


Emerging issues in computer science



Week 11: Green Computing and Sustainable Technologies

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Lecture Learning Outcome

- At the End of Lecture 11 you will be able to:
- Understand Green Computing and Its Environmental Impact
- Understand Green computing Life Cycle
- Identified Factors Promoting Negative Environmental Impact
- Understand the Implications of Computer-Based Wastes
- Understand IOT and Green Computing: The Green Internet of Things (GIOTs)
- Understand Green cloud computing

Understanding Green Computing and Its Environmental Impact

Definition and Goal of Green Computing (GC)

Green computing refers to the efficient and environmentally responsible use of computing resources and IT infrastructure. Its primary goals are to minimize environmental harm, enhance economic viability, and improve system performance. This encompasses a wide range of practices, including the use of alternative energy sources, energy-efficient technologies, recyclable materials, and the implementation of sustainable digital services.

- Green computing is viewed as crucial in the fight against climate change, pollution, and ecological degradation.
- Its widespread adoption can help reduce the ICT sector's carbon footprint, which is growing rapidly due to digital transformation.

Green computing Life Cycle

1. Green Design

- Energy-Efficient Hardware: Prioritizing the development of hardware that consumes less power without compromising performance.
- Environmentally Friendly Materials: Utilizing sustainable materials in the manufacturing process to reduce environmental impact.
- Modular Designs: Creating systems that are easy to repair and upgrade, extending the product's lifecycle.

2. Green Production

- Low-Energy Manufacturing: Implementing energy-efficient production methods to minimize energy consumption during manufacturing.
- Emission and Waste Reduction: Adopting practices that reduce emissions and waste throughout the production process.

Green computing Life Cycle

3. Green Procurement

- Eco-Labeled Products: Selecting products that have been certified for their environmental performance.
- Energy-Efficient Equipment: Choosing computing equipment that is energy-efficient and recyclable.

4. Green Operations

- Efficient Device Usage: Implementing practices such as turning off unused systems and utilizing cloud services judiciously to reduce energy consumption.
- Data Center Optimization: Enhancing data center efficiency through virtualization, improved cooling techniques, and the use of renewable energy sources.

Green computing Life Cycle

5. Green Disposal

- Safe Recycling Practices: Ensuring that electronic waste is recycled through certified programs to recover valuable materials and prevent environmental contamination.
- E-Waste Take-Back Programs: Encouraging manufacturers to take responsibility for the entire lifecycle of their products, including end-of-life disposal.

Green technology solutions

Green Manufacturing in ICT

- Green manufacturing in Information and Communication Technology (ICT) involves integrating environmental responsibility throughout the entire lifecycle of ICT infrastructure. Leading technology companies are adopting green standards to reduce ecological impact, enhance economic viability, and improve system performance.

Aspects:

- **Eco-Friendly Design:** Designing hardware to meet stringent environmental standards, such as Energy Star certification, which enables devices to enter low-energy states when inactive, thereby saving electricity and extending hardware lifespan.
- **Use of Bio-Based Materials:** Employing biodegradable and renewable materials, like plant-based biopolymers, to replace traditional toxic materials. This reduces energy consumption during production and minimizes environmental contamination.

Green Use in Computing

- Green Use in computing emphasizes optimizing energy consumption and reducing environmental impact throughout the lifecycle of computing resources. Key strategies include:
- **PC Power Management:** Utilizing the Advanced Configuration and Power Interface (ACPI) standard, systems can automatically enter low-power states such as sleep, standby, or hibernation when inactive. Additionally, technologies like Intel's SpeedStep and AMD's Cool'n'Quiet adjust processor voltage to match workload demands, conserving energy and reducing heat generation.



