.
- Electronic waste and data security.

There are approximately 40 million tons of PCs, CRT screens, fax machines, game consoles, mobile phones, and other electronic waste are produced annually (Jan, 2008). Worldwide, there were approximately 72 billion tons of e-waste in 2017. The United States is the world’s largest producer of electronic waste [15]. Although many nations recycle their e-waste today, many of them do it illegally [16] as a result of human egotism and a lack of proper information on the recycling of e-waste. The situation will improve if green policies are implemented, rules and regulations are adhered to, and all parties are committed to promoting sustainability [17].

There are four phases to the e-waste life cycle [18-21]:

- Phase I: EEE production (Electrical and Electronic Equipment)
- Phase II: UEEE generation (Used Electrical and Electrical Equipment)
- Phase III: The Final Choice
- Phase IV: E-Waste Processing

The most common materials in electrical and electronic equipment are iron and steel, followed by plastic, which is the second most common component. E-waste can be used as a coarse, fine, or fine filler in concrete, depending on its chemical composition [22].

The following is a description of how the designers intend to make future computers more environmentally friendly throughout their entire lifespan, from production to recycling:

► Energy-concentrated assembling of PC parts can be limited by making the assembling system more energy productive.

► By substituting bioplastics- plant-based polymers- for petroleum-filled plastic, which requires less oil and energy to produce than conventional plastics. However, it is difficult to keep these computers cool enough to prevent electronics from melting.

► Making optimal use of the device and upgrading and repairing it on time can control landfills.

► Implementing improvement and repair procedures.

► Easier, cheaper, and less likely to be thrown away will not only keep e-waste from ending up in landfills, but it will also save energy and materials that are needed to design and manufacture a brand-new computer.

► OLED (organic light-emitting diodes, etc.), green light displays often take the place of high-power display devices.

Recycling is costly and time-consuming because toxic materials like lead can be replaced with silver and copper. Recycling computer components separately with the option to reuse or recycle simplifies the process. E-waste is not waste or pollution; rather, it is a vital resource that we are only just beginning to fully value [23]. In recent times, green computing has grown in importance. In this field, several works have been done with different methods.

S. Mmeah conducted a literature review of the current literature on green computing and how it affects sustainable IT services to identify a core set of principles that should guide the design of sustainable IT services and leverage points that can increase customer, business, and societal value . S. Murugesan demonstrated how innovative IT solutions to escalating environmental issues and greener IT system usage can be [24] . He offered a comprehensive strategy for greening IT and emphasized how IT could assist businesses in environmental initiatives and carbon emissions reduction. Anthony B. Jr. verified the green computing life cycle strategies by collecting data from 133 respondents from industries that currently operate in-house data centers. He also talked about the green computing life cycle strategies that can be used to make IT-based industries' data centers green. Using the SPSS tool and the Wilcoxon Test, K. Suryawanshia discovered the most significant obstacle to the successful implementation of Green ICT. It helps policymakers create green policies and strategies based on obstacles. Ten obstacles were outlined in the paper, which combined sustainable development and green ICT [25]. S. Agarwal presented a systematic study on climate change issues that explained green computing from the business and IT perspective by looking for and teaching ICT users the best green computing practices. M. Salam examined a list of 20 success factors through the SLR process as well as a list of critical success factors (CSFs) for vendors in the development of green and sustainable software. He suggested that vendors might develop eco-friendly and long-lasting software as a result of the identified CSFs [26].

S. Agarwal presented all the references based on Desktop Virtualization that are related to host-based forms of desktop virtualization in which the client does not require any processor, memory, or storage facilities. These forms of desktop virtualization are the most common type. The proposed solution can be used in both LAN and WAN environments, where speed and bandwidth became critical considerations. A survey of several significant works in the field of green computing emphasized the significance of green computing for sustainable development [27–31] .

4. Discussion

The use of electronics and computational resources has increased exponentially in this era of information and communication technology. Numerous adversaries, including high energy consumption, global warming, the accumulation of electronic waste, environmental pollution, and others, have emerged as a result of excessive electronic device use [32]. Government agencies and private businesses around the world have begun looking into ways to protect the environment considering the severe realities of global warming and rising energy costs. There is a growing global movement to implement computing that is better for the environment to address these issues [33].

4.1. Green Computing

Green computing can be described as the effective utilization of computing resources. It stands for a way of computing that is better for the environment by using less power. It also helps to minimize the harmful effects of computing resources on the environment and is linked to their efficient use. Green computing is associated with two major issues: reduction in energy use and control of pollution [33]. The latter can be achieved through their reduced use, appropriate recycling policies, and the use of less toxic substances in equipment manufacturing, while the former can be accomplished through the development of hardware that is energy efficient and uses less power. Green computing also includes ensuring sustainability and maximizing economic viability [34, 35]. In this paper, we are concentrating on waste management and recycling issues among the aspects of green computing.

