National Research Journal of Information Technology & Information Science ISSN: 2350-1278
Volume No: 13, (January) Year: 2026 (Special Issue) Peer Reviewed & Refereed Journal (IF: 7.9)
PP: 303-310 Journal Website www.nrjitis.in

GREEN COMPUTING-A REVIEW

Chanpreet Kaur

Student, Guru Nanak Dev Engineering College, Ludhiana

Harminder Kaur

Assistant Professor, Guru Nanak Dev Engineering College, Ludhiana

ABSTRACT

The undertaking task of "Saving Planet Earth" has become essential to all of us for the sustainable life on the Earth. The necessity of sustainable development and urgency to save Earth stems from the increasing pressures of human activities which result in global warming and greenhouse emission. In today's world IT is playing a pivotal role in ensuring the integration of technologies and systems. Day by day there is an escalation in energy consumption by IT resources. To provide solutions and focus on this key problem, a new paradigm "Green Computing or Green IT" appeared. This paradigm promotes the environmentally responsible use of computer resources which involves employing energy-efficient processors, servers, and peripherals, along with responsible e-waste disposal practices. The goal is to minimize the carbon footprint of IT operations worldwide. Various dimensions of environment sustainability, energy efficient economy, reusability or recyclability of used products are included in the broader way of this paradigm. These dimensions have also paved the reasons for developing this approach as it manages to save power, produces long term benefits, reduces pollution and increases performance etc. Technologies like Green Cloud Computing, Internet of Things (IOT), Green Servers, and nano computing are the key drivers in the progress of Green Computing. Furthermore, various enforcement policies by government agencies or corporate sectors effectively catalyze the implementation of Green Computing. Additionally, it is also spreading awareness that sustainable computing practices are important and how to make their usage in an eco-friendly manner.

General Terms

Green IT, Eco-friendly IT, Energy Efficiency, Environmental Pollution

Keywords: Sustainable Development, Green Computing, IOT, Green Cloud Computing, Green Servers, Nano Computing, Bio Computing, Virtualization

1. INTRODUCTION

Recent global and economic expansion driven by geopolitical integration has led to the transformation of economies and industries. However, this growth has occurred at the cost of the environment and its resources creating challenges such as resource scarcity, environmental sustainability and rising potent problems.

In the article Harnessing Green IT: Principle and Practices, San Murungesan defines the field of green computing as "the study and practice of designing, manufacturing using and disposing of computers, servers and associated subsystems such as monitors, printers, storage devices and networking and communication systems efficiently effectively with minimal or no impact on the environment" [1].

In the previous decades IT users have grown so immensely that now it has become important to address concerns such as power consumption and development of sustainable solutions. Green Computing is the term that originated in the early 1990's in response to the negative concerns about the environmental impact. In the article Green Computing and its Impact: Dr Shailendra Singh emphasizes that green computing can be defined as, "Innovative approach to manufacture eco-friendly hardware devices and components, innovative techniques for developing energy saving software and set of practices to support the critical mission of saving Earth."[2].

As IT stakeholders have grown enormously, any business enterprise having the involvement of IT impacts on the environment. In today's era where everyone wants to store their respective data online resulted in an increase in data volumes which are going to double every 18 months. For the storage of huge amounts of data an improvement in data centers and hardware infrastructure is required. These improvements and requirements are responsible for heating and Carbon Dioxide emission (see Figure 1).

ISSN: 2350-1278
Peer Reviewed & Refereed Journal (IF: 7.9)
Journal Website www.nrjitis.in

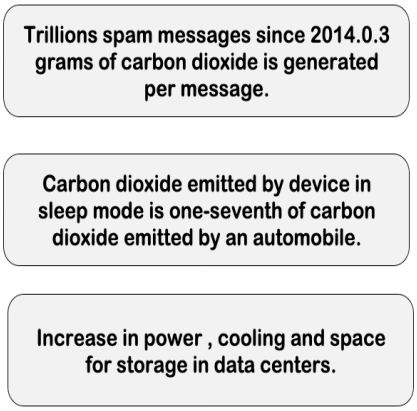

Figure 1. Activities responsible for carbon generation

Going Green also aims to reduce the carbon emissions that are substantially increasing by the Information Technology and Systems business and related industries.

