Recent Trends in Green Computing

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**Abstract.** Ever-increasing computing technology demand has marked several impacts on the planet. One of them is the depletion of the earth's resources. Green Computing is the term that denotes the practices that are used within the industry to minimize the perilous materials present in the environment, because of the usage of ICT resources. This usage accounts for 2% of carbon emission that is roughly the same as aviation. This data lead thinkers to the concept of environment-friendly computing or green computing. Following these studies regulatory bodies introduced number of standards to ensure that the IT sector operates in an environmentally sustainable manner. The current trends introduced in this regard, include efficient energy consumption, e-waste recycling and management, IT products eco-labeling and longevity, data centers optimization, virtualization, etc. To further strengthen the adaption of green computing, various measures have been taken which encompass certifications that would be mandatory for organizations to acquire, product longevity, etc. The concept of green computing is more critical as we move towards smart cities. The massive information and communication infrastructure of smart city will certainly need huge amount of energy to operate. Implementation and adoption of Green ICT products can help in clean energy production and utilization. Consequently, this clean energy cycle will mark comparatively less impact on environment. Realizing the importance of green computing, specifically, in smart cities and the role of government in developing and implementing sustainable computing polices, this paper presents an overview of existing policies implemented by the developed countries. Further, the paper discusses the measures taken by IT industry giants, the impact of green computing and the challenges of adapting green computing.

**Keywords:** Green Computing, E-waste management, clean energy, sustainable computing

1. Introduction

Green Computing basically proposes to preserve the environment from the repercussions of the whole computing process. It starts from manufacturing to use of the equipment and safely disposing-off of computers, peripheral or connected devices, networking hardware and communication equipment which has less impact on the environment [1]. Developed countries have devised rules for organizations as well as for typical users in order to meet the goal of environmentally responsible and eco-friendly computing. Organizations are moving towards the idea of making the least possible pollution that comes as a consequence of technology usage.

Internet users around the globe have increased from 413 million in the year 2000 to nearly 4 billion in 2020[2]. This exponential growth in technology usage demands the need for policies and regulations as it has marked several negative impacts on our planet. Studies have shown that Information and Communication Technologies (ICT) contribute 2% of global carbon emission resulting in climate and environmental damage [3]. It has been argued to ensure the minimization of unfavorable outcomes of ICT usage.

In order to address these challenges, various targets have been set on global and regional levels to analyze what the future will look like with this escalated exploitation of the earth's resources. It is important to understand the need of bringing sustainability in this whole scenario. In 1992, US Environmental Protection Agency launched an incentivizing method through which they awarded the label of Energy Star to the companies and organizations who take measures to minimize the energy consumption while maximizing efficiency [4]. First few approaches include the addition of sleep mode in computers, electronic recycling program, etc.

Europe has achieved comparatively more than the US in this regard as US ranks 35th in the list of countries that have taken measures to protect the environment while European countries dominates on that list [5]. Europe has focused on clean energy production through renewable sources in the past few decades. They have aimed to reduce Green House Gas emissions up to 40% by 2030 [6]. With measures like Ecodesign Directive [7], Europe has enforced the ICT manufacturers to bring product longevity for improving energy efficiency in devices and other equipment. Samsung claims that they collect the products that have reached the end of their lifespan, and recycle it for reuse. They have collected 3.55 million tons of discarded equipment and have transformed it for reuse [8]. Similar approaches are adopted by other technology manufacturers such as Apple [9], IBM [10], etc. [11].

The concept of smart cities is new to none now. Green computing can be looked upon to overcome the crisis related to clean energy consumption. Smart cities’ infrastructure with Green ICT concept can be most useful weapon in the fight against the climate crisis, helping in minimizing the influence on the environment in future, and alleviate the damage that is already done [12]. A smart city concept helps in focusing the intelligent usage of technology, network systems and infrastructure to upgrade the economic and political efficiency and foster development while reducing the environmental degradation and elevating environmental regeneration [13].

This paper discusses the grounds on which phenomenon of green computing is based such as e-waste management that is one of major concern of growing economies. It gives brief overview of how governments as well as industry leaders and tech giants world-wide are adopting this idea for achieving climate action goals. Impacts of adopting green computing observed till now are also discussed.