4.2. Management of E-Waste

Waste is any material that is discarded [35,36]. It is a valuable raw material that is incorrectly located. There is a lot of waste that is currently being used in an improvident way or not used at all, which puts the environment and people in danger. Using the right processing technology, it can be made into something useful [37]. There are many kinds of these wastes, and they can be classified as hazardous or non-hazardous. Municipal waste, electronic waste, biomedical waste, and industrial waste are all subcategories of these [38]. To establish a connection between hazardous wastes and health, numerous studies have been conducted worldwide. Polychlorinated biphenyls, cyanides, and mercury are examples of highly toxic chemicals that, if left untreated, can cause illness or death. Residents who were exposed to hazardous waste were found in some studies to have a higher prevalence of cancer.

E-WASTE is one of the world's fastest-growing waste streams. On average, it accounts for 1% of all solid waste in developed nations. E-waste is one of the fastest growing waste streams due to its rising "high obsolescence rate," "replacement market," and "market penetration" in developing nations [39,40]. It includes mobile phones, computers, plasma printing-scanning devices, Liquid Crystal Display (LCD) devices, and a wide range of household, medical, and industrial equipment that is simply discarded as new technologies become available. These wastes are disposed of in huge quantities each year, and the presence of toxic and carcinogenic compounds in them poses a significant environmental threat. Lead and cadmium can be found in computer circuit boards, lead oxide, and cadmium can be found in cathode ray tube monitors, mercury can be found in switches and flat-screen monitors, cadmium can be found in computers, and polychlorinated biphenyls can be found in old capacitors, transformers, and batteries [41–44]. Indians currently own approximately 14 million personal computers, 16 million mobile phones, and 80 million televisions [45]. Therefore, e-waste management must be addressed urgently, particularly in developing nations like ours. Electronic waste attracts informal and unorganized sectors due to the presence of valuable recyclable components, but their hazardous and environmentally hazardous practices pose significant threats to health and the environment [46,47].

The production of these devices and the use of rare materials represent a significant embodied energy source. Reducing electronic waste helps us save resources and use less energy from the earth. By recycling just, the precious metals and plastics found in old cell phones, as opposed to mining for more of them, we could save as much energy as it would cost to turn off the power to 24,000 homes in the United States for an entire year [48–52].

- Re-evaluate: Try to find a device that does a lot of different things.
- Make sure your electronics last longer: Buy a case, keep the device clean, and don't charge it too much.
- Buy electronics that are good for the environment: Search for items marked Energy Star or confirmed by the Electronic Item Natural Appraisal Device (EPEAT).
- Donate used electronics to social programs that help victims of domestic violence, initiatives that ensure the safety of children, environmental projects, and other causes.
- Reuse huge hardware: Add your items to Harvard's Reuse List Electronics and batteries can be recycled in e-waste recycling bins all over campus. Larger bins can be found in the buildings for large electronics. In the field of e-waste management, several studies have presented various technologies and approaches, demonstrating that, properly managed, electrical waste can contribute to green computing.

Below some analysis that shows several methods or technologies used in existing work is mentioned.

► Designing energy-efficient computing devices, reducing the use of hazardous materials, and encouraging the recycling of digital devices and paper [53]

► Quality Function Organization (QFD), a scientific device is proposed to find various boundaries from essential examination information that influence the e-squander reusing practice as a green figuring approach [54]

► Using less hazardous materials, using less energy, and getting the most out of the product over its lifetime [54]

► Standard remediation methods like disassembly and destruction of the equipment, mechanical separation, pyro-hydro- and bio-metallurgical processes, pyrometallurgical processes, and poor operations [54].

► A time-series multiple lifespan end-of-life model [55].

► Implement ERP systems that standardize the market for electronic product recycling [56]

► Recycle e-waste aggregate in concrete to increase its potential use and reduce its impact on the environment [57]

► The suggestion of recycling, keeping, and upgrading electronic waste. Creation of such an electronic device that can be powered by a low amount of power from sources other than conventional energy [57].

► Use of GIS to identify the primary source of electronic waste [58]
► Proposing an electric device-based monitoring system for e-waste dump yards [59].
► E-waste can be broken down using species like Aspergillus Glaucus and gram-negative bacteria like Pseudomonas [60]
► Uses of the Interpretive Structural Modeling (ISM) method to develop reciprocal relationships among the e-waste management factors [60]
► Virtualization's functionality and its role as an essential component of green computing to reduce e-waste [60]
► E-waste legislation, design, and management and involvement of a variety of principles, theories, and methods [60]

4.3. Risks to the Health

Waste recycling poses a threat to health if proper precautions are not taken. Chemical and metal-containing waste workers may be exposed to toxic substances and suffer severe health issues such as disabilities and physical disorders [61]. Even occasionally, toxic exposure can be fatal. To avoid major health risks, healthcare waste disposal and toxic metal waste disposal require special care.