A higher concentration business activity leads to more carbon generation. Therefore, a systematic approach is required so that eco-friendly hardware and software can speed up.

2. WHAT IS THE NEED FOR GREEN COMPUTING?

Green computing inspires us to research and reflect on current hardware and software trends and to identify the barriers that may contribute towards the degradation and depletion of the environment. We have always perceived that computers are non-polluting, clean and energy efficient. But computers and their use have impacted the environment by contributing towards environmental pollution.

In the article : Green Computing, a Contribution to Save the Environment, "It is estimated that out of $250 billion per year spent on powering computers worldwide only about 15% of that power is spent computing, the rest is wasted idling (i.e. consumed by computers which are not in use but still turned ON)."[3] Consequently the percentage of consumption by various data centers has been increased(see Table 1).

Table 1. Shows the Percentage of Power Consumption by Data Centre Device [5]

Equipments used in Cloud Data Center	Percentage consumption
Cooling Device (Chiller, Computer Room Air Conditioning (CRAC))	42%
IT Equipment	30%
Electrical Equipments (UPS, Power Distribution Units (PDUs), lighting)	28%

In the article: Green Computing Need and Implementation, "All computer related terms like Data Centers & its peripherals and Network & networking devices all produce a large amount of CO_2 emission. But the huge part of CO_2 emission produced from only Pc's is bad for the environment because they are not biodegradable, and the parts and pieces will be around forever, and they are rarely recyclable." [4].

Adequate techniques and optimal methods are required to reduce energy consumption and heat dissipation. The implementation of green IT standards is crucial for greener planet Earth.

In order to endorse Green Computing at all feasible levels, the following approaches have come into existence.

The following listed reasons justify the need of green computing:

- Reducing carbon consumption leads to lower operational costs in businesses.
- Drastic climate change also focuses on the development of Green IT

- It promotes the usage of disposable products so that environmentally friendly and efficient surroundings are created.
- It aims to reduce the pollution and negative impact of greenhouse gases.

3. HOLISTIC APPROACH OF GREEN COMPUTING

The serious issues such as global warming and improper management of energy consumption are caused by electronic equipment and the developing IT sector. Green Computing is the comprehensive and effective solution to ITs environmental impact. The solution requires a holistic strategy which tackles the issue from four complementary paths.

The major domains of the interconnected strategy are: Green Use, Green Design, Green Disposal and Green Manufacturing which are used in designing the effective and comprehensive strategy of Green IT (see Figure 2).

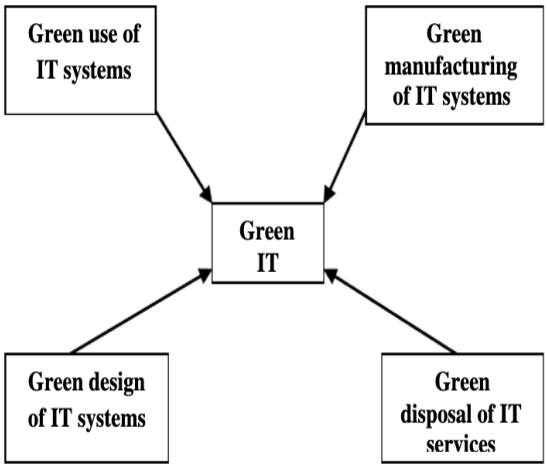

Figure 2. An Integrated approach to Green Computing

Green Design: It refers to creating energy-efficient equipment with reduced emissions and heat generation.

Green Use: It involves reducing energy use in an ecologically balanced way.

Green Manufacturing: It emphasizes making use of environmentally friendly materials and processes during production.