1. Need for Green Computing

The use of computing technology and its applications in everyday life has increased power consumption which ultimately marks harmful impacts on the environment in terms of heat generation and carbon footprints. Some of these outcomes are reversible while others are irreversible. Similarly, the electricity consumption of ICT accounts for more than 4% of the whole production which is huge when compared with other industries. Green Computing was initiated to limit these negative impacts of ICT. Following are the major considerations compelling for green computing:

* 1. Increasing Electronic Waste:

E-waste is created when any electronic device or equipment is disposed-off after the end of its useful life. Every year tons of electronic equipment is shipped around the world and upon its disposal time, it gets hard to manage this waste [14]. Global e-waste amounts to about 40 million tons per year[[15]]. Discarded equipment contains hazardous material such as heavy metals, acids, toxic material, and non-degradable plastics. Primary regulations applicable for ICT waste are Waste Electrical and Electronic Equipment (WEEE) regulations that restrict handlers from disposing of e-waste with general waste. Alone in Indonesia, 9500 tons of e-waste was produced from mobile phones while the recovery rate is only 1% [16].

* 1. Increasing Energy Consumption:

Computing power consumption of companies has reached a critical point. For example, the expenditure over server power by an Ecommerce business every year exceeds $20 million per year. More will be required to fulfill cooling and other management requirements [17]. Rather than burning fossil fuels for energy production, renewable energy sources are now preferred by tech giants. Approximately 30% of the total energy use of the UK was consumed by office equipment [18]. The Climate Savers Computing Initiative estimates that half of the power delivered to an average desktop PC is wasted while US EPA says that around 30-40% of computers are kept switched on even after office hours leading to wastage of energy [1].

* 1. Lowering Infrastructure Cost:

Green computing can lead to significant cost savings over the time. Due to increased demand, there is a need for lowering infrastructure and operational cost. Lowering the energy requirements by making existing equipment more energy-efficient, will help organizations reduce their energy cost. [19]. The need for conservation of resources lets the tech companies come up with such innovative strategies of promoting sustainability which grabs a position ahead of their competitors.

* 1. Increasing Carbon Footprints:

The number of greenhouse gases emitted in the atmosphere is called Carbon Footprint. Every single email account instantly adds 4g of CO2 to the environment. An email with attachment in common is an account for 50g of CO2 [19]. The total life cycle carbon footprint of the ICT sector is approximately 730 million tons CO2 equivalent (Mt CO2-eq). There is an acute need of manufacturing and using more energy-efficient computing equipment which naturally brings us to the appropriate Green equipment.

* 1. Strengthening Organization Sustainability Image:

Organizations and businesses have gained competitive edge over competitors by meeting the regulatory requirements and compliance related to sustainability. Developing environmentally proactive strategies and doing investment in this area helps the businesses to build up their credibility in front of customers and clients. It is termed as ‘Green Corporate Image’ [20].

1. Policies Devised and Implemented by Developed Countries

Governments can act as a driver for the green transition. Through regulatory instruments, governments around the globe can set up legal and political frameworks and can introduce economic incentives and standards that promote green computing. Developed countries have taken in lead and progressed much more than developing and third world countries. Joint efforts from government, businesses, and the public are crucial for promoting the green society and sustainable consumption. Below are the key initiatives taken by international organizations and countries for safeguarding the environment and adopting green computing.

* United States of America has proposed the idea of green computing and the roots of this idea were introduced by US Environmental Protection Agency. Some of the tech giants like AWS, Microsoft, Ali Baba are the largest Infrastructure as a Service (IaaS) provider in USA and China.
* United States was first country to take action in response of impacts of computing on the environment by introducing Energy Star program and it has continue to progress with initiatives like Green Grid for efficiency of data centers, Electronic Recycling program, Climate Saver Computing initiative for better power utilization, etc. Nearly all tech giants and manufacturers have adopted green computing practices such as clean energy production, efficient power consumption, virtualization, etc.In 2008, Germany generated renewable resources from 14.2% of its electrical power [21]. Before this, in 2002, this country adopted its [National Strategy for Sustainable Development](http://www.bundesregierung.de/Content/EN/StatischeSeiten/Schwerpunkte/Nachhaltigkeit/nachhaltigkeit-2006-07-27-die-nationale-nachhaltigkeitsstrategie.html?nn=393722) and created this sustainability a guiding rule for national policies. These key components are expanding the widespread use of renewable resources and making energy efficiency at high level. Germany wishes to reach the height of expanding the use of reusable resources from 17% to 80% in 2050, while completely chasing 100% electricity production from nuclear power plants by 2022. Also, it aims to cut Greenhouse gas (GHG) emissions from ICT industry by 40% by 2020 and at least 80% by 2050.
* UK Government introduced Greening Government Commitment in March 2011[(HM Government Cabinet Office 2011)] that reflects the government’s policies about a substantial reduction in e-waste and greenhouse gas emission. Commitments stated there include the Government’s encouragement for the manufacturing of ‘greener’ IT products, proactive management, and reduction of greenhouse gas emission and to ensure reuse of ICT products. It also frames the strategies for exploiting green ICT in Government operations and the public sector formulated for Data centers, End-users, Public services networks, and cloud computing. Following are the strategies govt. has framed to encourage practice of Green Computing at all levels:
* UK Government has planned to come up with their app store for government applications to restrict the redundancy and duplication of applications. This will ultimately lower energy consumption and resource usage.
* Data centers consolidation is enforced along with the adaptation of cloud computing which will minimize the energy requirements.
* The government has also urged end-users to follow the standards about the purchase, management, and disposal of devices.