Environmental scientists emphasize the 3R (reduce, recycle, and reuse) process as an alternative to the current e-waste management practice to address the issues of excessive use of electronics and their impact on the environment [62]. Reusing and recycling processes must be emphasized because reducing electronic equipment use is not an option for a developing society like ours. In addition, numerous businesses in the modern era are seeking additional eco-friendly options for industrialization and sustainable development. The generation of e-waste at the base level can be reduced by combining an integrated strategy with scientific methods. With careful planning, toxic substances can be separated at the ground level to reduce pollution and build a green society.

Electronic equipment that is no longer needed or wanted should be thrown away in a way that is both convenient and good for the environment. Computers contain toxic metals and pollutants that have the potential to pollute the environment. Never throw computers away in a landfill [63]. Computers should be recycled at recycling facilities in the community or through manufacturing programs like HP's Planet Partners recycling service. Donating working computers to non-profit organizations is an option. Open burning of circuit boards or the use of acid stripes, both of which have the potential to be harmful, are two recycling practices that have been adopted in India. IP chips are used again. To extract copper and other metals, the parts that cannot be used are sent to open dumping. PVC-covered links are transparently scorched. Nitric acid is likewise used to eliminate Gold and Platinum. Both open burning and acid baths put the health of nearby communities in danger and expose workers to pollutants. This has been linked to several health issues, including silicosis, irritation of the respiratory tract, and pulmonary oedema [64].

4.4. Solutions

Electronic waste can be a valuable source of secondary raw materials if handled properly. The effects of recent legislation like the Waste Electrical and Electronic Equipment Directive (WEEE) and the "restriction of the use of certain hazardous substances in electrical and electronic equipment" directive (RoHS), as well as current and future methods for treating, recycling, and disposing of this waste, would ultimately result in a society that is friendly to the environment and develops in a green way. While energy efficiency and power consumption are currently the primary goals of electronic equipment design, the time has come when manufacturers must prioritize the creation of environmentally friendly, biodegradable, and safe electronic equipment.

Since reducing the use of electronic equipment is not an option for a developing society like ours, we must emphasize processes of reuse and recycling We must move toward an eco-friendly strategy that helps the environment become greener. Recycling is included in the green computing category of green disposal, one of the most effective strategies for dealing with the e-waste issue. Additionally, recycling aids in reducing the greenhouse gas emissions generated by the production of cutting-edge products. The pillar of green computing, which teaches us to reuse our previously used laptops, computers, and other devices, underpins the entire concept of recycling, refurbishing, and repairing.

After evaluating every method of E-Waste Management, separating them into four main parts, and determining the best solutions for each part based on five factors, we will successfully contribute to Green Computing if we implement all these suggested methods. The best solutions for each Green Computing Component are shown in Figure 3.

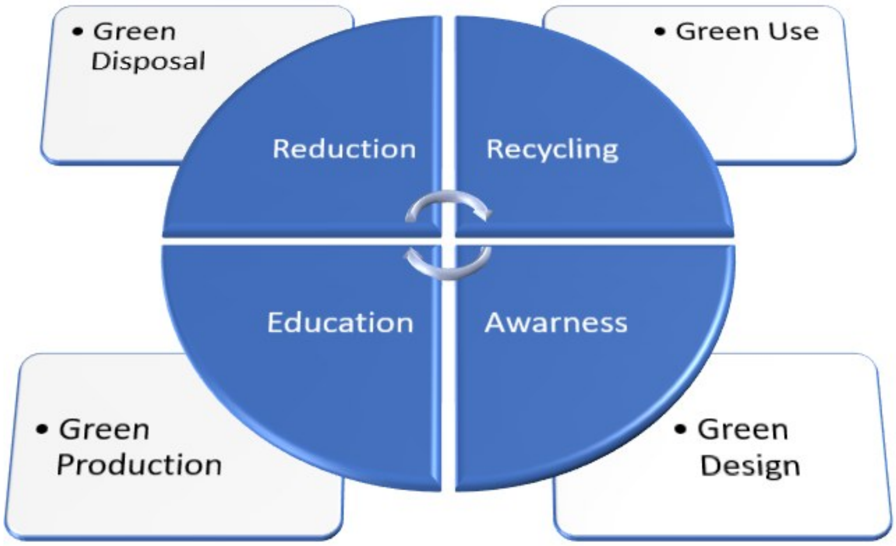

Figure 3. Components of Green computing

Businesses and computer users can alter their work practices to reduce their negative impact on the global environment. Small adjustments to our work routines can have a larger impact on environmental safety. To make computing greener, one can take the following small but effective steps:

► It is truly expected to print only the required materials.