Green Use in Computing

- Virtualization: This technique allows multiple virtual machines to operate on a single physical server, enhancing resource utilization and reducing the need for additional hardware. By consolidating workloads, virtualization decreases energy consumption and physical space requirements, contributing to more sustainable IT operations



Green Disposal

- Green Disposal focuses on extending the lifespan of computing equipment and ensuring its environmentally responsible end-of-life management. This approach encompasses:
- Reuse: Functional computers that no longer meet the user's needs can be donated to others or repurposed for their components. Many charities and non-profit organizations accept such donations to refurbish or utilize specific parts, thereby reducing environmental impact by delaying disposal.

Green Disposal

- **Refurbishment:** Reconditioning and upgrading old equipment can extend its usability. Refurbished hardware offers a cost-effective alternative to new devices, with the added benefit of reducing electronic waste. It's important to distinguish between "refurbished" products, which have been tested and restored to proper working condition, and "used" products, which may not have undergone such processes.
- **Recycling:** Recycling involves processing electronic waste to recover valuable materials and prevent environmental contamination. E-waste contains hazardous substances like lead, mercury, and cadmium, which can leach into soil and water if not properly managed. Recycling helps mitigate these risks and recovers valuable metals such as gold and copper, turning waste into a resource.

Scope of Green Computing

Green computing applies across all layers of ICT infrastructure, including: Large-scale computing environments:

- Data centers that power cloud computing, big data analytics, and AI models.
- Industrial ICT systems used in manufacturing, banking, and telecommunications.

Mobile and personal computing:

- Devices like smartphones, laptops, tablets, and wearables.
- Their increasing demand contributes significantly to e-waste.

Entire lifecycle impact:

- From raw material extraction to design, manufacturing, use, and disposal/recycling.
- Green computing seeks to address every stage in this lifecycle to limit resource depletion, pollution, and climate impacts.

Identified Factors Promoting Negative Environmental Impact

Unregulated ICT Infrastructure Deployment

- The rapid, often unregulated proliferation of ICT infrastructure—particularly data centers, telecom towers, and networked systems—is contributing heavily to energy consumption and greenhouse gas (GHG) emissions.
- These facilities require constant electricity, cooling systems, and high-performance computing, most of which are powered by fossil fuels in many countries.

Some of the Consequences:

- Increased carbon footprint from powering and cooling infrastructure.
- Accelerated climate change impacts through localized heating and emissions.
- Lack of energy-efficient designs leads to wasteful resource use.



Identified Factors Promoting Negative Environmental Impact

2. Post-COVID Surge: The shift to a digital-first global economy post-COVID-19—remote work, e-learning, digital finance, etc.—has led to:

- More data usage.
- Expansion of cloud services and data centers.
- Higher demand for always-on systems, especially in industries like banking, logistics, health, and education.

Identified Factors Promoting Negative Environmental Impact

3. Rapid Technological Evolution: The pace of innovation in ICT is extremely high—particularly in areas like smartphones, PCs, IoT devices, and AI-powered systems. Devices become obsolete quickly, not because they fail, but due to planned obsolescence or market-driven upgrades.

- Some of the Impacts that come with Rapid Technological Evolution: Frequent upgrades and newer models lead to shorter device lifespans.
- Working but "outdated" devices are discarded or exported to developing nations, which have turned into dumping places hence causing very level pollution
- Increased demand for rare earth metals and energy-intensive manufacturing, putting pressure on ecosystems.

Identified Factors Promoting Negative Environmental Impact

3. Socioeconomic Inequities in Developing Countries: Developing countries often lack the policy frameworks, financial capacity, and technological infrastructure to manage or recycle e-waste safely.

- These regions become the dumping grounds for outdated technology and hazardous waste under the guise of “second-hand” or “donated” electronics.

Challenges:

- Weak enforcement of environmental regulations allows unrestricted importation of e-waste.
- Many developing nations suffer environmental degradation, but have limited capability to respond.
- Economic inequality forces citizens to engage in informal recycling, risking their health and the environment.

Identified Factors Promoting Negative Environmental Impact

4. Environmental injustice, Unfair Competition, and Electronic Waste

- Electronic Dumping and Environmental Injustice: Countries in Africa (and others) receive tons of e-waste from Europe, North America, and Asia—often disguised as "used" or "donated" electronics.
- This practice has been labeled "environmental injustice" because:
 - Developed nations export their waste burden.
 - Recipient countries lack safe disposal mechanisms.