Green Disposal: Its motive is proper recycling and disposability of electronic waste to prevent resource depletion.

By focusing our efforts on these four key areas will allow us to achieve comprehensive environmental sustainability in IT, creating greener practices from the initial design and manufacturing stages all the way through to the end-of-life management of IT equipment.

4. MAJOR COMPUTING TECHNIQUES FOR GREEN COMPUTING

A lot of energy has been consumed by computing and its wrapped technologies. In the article A Study of Green Computing Techniques, "From 2000 to 2005 – a five-year period - the energy used by servers doubled. It is predicted that by 2010 the amount of energy used by these servers would have increased by up to 70%. This is only for servers, the figure for personal computers is likely to be higher as we had over 870,000,000 PCs in 2005, and the predicted number last year was over 1.1 billion." [8]

Energy consumption associated with widespread computing is unsustainable and contributes significantly to greenhouse gas emissions. Furthermore, the sheer volume of computing hardware globally presents a substantial environmental challenge. This equipment is often manufactured using highly toxic and hazardous chemicals, and its relatively short lifespan (sometimes less than three years) aggravates the problem. Improper disposal practices frequently result in hardware ending up in landfills or being exported to developing nations, leading to environmental contamination by these toxic substances. Recognizing these issues, both emerging and established industries are now actively pursuing the principles and practices of green computing.

The following techniques support the advancement of Green Computing as described below:

4.1 Green Cloud Computing (GCC)

A user on the Internet can communicate with many servers at the same time and these servers exchange information among themselves [9].

Cloud computing is a new computing model that can deliver computing and storage resources as per the needs of users. This paradigm is assisted by technologies like Virtualization, Software as a Service (SaaS) and broadband internet. The introduction of new technologies and computing parameters of cloud computing has increased its use. The results by Gartner in 2009 show the areas of its use (Figure3)[6].

Cloud computing (CC) has resulted in increased emissions of carbon dioxide because computers and peripherals draw significant amount of energy in sleep and standby modes. Data virtualization and energy-saving software strategies are being implemented to reduce the energy demand that save power of data center equipment. However, with the increased use of cloud computing and its supporting data centers it is expected that energy consumption will touch even higher levels.

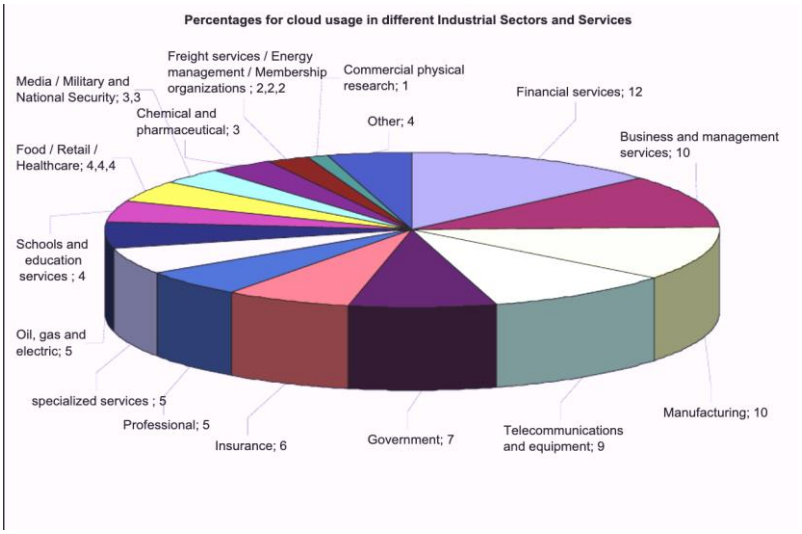

Figure 3. Cloud Usage

To minimize the impact of harmful substances and reduce energy consumption thereby increasing the energy efficiency, green cloud computing has been introduced. The idea "Green" is attached to cloud computing which indicates that cloud computing services will support Green IT.