► Utilizing reused content paper whenever the situation allows.

► Printing on both sides of the sheet of paper.

► Utilizing recycled and fully used toner and ink cartridges possible.

► Choosing energy-efficient, high-quality equipment with higher star ratings.

► Keeping the systems off when not in use rather than putting them in standby mode, as computers still use about 10 watts of power in standby mode.

► Purchasing new equipment only, when necessary, not just because a new model is on the market.

► Acquiring compact systems with few accessories and peripherals.

► Disconnecting devices that are not in use, such as a printer, audio system, scanner, or modem, for example.

► Optimizing the UPS battery's charging rather than leaving it on all day.

The goal of green computing is to lessen the amount of waste and the negative effects that e-waste has on the environment. The preservation of a respectable environment and society is the primary objective of electronic waste management [65]. Because collaborating on green computing and e-waste are having obstacles and challenges, however, working in the field of eco-friendly computing and e-waste management has become simpler; thanks to ever-increasing technology. For green computing to become an initiative, all organizations and businesses must adopt e-waste management as a mandatory practice. The world will have to deal with several issues otherwise. It is anticipated that significant progress will be made in this area. Virtualization, cloud computing, and carbon footprint could be the focus of research. That is something that could be developed in this field in the future [66].

4.5. Eco-Friendly Approach

The best policies and practices of green computing include using less power, using less paper, recommending new equipment that is better for the environment, and recycling old machines safely. Several environmental regulations have been established by government agencies in Europe to control pollution, recycling, waste disposal, industrial emissions, and waste management. Computer manufacturers are about to launch eco-friendly models, including desktops and laptops, to reduce electronic waste in the environment. In addition to desktops and laptops, efforts are made to ensure that other electronic hardware products strictly adhere to the limited use of hazardous substances. PVCs, brominated flame retardants, and heavy metals like lead, cadmium, and mercury, which are frequently used in computer manufacturing, are likely to be absent from them. Reliability presents the electronics industry with its greatest obstacle when it comes to using environmentally friendly materials in computers. Due to its high malleability, lead-tin solder is currently utilized as an excellent shock absorber. In real-world applications, more brittle replacement solders have yet to demonstrate the same dependability. Substitutions like the ideal one, a tin/copper/silver composite, likewise require higher dissolving temperatures, which can influence chip life. The following is a plan by the designers to make future computers more eco-friendly throughout their entire lifespan [67,68] from production to recycling:

- ► By replacing petroleum-filled plastic with bio-plastics- plant-based polymers- that require less oil and energy to produce than traditional plastics, the energy-intensive manufacturing of computer parts can be reduced. However, it is difficult to keep these bio-plastic computers cool enough to prevent electronics from melting.
- ► Making optimal use of the device, upgrading it, and making timely repairs are all ways to control landfills.
- ► In addition to keeping e-waste out of landfills and reducing costs associated with upgrading and repairing devices, reducing the amount of energy and materials required to design and manufacture a brand-new computer will save money and time.
- ► OLEDs, organic light-emitting diodes, and other green light displays can take the place of high-power display devices.
- ► Silver and copper can take the place of toxic materials like lead, making recycling costly and time-consuming. Reusing or reselling computer components separately can improve the efficiency of the process.

5. Conclusions

Until now, we consumers have only been concerned about the speed, cost, and performance of electronic devices, and we have not given much thought to how they affect the environment when we buy them. However, people have begun to consider safer and more environmentally friendly models as a result of the growing concern for environmental preservation and sustainable development. To ensure that waste does not harm the surrounding environment or the health of the residents, proper waste disposal practices must be implemented. At the time of collection, separating the electronic waste into a specifically defined stream is an efficient method for facilitating subsequent recycling and reuse. However, the production of highly mixed waste streams discourages component reuse and the recycling of materials with added value. Recycling would be much simpler if smaller electronic products were separated. Due to its ability to recycle a variety of wastes and its lack of chemical additives, Ultra High Shearing (UHS) technology is currently being developed by several businesses. It is based on the ultra-shearing principle, in which a very high mechanical shear stress is applied to break the chemical bonds between various polymers and form a copolymer as a bridge, stabilized compound of superior quality is the result. In January 2003, some nations issued a directive limiting the use of certain hazardous substances in electronic goods. Manufacturers are required by the legislation's eco-design component to evaluate the equipment's ecological profile and consider the entire lifecycle of specific product groups.

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Author Contributions

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Informed Consent Statement

Not applicable.

Data Availability Statement

The data presented in this study are openly available via the links provided in the data section. More detailed information can be obtained upon request to the corresponding authors.

Conflicts of Interest

The authors declare no conflict of interest.

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