Three Types of Dumped Electronics:

- End-of-life devices that are still sold.
- Devices phased out from global markets (no updates/support).
- Discarded products from individuals and corporations.

Identified Factors Promoting Negative Environmental Impact

5. Global E-Waste Statistics and Economic Pressures: E-waste growth: Causing huge economic incentive for developed nations to offload waste to the Global South.

- 49M tons in 2016 → 57M tons projected by 2021.
- 5.8 kg/person (2014) → 6.3 kg/person (2017).
- 53.6M tons generated globally in 2019.
- Cost disparity:
 - Proper disposal in developed nations: ~\$2,500 per ton.
 - Importing e-waste in developing countries: ~\$3 per ton.

Identified Factors Promoting Negative Environmental Impact

6. Energy-Intensive Computing (EC): EC involves high-power computing systems like:
- Data centers, Telecom base stations, Industrial cloud computing infrastructure
 - Essential for modern industries (e.g., telecoms, banking, education) but energy-draining and often unsustainable.
 - Environmental Impact: Significant GHG emissions, contributing to:
 - Climate change, Extreme weather events, Food and energy insecurity
 - The infrastructure also generates substantial e-waste due to short upgrade cycles and redundancy.



Health and Sustainability Concerns

- Environmental Impact:
- Soil contamination from heavy metals.
- Air pollution from burning electronics.
- Water pollution from leachates and acids.



Health and Sustainability Concerns-Health Risks

Health Risks:

- Respiratory issues, thyroid problems, cancer, reproductive defects, and neurological disorders.
- Children and pregnant women are especially vulnerable.
- Lifecycle Risk: The recycling/disposal phase is the most hazardous stage of ICT's lifecycle.
- Without proper recycling systems, environmental degradation will accelerate.

Implications of Computer-Based Wastes

1. Nature of Computer Wastes

- Primarily solid waste (e.g., desktops, smartphones, motherboards, routers).
- Unlike industrial waste, they appear harmless but can become dangerous upon decomposition or incineration, releasing toxic gases and leachates.

Implications of Computer-Based Wastes

2. Hidden Chemical Risks

- E-waste contains reactive and hazardous substances:
 - Heavy metals: Lead, cadmium, mercury
 - Other elements: Lithium, cobalt, selenium
 - Plastics & Chemicals: PVC, brominated flame retardants

These chemicals accumulate in ecosystems and bio-magnify, posing risks to both humans and wildlife.

Implications of Computer-Based Wastes

3. Resource Concentration in E-Waste

- E-waste is extremely resource-rich:
 - Gold in circuit boards: 40–800× more than mined ore.
 - Copper: 30–40× higher concentration than raw ore.
- Despite this value, unsafe recycling practices dominate in many regions.

Implications of Computer-Based Wastes

4. Environmental and Health Implications: Improper disposal leads to:

- Air pollution (e.g., from burning plastics)
- Water and soil contamination
- Health effects include: Respiratory stress, infections, neurological damage, Cancers, birth defects, kidney failure, behavioral changes

Global and Regional Responses to E-Waste and Environmental Challenges

1. Key International Initiatives

Libreville Declaration (2008)

- A landmark African ministerial conference on health and the environment.
- It emphasizes the interconnection between environmental degradation and public health across African nations.

Urges African governments to integrate environmental health policies into national development plans



Global and Regional Responses to E-Waste and Environmental Challenges

Busan Pledge (2009)

- A global commitment under the WHO to protect children's environmental health.
- Recognizes the heightened vulnerability of children to environmental toxins, including those from e-waste.
- Encourages governments to implement child-focused environmental safety standards.