 The document also reveals the outcomes of strategies implemented until then. There was a reduction in carbon emission up to 13.8% in twelve months. Later on, these policies and strategies were restated for the next financial year as there was the progress of savings of £159 million as a result of imposing those policies.

* Japan is among the nations that are massively investing in the ICT sector. It was Japan [[22]] who followed the US’ Energy Star Program with the help of the PC Green Label System that indicates the environment-friendliness of personal computers. In 2007, Green IT Initiative was introduced to enhance the collaboration between industry, academia, and government to address the manufacturing of IT products that are energy saving. In 2008, the Green IT Project under the banner of New Energy and Industrial Technology Development Organization (NEDO), with a budget of three billion yen ($33 million) was introduced to cut down electricity consumption of data centers and networking systems up to 30 percent.
* South Korea ranks second in Asian countries with the highest expenditure on ICT. Policies and strategies are introduced for both public and private sectors related to Green Computing. Like the US and Japan, Korea’s Eco-Products Institute [[23]] has also initiated a carbon labeling program to indicate the greenhouse gas emission encompassing the whole product life-cycle. The government has focused on enforcing low-energy consumption for emerging technologies like Radio Frequency Identification, ubiquitous sensor networks, next-generation networks, and smart home appliances.
* Switzerland tops the list of eco-friendly countries and was among the first few countries that have introduced fuel tax and CO2 tax [(Bretschger and Brunnschweiler 2009)] to reduce carbon and greenhouse gas emission. Green IT Switzerland was founded to encourage practicing more energy-efficient and sustainable solutions for the operation of IT infrastructure.
* The Global Footprint Network (a universal research organization of researchers situated in the United States, Switzerland, and Belgium) presumed that natural manageability is evaluated by the complete size of the environmental impression that compares to the reason set by financial action applied on the biosphere. To guarantee this universal likeness, an environmental impression is communicated in units of world-normal bio-capacity region alluded to as worldwide hectares.
* The organization Telecommunications Regulatory Authority (TRA) in the United Arab Emirates plays an incredible job in executing green arrangements in the Information Communication Technology (ICT) zones, by diminishing the percent of ozone-depleting substance impacts from the ICT business. Dubai transport authority propelled green IT activity in 2008 that will have superior control over IT frameworks' vitality utilization. Three key segments are going paperless, propelling video conferencing, and making server farm ground-breaking and productive. In the wake of actualizing that system, CO2 outflows will be most likely diminished by 596 tones yearly. The reason for this system is to set a green data center dependent on the "Hot Aisle Containment" innovation.
* The Kingdom of Morocco has launched numerous activities for ecological turn of events. The national charter of the kingdom for environment assurance was one of their earlier initiatives propelled in April 2010. It supportively provides a chance to spread an eco-friendly condition and culture at country al level. At that point, Green-IT begins establishing in Morocco through the best act of green buying rules and strategies. While, some open solicitations for proposition likewise incorporate natural terms, for example, vitality effectiveness and consistence with international principles.
* In China, The Institute of Public & Environmental Affairs (IPE) a nonprofit research organization is dedicated to collect and analyze environmental data from the government and corporate agencies. The website and mobile app called “Blue Map,” uses data for green procurement, green finance, and to control government policies focused on green development. At present, China is one of the largest consumption nations of electrical products which makes it most vulnerable to environmental pollution due to ICT. To improve the climate conditions and in response to its own poisoned environment, China has turned out to be a world leader in electric vehicles, renewable green energy, and green energy storage.

1. IMPACT OF IMPLEMENTING GREEN COMPUTING TRENDS

The process of greening the whole industry and following basic principles of green computing as obligation is quite slow and costly. Moreover, significant improvements in environment are even slower.

