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An Imperative Exists to Embrace Energy-Efficient Systems and Sustainable Computing Practices as Crucial Measures to Mitigate the Hazardous Impact of Climate Change

Dr. Sanju Gupta[1] and Prof. Archana C[2]

[1]Assistant Professor, Department of MCA, SIES Institute of Management Studies, Nerul, India
[2]Assistant Professor, Department of MCA, SIES Institute of Management Studies, Nerul, India
[1]Ksanjana.khandelwal@gmail.com and [2]archanachandrabhanu@gmail.com

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ABSTRACT
The technological and social advancement demands for an escalated usage of information and Communication Technologies (ICT) in educational and social spheres. This revolutionary change is the major contributor towards global warming and carbon footprint issue. Climate change activists have often concentrated on cutting emissions in sectors such as automotive, energy, and aviation. It's imperative to address sustainability within the educational sector as well. Various standards and practices are available to tackle these challenges. Green computing is taking an edge over its counterparts to provide a vital solution to this concern. This paper delves into the adverse impact of the surging usage of ICT in the educational sector and explores current protective measures and standards to tackle the same using a comparative analysis. It underscores the significance of transitioning to green computing practices and sustainability to mitigate the hazardous impacts of climate change.

Keywords- Information and Communication Technology (ICT), Green ICT (GICT), sustainable computing practices, Environment, hazardous, E -waste, CO2 Emission, renewable Energy.

I. INTRODUCTION

The world is confronting unparalleled environmental challenges, and the education sector is not exempt. Is the growing reliance on computing devices, cloud technology, and machine learning algorithms significantly contributing to environmental degradation through carbon emissions, energy consumption, and E-Waste generation? The affirmative answer lies in the fact that the cumulative use of computing currently consumes up to 10% of the world's electricity, a figure projected to potentially exceed 20% by the end of the decade. Consequently, in our resource-limited world, there is an imperative to embrace eco-conscious and sustainable computing approaches to alleviate these effects and foster an environmentally responsible computing industry [1].

Green computing involves the environmentally responsible utilization of computers and associated resources. It encompasses the study and implementation of efficient and effective design, manufacturing, usage, and disposal of computers with minimal or no adverse impact on the environment. The objective of green computing is to diminish the use of hazardous materials, optimize energy efficiency throughout a product's lifecycle, and advocate for the recyclability or biodegradability of products. While computers have become an essential necessity for many, a significant portion of users remain unaware of the harmful repercussions of computing and its devices [2]. In this research paper, we employ a questionnaire to gauge public awareness regarding green computing and assess various initiatives and practices they are following in their daily lives, specifically within the realm of education.

ICT for sustainability has a dual purpose: firstly, to examine the direct environmental impact of the ICT sector and explore sustainable design-based solutions to mitigate it; and secondly, to underscore the potential of the ICT sector in combatting climate change and significantly enhancing energy efficiency across various sectors, with a focus on the education sector[3]. The study's scope is confined to the education sector, addressing three broad areas: the environmental impact of ICT, its sustainability, and the imperative for sustainable computing practices within education.

This study is divided into six main focus areas as shown in figure 1.

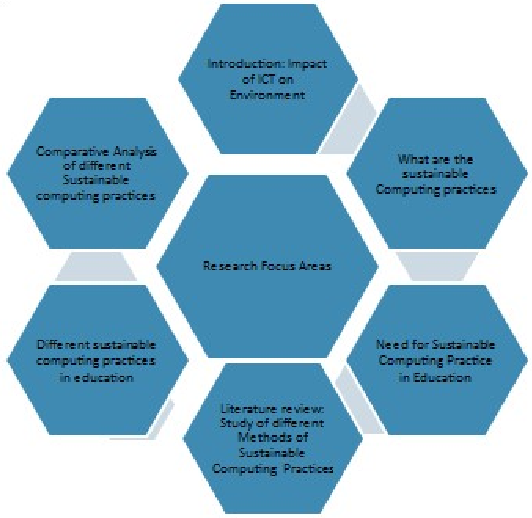

Fig. 1 Outline of the research work

II. SUSTAINABLE COMPUTING PRACTICES

Sustainable computing pertains to the utilization of computing resources in a manner that ensures a neutral impact on the environment, encompassing various aspects such as energy usage, ecological balance, pollution mitigation, and conservation of natural resources [4].