UN Decade on Ecosystem Restoration (2021–2030)

- Aims to prevent, halt, and reverse ecosystem degradation worldwide.
- Includes restoring environments affected by industrial pollution, including e-waste dumping sites.
- Supports sustainable production practices and the minimization of industrial and electronic pollutants.



Global and Regional Responses to E-Waste and Environmental Challenges

UNFCCC (United Nations Framework Convention on Climate Change)

- The umbrella treaty guiding global climate change policies.
- Addresses emissions from ICT and energy-intensive computing, pushing for low-carbon technologies.
- Promotes frameworks for sustainable energy and technological innovation that reduce carbon footprints.

Gaps in Existing Responses

- **Broad Focus:** Most international frameworks treat e-waste as a general environmental hazard without singling out computing devices, which have unique challenges (e.g., short lifespans, complex materials, embedded software).
- **Lifecycle Oversight:** There's a lack of targeted strategies that address the entire lifecycle of computing devices—design, production, usage, and disposal.
- **Policy Implementation Failures:** Especially in developing regions, policies exist on paper but lack enforcement, infrastructure, or public awareness backing.

Challenges Confronting Green Computing

1. Manufacturer-Induced Bottlenecks: Manufacturers control obsolescence:

- Design devices with non-removable parts (e.g., batteries)
- Stop supporting older models to push sales of new ones
- Often use non-biodegradable materials and avoid green manufacturing due to cost concerns.

Challenges Confronting Green Computing

2. Economic Challenges: In developing nations, economic struggles lead to:

- Importation of second-hand electronics (often banned).
- Thriving grey markets (e.g., Nigeria's Alaba Market, Ghana's Agbogbloshie).

Corruption at ports facilitates illegal entry of e-waste.

Policy Challenges: Laws exist but are poorly enforced:

- Weak institutional capacity
- Nepotism, poor infrastructure, corruption
- Lack of inter-agency coordination
- Policies often fail at the implementation stage.

Challenges Confronting Green Computing

4. Consumer Attitude

- Consumers demand newer and flashier devices, regardless of need.
- Status symbol behavior drives overconsumption.
- Awareness is low about the environmental costs of constant upgrading.

5. Social Exploitation

- Importers/manufacturers exploit weak regulations and public ignorance.
-]In places with no clear green computing laws, unregulated dumping and sales persist.
- The lack of accountability enables unchecked environmental harm.



Solutions to the challenges confronting green computing

- 1 . International and National Policy Reforms: Prevent illegal dumping and encourage uniform global action.
 - Trans-border enforcement: Many developing countries face an influx of obsolete electronics disguised as “usable second-hand devices.” Strong border controls, harmonized customs policies, and regional surveillance taskforces (e.g., African Union taskforce) are essential to stop this flow.



Solutions to the challenges confronting green computing

2. Global ban on second-hand computing devices: A coordinated international ban could drastically reduce the volume of toxic e-waste exported under the pretext of reuse. This would require cooperation through trade treaties and environmental agreements.

- Policy harmonization: Policies must be aligned internationally to prevent "e-waste tourism," where polluters seek out lax regulatory regions to dump waste.



Solutions to the challenges confronting green computing

3. Manufacturer Regulations: Make sustainability a core obligation of tech manufacturers.
- Mandatory eco-friendly materials: Regulators should require the use of biodegradable, recyclable, and non-toxic materials. Examples include bio-plastics, aluminum casing instead of PVC, or lead-free solders.
 - Accountability for lifecycle design: Hold manufacturers responsible for:
 - Planned obsolescence (deliberate shortening of device lifespan)
 - Design for recyclability (easy disassembly, replaceable batteries)
 - Support for repair and upgrades (hardware modularity)
 - Extended Producer Responsibility (EPR): Manufacturers should be legally mandated to collect and recycle their products after consumer use.



Solutions to the challenges confronting green computing

4. Education programs: Governments and NGOs can collaborate to launch public campaigns on:

- Proper e-waste disposal
- Environmental consequences of constant tech upgrades
- How to identify sustainable products (e.g., ENERGY STAR certifications)
- Consumer watchdogs and green labeling: Promote transparency through eco-labels, ratings, or apps that inform buyers of a product's environmental impact.