Google has cut down its power consumption to half of the power typical data center uses [24] and has planned to move entirely for renewable energy in the near future. Some of the major consequences of adopting green computing are mentioned below:

* It will surely save the sufficient amount of cloud data centers’ energy. It will reduce the impact of carbon dioxide emissions and the greenhouse effect due to the usage of too much energy by modern IT systems.
* Green computing will change the concepts of government arrangement and will empower reusing concept followed by people and organizations and will lessen vitality utilization.
* The another impact of green computing will be the placement of breakthroughs for cloud sustainability, whether it can be big or small and will provide the better infrastructure to cloud, high-performance servers, and the reduction of carbon gas emissions to be accessible more to renewable energy resources like solar power.

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| Green Computing Practice | Outcome |
| Clean Energy Usage | Reduces power consumption up to 75% |
| Product longevity | Lower cost up to 73% |
| Removal of Hazardous Material | 56% lower carbon emission |
| Green Designing | Improved system efficiency up to 47% |

1. Challenges

Implementation of Green computing across all ends is not much easy at all as fabricated by some of the influencers because every strategy described as a way to implement has some sort of challenge in it. Some of these challenges in implementing are discussed below:

* 1. Privacy maintenance

Cloud Computing is one of the ‘greening’ way as it makes processing and computing infrastructure efficient. Moving data to cloud increases the vulnerability of data because of increased Cloud Service Provider’s control over the data. Meeting the privacy concerns in green computing is considered as the biggest challenge because typically, green computing devices have embedded mechanisms that share the data with concerned organizations. [25]

* 1. Decrement in Efficiency

The evolution of devices in order to make them more environment- friendly brings concerns for the users whether those devices will be more or at least same efficient as before or not [25]. The fear of compromise in efficiency is also considered as the challenge because the computers need to have same features like efficiency, speed, versatility, diligence, and other specifications along with green IT enablers. Though these concerns are proven wrong as these ‘greening’ IT products increase their lifespan[26]. need to have same features .

* 1. Green Design

In green computing, the term green design occupies great importance as it enables green computing to work effectively. The term green design is used for the manufacturing of products that consumes lesser energy. Considering the environmental conditions which have got highly disrupted because of the technology, it is, therefore, a provocation of green computing to manufacture eco-friendly technological devices, due to many colliding key objectives that require high operating speed and cost-effectiveness [25].

* 1. Green Practices and Green Management

Green practices bring the techniques for green manufacturing along with the components required for the manufacturing of products. This practice is also a challenge in green computing because the manufacturing typically requires lead-free physical science, halogen-free flame retardants, environmentally-friendly electronics, and the trend towards integrating electronic functions both on and within printed circuit boards. (PCBs) [27]. This practice is adopted because of its long term benefits which include the reduction of carbon footprints in massive amounts. However, it is quite difficult to completely avoid these harmful elements in manufacturing of products as little percentage is needed. Also, green practices make product a lot most costly than the usual price.

While green management refers balance between human activities and the environment. Environmental laws and standards are often overlooked by management tier for monetary benefits [28].

* 1. Green Management
  2. Reduction in Carbon footprints

Though the main objective of green computing is to minimize carbon footprints it is still considered as a challenge because of the rapid growth of technologies. Earlier in time, the technology was limited to certain fields but now as the world is getting globally advanced in technology, it is therefore certainly becoming more challenging.

* 1. Focused Green Computing

The green computing technology is trying its level best to achieve the eco-friendly environment along with the maximum reduction to the carbon footprints but it is still required to put more concerns to the green computing. In past few years, the prerequisites for the high transfer speed, organize availability of data center, and force necessity of a data center will go past our creative mind which would require a sharp report towards green processing which may turn into the most basic test. [29]

* 1. Cost

In order to apply green computing that widely, the cost is the biggest challenge. The devices which are made for greening IT require a huge cost. Along with the end-devices, the servers that can serve the cause of green computing would also need high cost. Manufacturing and maintenance of such equipment is possible for giants but it is almost impossible for Small Medium Enterprises and low scale businesses to have budget for such high-cost infrastructure.

1. Initiatives for Green Computing
   1. Measures by Companies

In order to implement green computing, many companies are putting efforts that come up with cost-effective and less energy consumption solutions. Companies like IBM, Hewlett Packard, SprayCool, and Cooligy are bringing technologies and methods for improving data center management regarding environmental impacts like liquid cooling, Nano fluid-cooling systems, and in-server, in-rack, in row-cooling[30]

* 1. Implementation of other ways

Many companies are striving to implement innovative initiatives to make data centers eco-friendly which generally includes introduction of high density servers, hydrogen fuel cells as alternative green power sources and implementing the concept of visualization that lower down the heat generation and reduce overall power consumption.