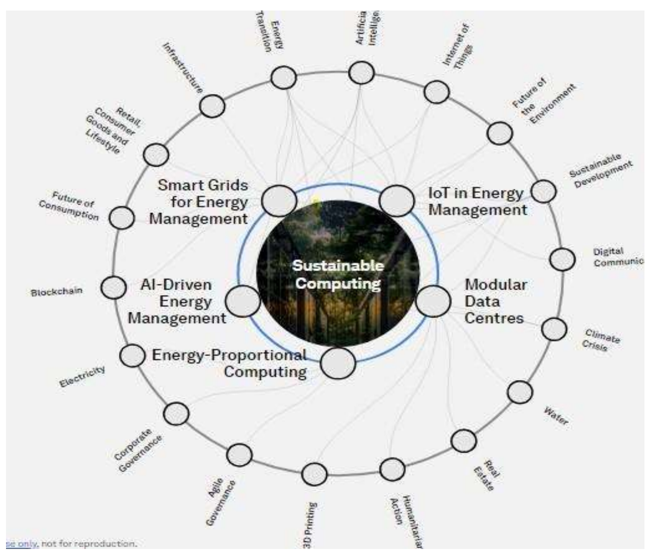

Fig. 2. Sustainable Computing Practices [4]

Green computing, often known as green IT, is another widely used word that is synonymous with sustainable computing. This method focuses on minimizing the environmental impact of computer design, manufacture, use, and disposal of chips and other technical peripherals. It includes programs aimed at lowering energy usage and carbon emissions from manufacturers, data centers, and end users.Green computing encompasses several measures such as selecting materials obtained sustainably, minimizing electronic waste, and advancing sustainability through the utilization of renewable resources [5].

Sustainable computing practices in education involve the adoption of technologies and methodologies aimed at minimizing environmental impact while supporting educational objectives. Examples include the utilization of energy-efficient devices, implementing virtualization techniques to optimize server usage, and embracing cloud computing to reduce reliance on physical infrastructure [6].

III. NEED FOR SUSTAINABLE COMPUTING PRACTICE IN EDUCATION

Education has been profoundly impacted by technology, which has changed traditional teaching approaches and the nature of education as it exists today. Like any other innovation, technology has both positive and negative effects on education. The revolutionary character of technology in education is highlighted in several important areas:

1. Accessibility of Information: There is now a wealth of information available on the internet. Beyond the limitations of textbooks, digital libraries, educational websites, and internet tools have increased learning opportunities.

2. Interactive and engaging Learning: The incorporation of technology has enhanced the interactivity and engaging nature of learning. Students are captivated by virtual simulations, educational games, and multimedia presentations, which make difficult subjects more approachable and pleasurable.

3. Efficiency in Administration: The system's overall effectiveness is improved via digital platforms for communication, grading, and enrolment.

4. Acquisition of Skills for the Digital Age: Students who receive instruction including technology are given the tools they need to succeed in the digital world. They develop critical thinking, problem-solving, digital literacy, and teamwork—skills that are becoming more and more important in today's workforce.

5. Flexibility in Learning: Digital resources and online learning environments provide flexibility in learning.

6. Technology integration: Real-time feedback tools, online assignments, and digital quizzes are all part of the evaluation process.

Technology's involvement in education is expected to grow as it develops further, offering even more chances for the learning process to be transformed and improved.

It is imperative that K–12 education use technology to ensure that children are ready for success in the digital age. Research on the use of technology in education suggests that improving learning experiences is one main justification. Students can be engaged in ways that traditional techniques cannot by using the dynamic and interactive tools that technology offers. Lessons become more approachable, interesting, and productive with the use of interactive whiteboards, instructional apps, and multimedia tools that accommodate a variety of learning styles. Technology has a big influence on education in the modern day. Through adaptive learning platforms and instructional tools that customize the approach to meet a range of learning demands, technology promotes individualized learning. With this individualized approach, every student may advance at their own speed and have a deeper comprehension of the material[7].