To address this issue, adoption of an environment friendly solution is essential for sustainability which ultimately rediscovered Cloud Computing to Green Cloud Computing. GCC may be defined as an energy efficient eco-friendly flavor of CC.

The GCC model ensures the use the resources whenever required, thus preventing idle energy consumption. The major key feature of this system is Virtualization which allows multiple operating systems to run on one hardware and therefore eliminating the need of multiple machines. Hence with this approach a considerable number of emissions can be controlled.

4.2 Internet of Things (IOT)

IOT has immense capability in bringing the improvement in our lives and creating a more sustainable world, but on the other hand it also presents environmental challenges. However, with the application of "Green IOT" these potential challenges can be minimized by reducing the energy consumption and carbon footprint of IOT devices and infrastructure. It primarily focuses on developing energy-efficient hardware and software thus promoting sustainable manufacturing, deployment and recycling processes (see Figure4). Therefore, it uses IOT to build eco-friendly solutions.

ISSN: 2350-1278
Peer Reviewed & Refereed Journal (IF: 7.9)
Journal Website www.nrjitis.in

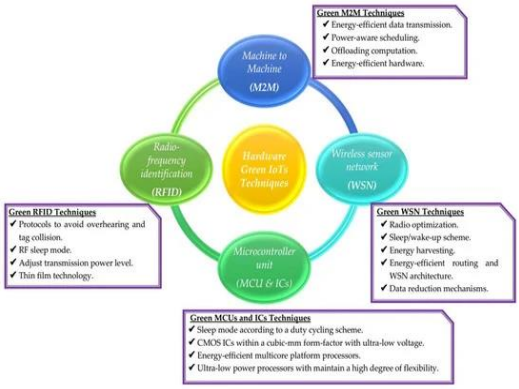

Figure 4. Proposed Framework and energy efficient techniques for Green IOT [7]

4.3 Green Servers

The rapid expansion of data centers has been driven with the rise of the internet and web applications. Different businesses are constantly adding more servers or increasing their existing capacity. Over the past ten years, the number of servers in data centers has increased six times and therefore the total electricity consumption of servers doubled between 2000 and 2005, primarily due to businesses installing large numbers of new servers. As energy costs rise globally, the operational expenses of data centers are steadily increasing. The social, financial, and logistical pressures will compel businesses and IT departments to reduce energy consumption in their data centers. Improvements can be achieved through several strategies: deploying new energy-efficient equipment, optimizing airflow to minimize cooling needs, implementing energy management software, and adopting environmentally conscious designs for both new and existing data centers. In modern IT, the term green data centers were coined to uplift the paradigm of green computing. These servers work in a manner to minimize carbon dioxide emissions, reduce heat dissipation and make use of biocompatible devices and components. Data centers can reduce their environmental impact by incorporating eco-friendly components, software optimization which reduces energy consumption. Usage of green electronic components and devices and secondly optimization of power consumption with the aid of software techniques can support the data centers. Businesses, enterprises, multinational companies and individuals are called upon to observe the parameters like power usage, carbon usages and energy usages. The observation of these usages can be helpful to solve the problem of energy consumption during sleeping mode of the device. Further points to consider are that CPU frequency can also be dynamically set as per instructions and sending hardware components to zero power mode curtails the unnecessary power consumption. In addition to this, software techniques can also promote green solutions such as power optimization coding to search data and visualization. Leveraging virtualization has cut down the installations and configurations of different servers and thereby reducing the hardware footprints. Furthermore, dynamic memory allocation of virtual machines allows for more CPU utilization and greater energy savings are provided.

4.4 Virtualization

Use of virtualization leads to the reduced number of servers thus giving a pathway to Green IT. The traditional approach of assigning dedicated servers to specific computing tasks because of its safer way has become widespread. Vendors like Microsoft have often recommended this model, leading to a significant increase in the number of servers within data centers to handle various functions like domain control, file storage, email, and databases. This proliferation of servers has resulted in escalating power and cooling demands, along with increased challenges in standardization and patch management, ultimately driving up the total cost of ownership. In environments where servers are underutilized, virtualization offers a solution by partitioning a single physical server into multiple virtual servers. This approach typically leads to a significant reduction in power and cooling needs, resulting in energy and cost savings, and a smaller carbon footprint for the server infrastructure.