* 1. Energy Conservation Program

Considering the effects of the growing technological environment, China National Development and Reform Commission (NDRC) took a step for China Energy Conservation Program (CECP) which is a non-profit organization to administer, manage, and implement the certificate for energy- conserving water-saving and environmentally friendly products. In other words, the organization assures the manufacturing of resource-effective products. [25]

Alongside this, one of the non-benefit associations in Japan likewise served for this reason. This association planned to make mindfulness on vitality preservation, preparing and state assessments for vitality administrators, and their vitality protection battle and show.

* 1. Eco-friendly Designs

It is observed that the data centers are adopting the concept of eco-friendly designs. These plans are made practicable by utilizing engineered white elastic rooftop, paint, and floor covering that contain a volatile organic compound (VOC), ledges made of reused items, and vitality proficient mechanical and electrical frameworks at ideal effectiveness. Additionally, these eco-structures utilize both common light just as green force, which is essentially power produced from sunlight based or wind vitality, to run the data center. [30]

* 1. Facebook's Initiative

Facebook took an initiative for using renewable energy by converting the data centers to consume only the wind powers. The thought for this was not pleasing for the people who work for the renewable energies for Facebook because they thought about the availability of clean energy. But year after the thought, Facebook was able to get the wind power deal. In this manner, Facebook took a step toward eco-friendly computing. [8]

According to their report, after these steps, Facebook was able to reduce up to 59% of greenhouse gases along with the achievement of 86% of renewable energy. [31]

* 1. Google's Initiative

Google also took a step forward to greening IT. For such purpose, Google bought the wind farm. In the wake of buying a wind farm in Iowa just a couple of years back, Google declared its consent to purchase power from a wind generation office in Oklahoma, boosting the utilization of inexhaustible force on the electric network that self-control one of its new server-farms. Under a twenty-year concurrence with the neighborhood specialist co-op, Google's drawn out objective of running completely on sustainable power source is developing ever nearer.[32] It is also noticed that Google has reduced IT energy usage and carbon emission to 65% to 85% by shifting the business to the G Suite [33]. Along with this, Google also has implemented machine learning which constantly optimizes the data centers. The reason of this implementation is to observe the weather condition every 5 minutes so if any drop in temperature occurs, the energy devotion is decreased [34]. Google is not only taking initiatives on the computational side but also providing the services of clean transportation, by which 40,000+ metric tons of CO2 emissions. This service is taken in practice by the Google Shuttle in the Bay areas [35].

* 1. Amazon's initiative

The data center of Amazon in the US and UK were likewise thought about for green computing. Amazon chose to put $10 million in the Closed Loop Fund, which supports reusing framework all through the US. Alongside this Amazon additionally introduced the sunlight based boards on its focuses in the US. Throughout the following year and a half, Amazon intends to introduce solar systems on 10 of its UK fulfillment centers as well, and once finished, its UK universes will have the option to control what might be compared to 4,500 homes. These steps of Amazon are one of the biggest steps in green computing. [36]

* 1. Microsoft's Initiative

Like any other tech giants, Microsoft is also bringing the products which aim to reduce energy consumptions. For instance, a year ago, the organization introduced a smallish data center on a fix of seabed simply off the bank of Scotland's Orkney Islands; around it which is roughly encircled by 933,333 bucketfuls of saline solution. As such, Microsoft can approach considerably more clients for arrangement of green computing administrations as it could lower or take out cooling and other vitality costs [34]. A portion of the Microsoft's items are likewise made with the point of decreasing the consumption of vitality like, Microsoft Vista can help lessen an organization's vitality use by as much as 30 percent, Windows 7 as a working framework brings power the board diagnostics.

Along with these examples, Microsoft also brings virtualization which reduces energy usage up to 90% according to their claim. [37] Since these products are deprecated hence Microsoft has brought the plans to remove carbon dioxide from air more than its generation, by 2023 and by 2050, it will remove all the emissions since Microsoft is founded. [38]

1. Conclusion

Growing concerns related to the environment has forced computing industry leaders and governments to focus on Green Computing. Various policies have been proposed and implemented in this regard around the world. These steps, though are beneficial, but will not have greater impact until end-users are also prepared to adopt it. Though data centers and tech giants have adopted it to significant level, but a lot remains to be done. For every data center machine, there can be from thousands to more than tens of thousands of end-user computers.  It is estimated that simply educating end-users about the power consumption of PCs could result in a 10% energy savings for organizations. Green Computing strategies and actions need collaboration with government, ICT industries/institutions, education institutions and society. Partnerships throughout the world and hand-in-hand cooperation are key to successful implementation of future green lifestyles.

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