As we've observed the significant positive influence of technology on education, it's essential to acknowledge and be aware of its negative impact as well. Just as a coin has two sides, we must recognize the potential adverse effects of technology on education.

The widespread availability of the internet and the growing embrace of devices like laptops, tablets, and smartphones in the field of education will result in a heightened utilization of these IT resources and their by-products. As per the research and study conducted by the global young scholar talent search for the title "How Technology in School Education Can Impact Millions of Indian Students," The size of the EdTech market in India is anticipated to increase by 3.7 times over the following five years, reaching $10.4 billion by 2025 [8]. This statistic is derived solely from the Indian education system, but it's fair to say that a similar trend is mirrored in the global scenario as well. This scenario raises a serious urge for sustainable computing practice in the field of Education

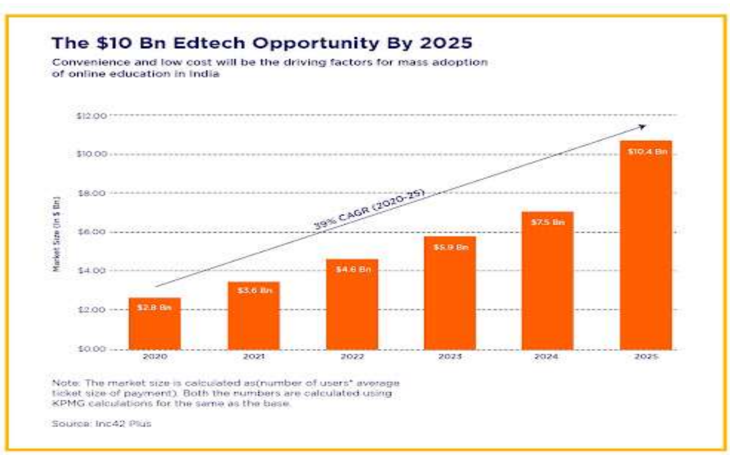

Fig. 3. Growth of ICT market in India [8]

IV. LITERATURE REVIEW

In today's rapidly evolving world, information technology (IT) holds a crucial role in education. However, amidst growing environmental concerns and the urgent imperative to adopt sustainable practices, the education sector must contemplate transitioning to sustainable IT solutions in their classrooms. By embracing green technology and harnessing IT innovations, schools can diminish their carbon footprint and motivate future generations to pursue a sustainable path forward. Moreover, it offers an opportunity to educate students about the significance of conserving the planet's resources and safeguarding our communities.

The exponential growth in processing capacity across data centres, cloud computing, electronic devices, and digital services has increased the energy demands and greenhouse gas (GHG) emissions associated with IT operations, as IT continues to pervade every part of our lives. The extent of this effect highlights the need for a shift toward ethical and environmentally conscientious behaviour, paving the way for a more sustainable and greener future. [9].

The concept of sustainable IT has been around for a while, but because of increased awareness of environmental issues and sustainability, it has gained more attention recently. When we talk about how sustainable technologies affect the environment, we are basically talking about how they affect the environment over the course of their lifetime, as measured by particular metrics like greenhouse gas (GHG) emissions and renewable energy practices. [10].

Encouraging sustainable IT involves a range of actions and programs designed to lessen the negative environmental effects of manufacturing, using, and discarding IT infrastructure and devices. It includes guidelines for information system investment, deployment, use, and administration that aim to reduce the adverse effects of business operations, IS-based goods and services, and information systems on the environment. [2].

The Green Software Foundation (GSF) describes sustainable IT as a burgeoning field that intersects with hardware, data centre architecture, software design, electrical markets, and climate research. Established by industry experts and organizations, GSF aims to create a reliable network of individuals, standards, tools, and best practices to advance sustainable software development. [11].

Embodied carbon encompasses the carbon emissions released throughout a device's entire life cycle. To accurately assess overall environmental impact, it's essential to account for both operational emissions during the device's use and the embedded carbon linked to its manufacturing and disposal processes. For instance, cloud computing offers greater energy efficiency compared to on-premise servers, as it allows for techniques like demand shifting and demand shaping to be implemented effectively [12].