Additionally, power and disposal requirements of desktops can be reduced through this strategy. It involves moving users' existing PC environments to virtual machines running on central servers. Users retain their familiar setup, and even better, their virtual PC becomes accessible from anywhere with an internet connection – the office, home, or even across the world. Accessing these virtual PCs remotely is straightforward, and boot times are significantly faster. Users also gain reliability and reduced maintenance of the company's server infrastructure, leading to lower costs. Environmentally, desktop virtualization offers two key advantages: lower power consumption and less frequent hardware upgrades, since

thin clients or terminals have a longer lifespan than traditional PCs. Furthermore, centralized maintenance reduces the need for engineers and support staff to travel, thus minimizing their carbon footprint as well.

4.5 Bio-Computing

Bio-computers are computing systems that represent a radical departure in computational paradigms, leveraging the inherent characteristics of molecular structure and behavior for information processing. This emerging field encompasses various approaches, including bio-chemical, biomechanical, and bio-electronic computing, each with distinct mechanisms for representing and manipulating data. Biochemical computers utilize changes in chemical bond structures and configurations to encode information states. Similarly, bio-mechanical computers process information by manipulating chemical bonds, but interpret the resulting mechanical shapes of molecules as data. While these information processing systems exist naturally in non-living systems, they currently lack human control. Bio-electronic systems, on the other hand, employ measurements of electrical activity within biomolecules to represent information. The inherent use of natural elements in bio-computing offers significant potential for developing environmentally sustainable and eco-friendly computational technologies.

4.6 Nano Computing

Green Computing can be further advanced with the aid of Nano Computing which uses extremely small or nano devices. This small working nano unit which is as small as biological viruses facilitates the development of devices having less operating power and increases the battery life. In this way they have an impact on revolutionizing green computing which leads to sustainable development.

5. ISSUES AND CHALLENGES AHEAD

As coin has two sides, similarly despite having advantages of Green Computing there are some critical issues that need to be taken care of with this eco-friendly paradigm. Some of the setbacks are as follows:

- Involvement of high Research Cost
- Inadequate awareness among people about the new paradigm.
- There is a lack of good recycling options.
- Re-development optimized green solutions and re-design of architecture of hardware devices.
- Needs more enforcement of eco-friendly standards and policies.
- Available eco-friendly devices are costly
- Lack of proper research on best programming practices and software techniques.

6 FUTURE OF GREEN IT

The growing adoption of green computing practices has a positive impact on environmental concerns. A key focus of future green technologies is minimizing the environmental harm caused by computing. In the article Green Computing: Future and challenges in IT industry from system design to application: “Green Computing involves minimizing waste by purchasing only what is needed, sharing computers and printers, turning off the monitor and computer when not in use, refilling inkjet cartridges with soy or non-petroleum based inks, printing only what is necessary, recycling office paper waste, giving away your computer to charity, family or friends, choosing computers that minimize energy consumption (laptops consume 1/10 energy of a desktop and inkjets consume 80% less energy than laser printers, smaller monitors consume less energy, energy consumption varies from model to model) and participating in computer recycling programs.”[8].

In near future Geen IT will likely encompass the following key aspects:

6.1 Shift towards Eco-friendly Components in Computers

The shift towards eco-conscious computer components marks a significant step in mitigating the environmental impact of technology. A growing number of PC manufacturers are embracing sustainable practices by integrating biodegradable and renewable materials into their products. HP, for instance, has pioneered the use of a biodegradable plastic derived from corn in the construction of its printer casings, demonstrating a commitment to reducing reliance on traditional petroleum-based plastics. Other manufacturers are exploring the aesthetic and ecological benefits of incorporating wood and bamboo, rapidly renewable resources, in the design of computer towers, monitors, and input devices. This trend reflects a broader industry recognition of the need to minimize the environmental footprint of electronic devices.