Solutions to the challenges confronting green computing

5. Consumer Protection and Awareness: Empower consumers to make sustainable decisions.
- Right to repair: Legislation should guarantee users the right to disassemble, repair, or upgrade their devices. Companies like Apple have historically resisted this but are now slowly complying in some jurisdictions due to public pressure and policy changes.



Solutions to the challenges confronting green computing

6. Support for the Formal Recycling Industry: Transition from unsafe informal practices to regulated systems.

- Global grants & financial incentives: Funds from international bodies (e.g., UNDP, World Bank) can support:
 - Infrastructure development
 - Training and formal employment for informal recyclers
 - Research into safe, low-cost recycling technologies



Solutions to the challenges confronting green computing

- ▶ Displace informal e-waste burning/dismantling: Informal practices (e.g., burning wires for copper) release toxins like dioxins and furans. Formal facilities should adopt mechanized and closed-loop systems with proper air and water treatment.
- ▶ Localization of solutions: Recycling centers should be regionally distributed, creating local jobs and reducing transportation emissions.



Solutions to the challenges confronting green computing

5. Green Manufacturing Advocacy: Shift the tech industry toward low-impact production methods.
- Use of renewable energy in production: Encourage manufacturing plants to switch from fossil fuels to solar, hydro, or wind energy sources.
 - Energy-efficient production equipment: Support innovation in low-energy fabrication of microchips, displays, and batteries.
 - Material efficiency: Minimize raw material usage through smart design, reducing waste during fabrication.
 - Government incentives: Tax breaks or subsidies for manufacturers investing in green R&D and sustainable supply chains.

Solutions to the challenges confronting green computing

7. Green Computing Standards: Establish green computing as a globally accepted and enforced standard.
 - Integration into ISO framework: International Organization for Standardization (ISO) should develop and maintain green computing standards for hardware design, software efficiency, and disposal.
 - National adoption of standards: Countries can then domesticate ISO frameworks into enforceable regulations, influencing everything from procurement policies to tech imports.
 - Compliance monitoring: Establish auditing and reporting mechanisms to ensure manufacturers and industries follow green computing standards.



Solutions to the challenges confronting green computing

8. Promotion of a Circular Economy: Ensure computing products are reused and recycled, not discarded.
- Design for circularity:
Devices should be designed for easy refurbishing, upgrading, and disassembly.
 - Producer take-back schemes:
Manufacturers should provide channels for customers to return used devices for refurbishing or recycling.



Solutions to the challenges confronting green computing

- Waste-to-resource pipelines:
Establish systems where discarded electronics are fed into the supply chain for new products, reducing dependency on raw materials.
- Legislative support: Countries should legally require product lifecycle tracking, especially for large ICT imports.



Solutions to the challenges confronting green computing

- 9. Technology-Driven Waste Management: Use smart systems to optimize e-waste tracking and processing.
- Intelligent resource planning systems: Implement digital platforms that:
 - Track devices throughout their lifecycle
 - Assess environmental risks per sector/location
 - Manage logistics of collection and recycling