Digital technology has ushered in a new era of teaching and learning, transforming the face of education. Dynamic and revolutionary advancements such as smart devices, the Internet of Things (IoT), artificial intelligence (AI), blockchain, augmented and virtual reality (AR/VR), and various software applications have created new opportunities for enhancing educational practices. [13].

Given the adverse environmental effects of information technology (IT), green computing has garnered significant attention from researchers, businesses, universities, governments, and others. It is recognized that IT can serve both as a solution and a challenge to environmental sustainability. It's notable that both the production and operation of IT equipment consume energy, accounting for roughly 2% of total carbon emissions However, with the continued proliferation of IT devices, these emissions are expected to increase unless proactive measures are implemented to mitigate or eliminate associated environmental risks. [14].

V.RESEARCH METHODOLOGY

Every day, newer models of Information and Communication Technology (ICT) devices flood the market, making older versions obsolete [15]. This underscores the importance of implementing green computing practices to mitigate the environmental impact of these devices[16]. This paper seeks to explore the significance of raising awareness and implementing ICTs in adopting green computing within educational institutions.

The objective was accomplished through assessing the awareness of green computing among academics and students, as well as identifying their green computing practices. The research employed both quantitative and hybrid research methodologies. Primary data was collected through a survey form, distributed to individuals associated with the education sector, including students, teachers, and research scholars.

The survey research's primary focuses are as under:

1. How Academicians and students use technology and IT resources.

2. Green computing awareness and best practices by the students and academicians.

3. Attitude of the students and academics toward green computing practices.

To address these inquiries, a survey questionnaire was developed and circulated among students and faculty members. The questionnaire is structured into three main sections: (A) demographic inquiries, (B) a segment on computer usage comprised of five questions, and (C) an evaluation of green computing expertise and methods, encompassing inquiries about the sources and mediums utilized to acquire environmental knowledge related to IT.

In the demographic segment, participants were asked about their gender and educational level.

The survey's Section B encompassed the following inquiries:

(i) How many years have you been using a computer?

(ii) How many hours do you typically spend on the computer each day?

(iii) How many hours a day do you typically have access to the internet?

(iv) In total, how many computers have you owned?

(v) What is the average number of pages printed per day?

Questions about the attitudes of students, faculty members, and others connected to the education sector regarding environmental responsibility and knowledge of green computing techniques were included in Section C of the survey.

Section C of the survey comprised the following inquiries:

(i) To what extent does Information and Communication Technology (ICT) contribute to your educational practices?

(ii) What kind of computing device are you currently using?

(iii) Which type of Operating System you are mostly using?

(iv) Which type of processor do you use?

(v) Do you have the practice of turn off computer, monitor and other devices when not in use Do you regularly utilize sleep settings when your computer is powered on?

(vi) Do you engage in the practice of reusing and responsibly recycling old computers and devices?

(vii) Are you using Energy Star-qualified products that significantly contribute to energy conservation?

(viii) Select the type of Monitor that you are using.

(ix) How often do you replace your gadgets?

(x) How often do you upgrade your gadgets?

(xi) What methods do you employ for the disposal of your electronic waste?

(xii) Select the types of practices that you use to conserve energy.

(xiii) What methods are you familiar with regarding green computing practices?

(xiv) Do you use renewable energy to power your server/ data centre?

The scope of research in this field is extensive, making it challenging to encompass all data within a single study. The survey has delved into all significant aspects of sustainable computing practices, categorizing the entire section C of the questionnaire into four primary domains based on their functionality.

Under the heading "Awareness and Usage of Renewable Energy Practices," questions XIV, XVIII, XIX, and XX are grouped. The second domain, "Disciplined IT Resource Usage," encompasses questions X and XI. “E-waste management practices” form the next functional area, incorporating questions XII, XV, XVI, and XVII. Lastly, the domain of "Availability of Energy-Certified Products" includes questions VII, VIII, IX, and XIII. The survey analysis is illustrated in Figure 4.