6.2 Developments in Energy Efficiency

The pursuit of energy-efficient computing extends beyond display technology. Significant strides are being made in the development of more energy-conscious computer hardware. The Energy Star 4.0 specifications, coupled with the 80 PLUS certification program, are driving manufacturers to adopt power supplies that maximize energy conversion efficiency. These standards incentivize the use of power supplies capable of converting at least 80% of the electricity drawn from the wall outlet into usable computing power, minimizing energy waste and reducing heat generation. VIA Technologies stands out as a prime example of a company prioritizing energy efficiency in its chip design. Their focus on developing efficient chips and fan less ITX circuit boards, exemplified by their 2 GHz chip that consumes a mere 20 watts, demonstrates a commitment to low-power computing. Furthermore, VIA's "Carbon-Free Computing" initiative, which offsets the lifetime energy consumption of their chips through investments in reforestation, alternative energy development, and conservation projects, highlights a holistic approach to environmental responsibility.

Intel's Core 2 Duo processor marks a significant step forward in environmentally friendly computing. It only consumes power for the parts of the chip actively in use. Marvell's processor chip utilizes power factor correction (PFC) to assess the power needs of specific applications, optimizing energy consumption for maximum efficiency. These energy-saving technologies are expected to become standard in the future, with continued advancements leading to even greater innovations. Additionally, the progress of nanotechnology promises improved energy efficiency. Future nano-computer chips could be several times smaller and far faster than current models like the i3 and i5 processors. Another groundbreaking concept that may emerge is the ability to generate the power required for computing from keystrokes, mouse movements, and the light emitted by the monitor.

6.3 Decarbonizing Computing

Decarbonizing Computing refers to carbon free computing which means that in the future green computing focusses on reducing the carbon footprint. The pursuit of energy-efficient computing extends beyond display technology. Significant strides are being made in the development of more energy-conscious computer hardware. The Energy Star 4.0 specifications, coupled with the 80 PLUS certification program, are driving manufacturers to adopt power supplies that maximize energy conversion efficiency. These standards incentivize the use of power supplies capable of converting at least 80% of the electricity drawn from the wall outlet into usable computing power, minimizing energy waste and reducing heat generation. VIA Technologies stands out as a prime example of a company prioritizing energy efficiency in its chip design. Their focus on developing efficient chips and fan less ITX circuit boards, exemplified by their 2 GHz chip that consumes a mere 20 watts, demonstrates a commitment to low-power computing. Furthermore, VIA's "Carbon-Free Computing" initiative, which offsets the lifetime energy consumption of their chips through investments in reforestation, alternative energy development, and conservation projects, highlights a holistic approach to environmental responsibility. VIA is striving to pioneer the world's first truly carbon-neutral computing experience. While these "carbon-free" computers do contribute to greenhouse gas emissions during their lifespan, VIA aims to counterbalance this "carbon footprint" through various offsetting initiatives. These offsets include investments in projects like reforestation, which actively remove carbon dioxide from the atmosphere.

The pursuit of carbon neutrality in computing is also driving innovation in other areas. One such avenue is the development and integration of solar energy cells to power computing devices. Furthermore, the broader push for carbon-free computing is fueling the development of green energy sources that produce zero carbon emissions, providing a sustainable power foundation for the future of technology.

6.4 Advancements in Recycling Technology

While the recycling of electronic waste (e-waste) has already become a significant initiative worldwide, the potential for future green technologies promises to bring even greater advancements in sustainable recycling practices. As environmental concerns continue to rise, there is a growing push for innovation in how we handle and repurpose outdated technology. The next generation of green technology is set to take e-waste recycling to a new level, contributing to a more sustainable future and minimizing environmental harm.