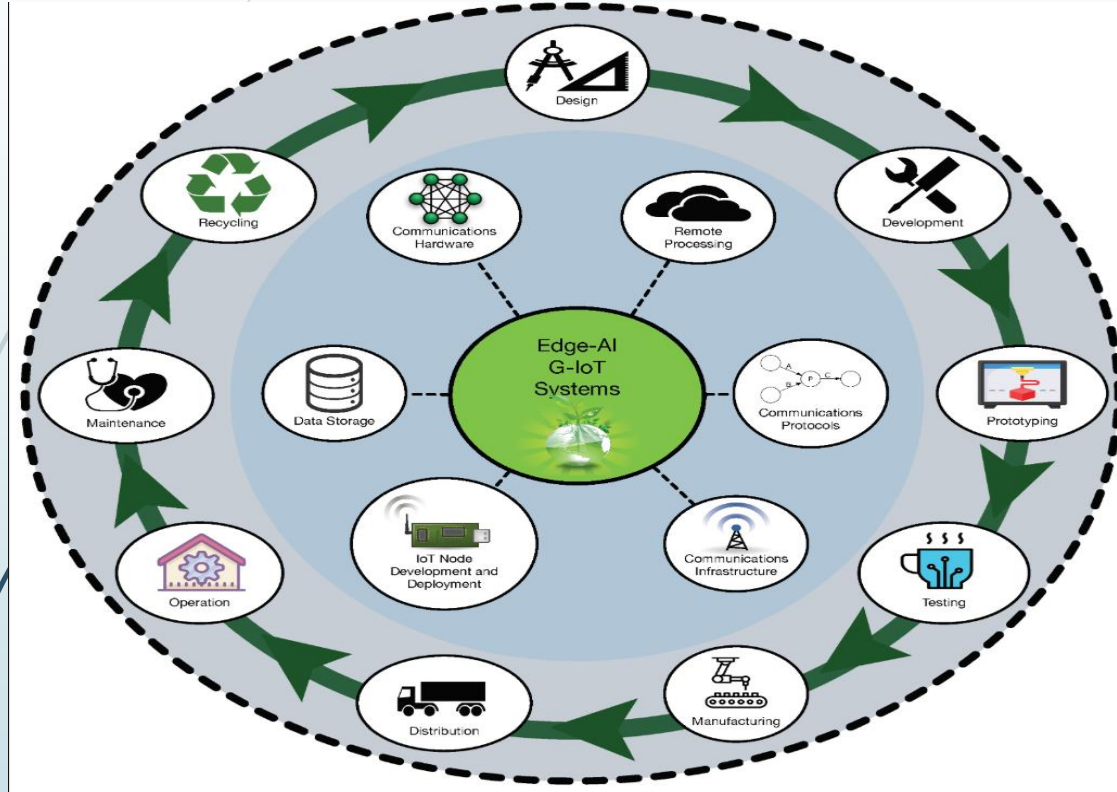
Solutions to the challenges confronting green computing

- Advanced disposal technologies:
 - Bioremediation: Using microorganisms to detoxify contaminated sites.
 - Biomining: Extracting valuable metals (like gold or copper) from e-waste using biological agents.
- Risk and hazard profiling: AI-powered models can evaluate pollution risks from ICT infrastructure and recommend eco-friendly practices per industry (e.g., banking vs. agriculture).

IOT and Green Computing: The Green Internet of Things (GIOTs)

- The Green Internet of Things (GIOT) aims to significantly minimize carbon dioxide (CO₂) emissions, reduce other harmful pollutants, promote environmental preservation, and cut down on the energy consumption of IoT devices. Implementing energy-saving techniques within these devices contributes to a more sustainable and eco-friendly technological environment.
- According to Faisal Karim et al., GIOT encompasses energy-efficient practices—both hardware and software—that either help existing applications and services reduce their greenhouse impact or directly mitigate the environmental footprint of IOT technologies. In the first case, IOT serves as a tool to combat greenhouse effects; in the second, IOT systems themselves are optimized for greener performance.

IOT and Green Computing: The Green Internet of Things (GIOTs)



[Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition towards a Smart Circular Economy: An Industry 5.0 Use Case](#)



IOT and Green Computing: The Green Internet of Things (GIOTs)

The entire lifecycle of GIOT should be aligned with eco-conscious principles, including:

- Green design
- Green manufacturing
- Green usage
- Green disposal and recycling

Key attributes of GIOT include: Energy-efficient designs for both hardware and software to reduce power requirements in IoT applications.



IOT and Green Computing: The Green Internet of Things (GIOTs)

- Enhanced encryption and decryption protocols with minimal data processing overhead.
- Minimization of continuous or redundant data transmission.
- Use of environmentally sustainable practices in the production of IoT devices.
- Integration of renewable energy sources into IoT networks, reducing reliance on fossil fuels.