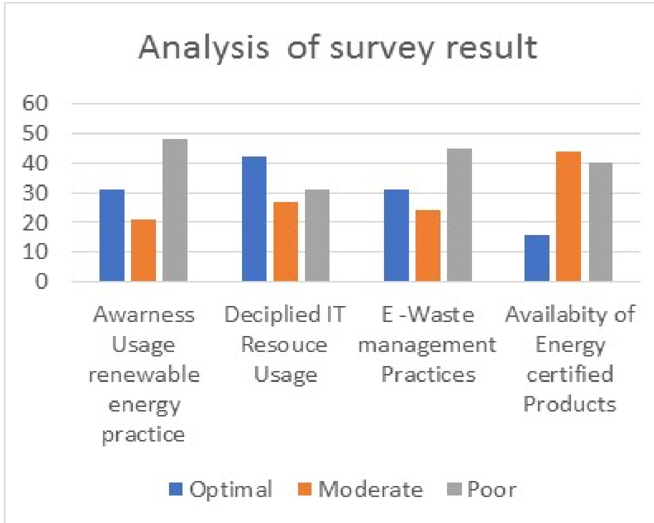

Fig. 4. Analysis of Survey Result

The results revealed that awareness and adherence to green computing practices do not directly impact the adoption of green computing. However, a notable correlation was identified between knowledge of green computing and the utilization of computing devices both at home and in educational settings. It is recommended to enhance awareness regarding the safe and eco-friendly use of computing devices among staff and students. To promote better green computing practices, a descriptive literature study approach was employed. Various methods of green computing practices were examined, and some of them were selected for analysis, considering certain parameters for bias evaluation.

VI. DIFFERENT SUSTAINABLE COMPUTING PRACTICES IN EDUCATION

As per the assessment conducted by the Intergovernmental Panel on Climate Change (IPCC) in 2022, climate change induced by human activities has resulted in a spectrum of significantly negative impacts [17]. As individuals become more educated about environmental challenges, they are better prepared to devise and execute innovative solutions that aid in carbon reduction, spanning from renewable energy technologies to sustainable technological practices. Through prioritizing sustainability in computing practices, the education sector is poised to spearhead transformative efforts, nurturing a cleaner and more sustainable world for future generations. The amount of power used in the ICT sector increased from 710 TWh to 915 TWh between 2007 and 2020. The ICT sector's carbon footprint increased from 620 million metric tons (Mt) of carbon dioxide equivalent (CO_2e) in 2007 to an estimated 763 million Mt by 2020[18]. As the field of computing continues to grow and prioritize sustainability, efforts have emerged to examine sustainability within the realm of computing education. This section delineates the optimal approaches to be adopted regarding sustainable computing in educational settings.

A. Usage of thin Client model.

B. Recycling of IT Equipment

C. End-user IT Resource power management

D. Buying of energy-certified equipment

E. Use of renewable energy sources for ICT

A. Usage of Thin Client Model.

PCs are increasingly prevalent worldwide and utilized by individuals of all ages. Observing the figure 1, it's evident that PCs dominate the market share among various ICT products available, thereby attributing to the significant power consumption they incur. As a result, this increase in power consumption results in a heightened demand for power generation, potentially intensifying the global climate crisis. The optimal solution to address these issues is transitioning to a computing paradigm with lower power consumption, such as thin clients. A thin client is a computing device or software application that relies heavily on a central server for processing and data storage. Unlike traditional PCs, thin clients typically have minimal processing power, memory, and storage capacity. A thin client typically consumes an average of 800 to 1400 MWh per year, whereas a PC consumes between 3000 to 4500 MWh annually [19]. The contrast becomes even more pronounced with resource-intensive applications. This results in minimal wastage of IT resources and has a significant impact on conserving energy resources. The extended lifespan of thin clients, often exceeding 10 years, contrasts with the average 5-year lifespan of a PC. This prolonged lifespan reduces the frequency of hardware renewal cycles, leading to lesser E-waste generation. Consequently, not only do thin clients consume less energy throughout their lifespan, but one thin client can serve for the same duration as two PCs[20]. Significant decreases in power usage, coupled with a diminished carbon footprint across the entire lifespan of these devices, will offer substantial support toward achieving sustainability in computing.