In the coming years, we may see major developments that include desktop computer manufacturers fully embracing the concept of zero waste. By reusing or recycling every single part of old computers, manufacturers can ensure that nothing goes to waste. This could involve salvaging components like circuit boards, memory chips, hard drives, and even smaller items like screws and cables, which could all be refurbished or repurposed for new devices. Such practices would not only reduce the volume of e-waste that ends up in landfills but also promote a circular economy where resources are continually reused, creating a more sustainable life cycle for electronic products.

Another exciting possibility for the future is the concept of networking multiple old computers into a single, more powerful processing unit. This system would allow several smaller devices to access the combined processing power of older, underutilized computers. By connecting these machines in a network, businesses and individuals could maximize the value of older hardware, reducing the need to discard devices prematurely. This approach could also lead to more efficient use of resources and energy, further contributing to the reduction of electronic waste and the carbon footprint associated with manufacturing new devices.

The concept of green computing is expanding rapidly, driven by the growing awareness of the need for environmentally sustainable practices in the technology industry. As the world becomes more focused on sustainability, green computing is emerging as a booming industry. From reducing energy consumption in data centers to using eco-friendly materials in computer manufacturing, green computing encompasses a wide range of practices aimed at minimizing the environmental impact of technology. All major companies across the globe, including those in the tech industry, are increasingly embracing some form of green computing technology. These companies are not only adopting sustainable practices in their operations but are also actively seeking new ways to deepen their involvement in green initiatives. Whether through investing in renewable energy sources, improving product energy efficiency, or advancing recycling efforts, these companies are setting the stage for a more sustainable future in computing.

As the demand for sustainable solutions grows, further advancements in green technologies will play a crucial role in reshaping how the world uses and recycles technology. By continuing to innovate in recycling practices and energy efficiency, we can look forward to a future where technology and sustainability work together for the benefit of the environment and future generations.

7. CONCLUSION

To accomplish the mission of greener and safer environment, energy consumption must be minimized to meet the sustainability criteria and environment friendliness of smart cities. The paradigm of Green Computing is the considerable approach to sustaining the computing capacity. By adopting and implementation of biocompatible techniques recyclable equipment can be manufactured, disposable material can be reused, and greenhouse gases can be properly controlled. Green Computing is therefore a great solution to create the foundation of a sustainable ecosystem as it has strengthened its deep impact on society and environment to make earth green. Adopting green computing strategies isn't just ethically sound; it's a smart business decision. Implementing such strategies offers numerous commercial advantages, including cost reductions, improved resilience, enhanced disaster recovery and business continuity planning, and positive public relations. Looking to the future of green computing, IT leaders in today's information-driven economy have a unique opportunity to make a substantial contribution to combating global warming while simultaneously improving business operations and efficiency. In today's competitive landscape, green computing is essential for environmental protection, energy conservation, and cost savings. Embracing a holistic approach to greening IT is our collective responsibility towards building a more sustainable future.

REFERENCES

1. San Murugesan, January-February 2008 Harnessing Green It: Principles and Practices, pp 24-33
2. Shailendra Singh, November 2015, Green Computing and its Impact, pp 69-83
3. Maria Salama, May 2020, Green Computing, a Contribution to Save the Environment
4. A.Sivasankari, S.Poovarasi, R.Rasathi,2015 Green Computing-Need and Implementation,International Journal of Science and Technology and Management,Vol No 4,Issue 10,October 2015
5. Ms. V.Srimathi, Ms.D.Hemalatha,Me. R.Balachander ,December 2012 Green Cloud Environmental Infrastructure,International Journal of Engineering and Computer Science,pp 168-177
6. Gartner, 2009,Cloud computing Inquiries at Gartner
7. Mohammed H.Alsharif, Abu Jahid, Anabi Hilary, Kelechi and Raju Kannadasan, March 2023 Green IoT: A Review and Future Research Directions
8. Shyoraj Jat, Siyaram Yadav, January 2014,Green Computing: Future Challenges in IT industry from system design to application,
9. B.Hayes, 2008,Cloud Computing,pp 9-1