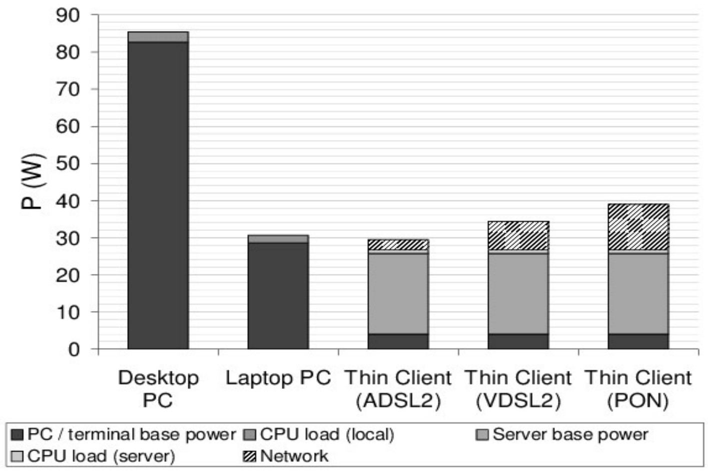

Fig. 5. Comparison of Power consumption in PC vs thin clients [20]

B. Recycling of IT Equipment

As per the data released by the United Nations Institute for Training and Research for the programme sustainable cycle (SCYCLE) program -2024 "In 2022, a staggering 62 million tonnes (Mt) of e-waste was generated, marking an 82% increase from 2010. Projections indicate that this figure is expected to surge by another 32% to reach 82 million tonnes by 2030". The diagram illustrates the manner in which the rate of e-waste production increases in India [21].

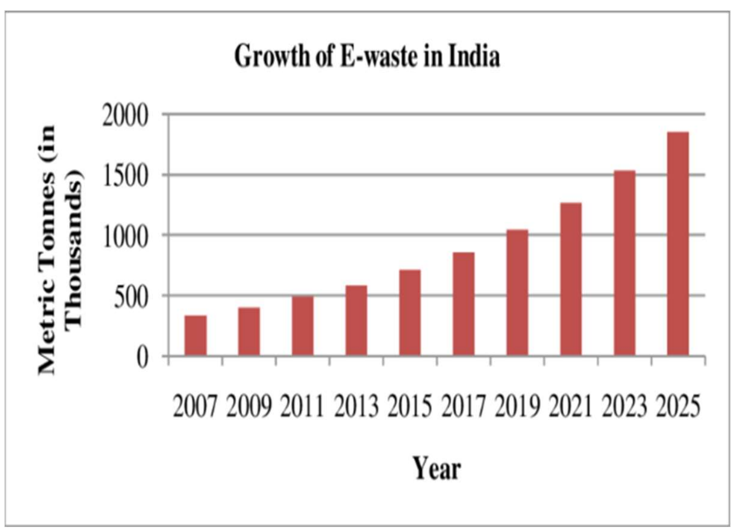

Fig. 6. Growth of E-waste In India [21]

The rapid and concerning expansion necessitates the adoption of an eco-friendly approach, imperative for fostering a sustainable practice of IT E-Waste management. Recycling is categorized within the green disposal domain of green computing and stands out as one of the most effective methods to address the e-waste issue. Recycling involves repurposing end-of-life products, which contain a variety of recyclable materials, that can undergo reuse or recycling, ultimately lowering the expenses associated with manufacturing new IT equipment. Additionally, recycling aids in reducing greenhouse emissions stemming from the production of new IT resource products.

C. End-user IT Resource power management

Discipline in electronic device usage is essential for promoting sustainable computing practice, small initiatives often mark the beginning of significant change. Take, for example, simple yet impactful actions such as configuring power settings on computers or phones to transition into sleep mode during periods of inactivity. By setting your PC to standby mode and powering off the monitor when you anticipate being away for more than a few minutes, substantial energy savings can be achieved[22].When your computer is powered off, it consumes no energy [23].

Table 1- End-User It Resource Power Management

End-user IT Resource power management	
Mode of operation	**Power Consumed (Unit in Watt)**
Power off	0
Stand By	2.3
Sleep	3.1
Hibernate	2.3

Along with that Operating System (OS) is instrumental in effectively managing the power consumption of a computing system. Figure 7 illustrates the power consumption rates of different operating systems currently available in the market [24].

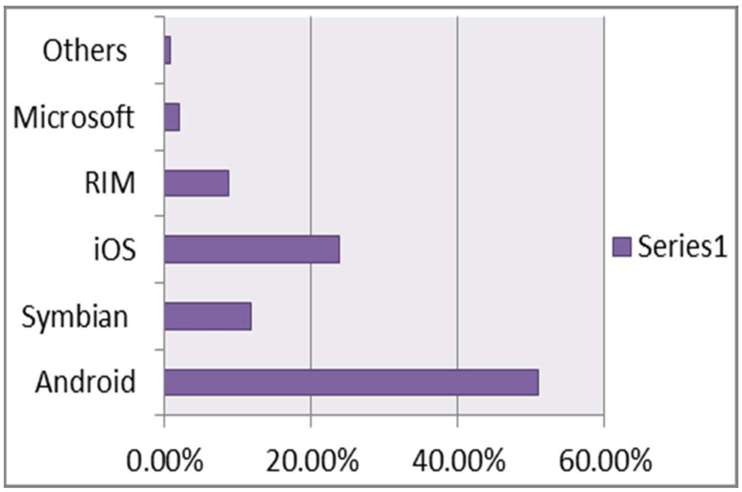

Fig. 7. Power consumption rates of different operating systems [24]

D. Buying energy-certified equipment

ENERGY STAR products surpass conventional counterparts by either matching or surpassing their performance while consuming less energy [25]. Energy Star computers are more efficient by 30-70% when compared to equivalent non-Energy Star devices. Another notable benefit of ENERGY STAR is its focus on sustainability, which impacts users in multiple ways. Primarily, it stems from decreased energy consumption, helping to lower carbon footprint. The table 2 provides a comparison of different IT resources and their corresponding carbon emissions.

Table 2: Carbon Footprint of Different It Resources

Carbon Footprint of Different IT Resources	
IT Resource (8 Hours Usage)	Amount of Carbon Emissions (Annually)
Desktop and Screen	621 kgs of CO_2e
Laptop and Screen	691 kgs of CO_2e
Printers	474g of CO_2e
Servers	6 tons of CO_2e
Internet Connection	1.6 billion tons of CO_2e

The choice of device significantly influences power consumption, consequently affecting the carbon footprint.

Therefore, opting for IT resources that are more energy-efficient than conventional ones is advisable.

E. Use of renewable energy sources for ICT

Renewable energy is derived from naturally replenished sources that are inexhaustible, including sunlight, tidal movements, and wind. Utilizing conventional fuels releases greenhouse gases and other harmful pollutants, which can result in respiratory and cardiovascular health problems. By adopting renewable energy sources, you're aiding in reducing the prevalence of these pollutants and promoting a healthier and safer environment [26][44][45][46].

Educational institutions can embrace renewable energy integration through diverse methods, including rooftop solar panel installations for electricity generation, harnessing wind energy via turbines on suitable campus sites, and exploring small-scale hydroelectric options near water sources. Biomass energy derived from organic waste can serve for heating or as a fuel source. Implementing educational programs on renewable energy and sustainability can heighten awareness among students, faculty, and the wider community, fostering an ethos of environmental stewardship. By engaging in research, innovation, and partnerships with renewable energy stakeholders, educational institutions can lead in advancing renewable technologies, curbing their carbon footprint, and setting sustainable examples for future generations [27].

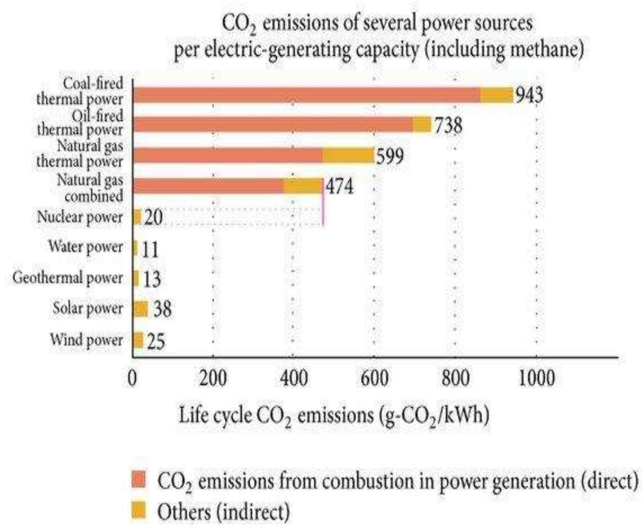

Fig. 8. CO2 Emissions of Several power sources [28]

According to the report by the World Resource Institute's Sustainability Data, educational institutions, including colleges, universities, junior colleges, and professional schools collectively ranked second in carbon emissions production.

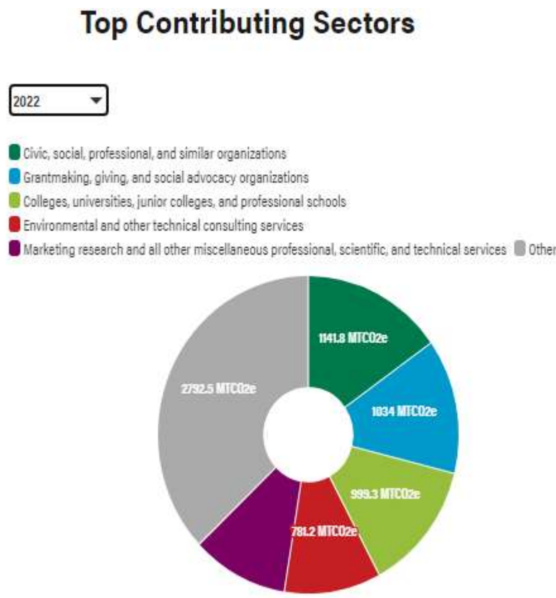

Fig. 9. Top Contributors of CO2 emissions [29]

Given that the education sector ranks as the second-largest contributor to CO2 emissions, it is crucial to adopt and adhere to best practices in achieving sustainable computing.

VII. COMPARATIVE ANALYSIS OF DIFFERENT SUSTAINABLE COMPUTING PRACTICES IN EDUCATION.

The survey conducted among key stakeholders in the education sector, including students, academics, and researchers, has revealed that a significant majority still adhere to traditional computing methods. This reliance on conventional practices poses potential hazards to both the environment and humanity as a whole. As part of our research, we have conducted a comparative analysis between the prevailing conventional approaches and the recommended best practices in sustainable computing.

Table 3: Comparative Analysis of Different Sustainable Computing Practices in Education

Comparative Analysis of different Sustainable computing practice in education		
Parameter	**Traditional computing**	**Sustainable Computing**
Life span	4-5 years	8-10 years
Power Consumption	3000 to 4500 MWh	800 to 1400 MWh per year
Annual CO2 emissions (kgs)	237,930 (5000 Users)	183,408(5000 Users)
E-Waste Management	It consists of toxic materials Due to lower life span leads to higher landfills.	Thin clients having a longer life span and lesser HW requirements create less waste compared to a regular PC
Cost Effectiveness	High-cost Requirement	Minimal Cost due to less power consumption and reusability
Safety	Hazardous Martial usage, Increased Carbon Footprint	Green reusage and recycling of materials. Reduced carbon footprint.

VIII. RESULT AND CONCLUSION

This paper addresses these issues stemming from extensive technology usage and IT resource utilization. Its primary aim is to assess awareness levels regarding green computing and sustainable IT practices within the education sector. To achieve this, a questionnaire was administered to students, educators, and researchers. Analysis of the questionnaire revealed a substantial gap between knowledge and actual practices, with respondents demonstrating moderate familiarity with green computing concepts and minimal engagement in sustainable practices. Through this paper, we endeavour to bridge this knowledge-practice gap by suggesting the best practices in sustainable computing, supported by comparative analysis. Our central objective is to raise awareness about the detrimental effects of conventional computing practices in the education sector.

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