IOT and Green Computing: The Green Internet of Things (GIOTs)

- To implement GIOT effectively, technologies such as green RFID, green data centers, green sensor networks, and green cloud computing are employed. These strategies are categorized under various domains, as outlined in specialized GIOT taxonomies.

1) Efficient Hardware Implementation

- Hardware-based GIOT strategies can be grouped into four main categories. A key component is Machine-to-Machine (M2M) communication, which enables automated, direct data exchanges between connected devices—crucial for autonomous operations without human input.



Other techniques include:

- Energy-efficient routing during data transmission
- Network cooperation protocols
- Dynamic transmission power regulation
- Transitioning idle nodes to sleep mode
- Minimizing signal interference
- Energy harvesting from ambient sources
- Wireless Sensor Networks (WSNs) consist of sensor nodes that collect and forward data to base stations. These networks help in scheduling tasks, managing interference, allocating resources, and routing data. WSNs also serve as gateways to local area networks.

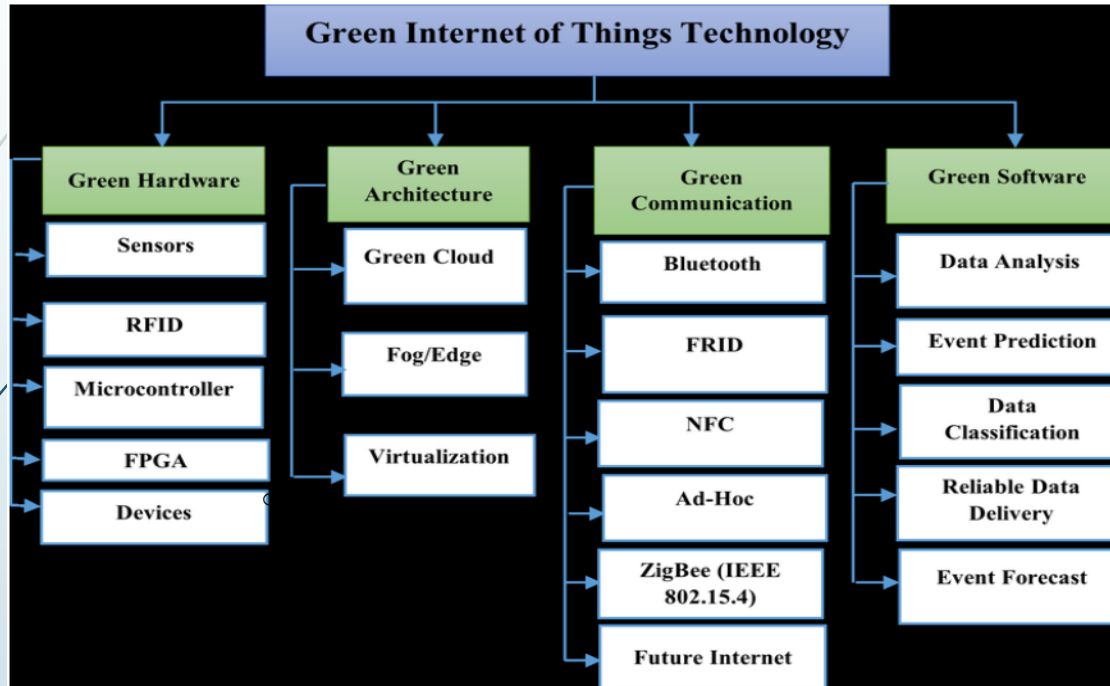
Wireless technologies used in GIOT include:

- WLANs: For higher data rate applications over longer distances
- WPANs: For low-data-rate, short-range communication
- LR-WPANs (Low-Rate Wireless Personal Area Networks): Based on IEEE 802.15.4, these networks offer device-level connectivity with low power usage, ideal for cost-sensitive and energy-efficient IoT implementations.
- As IoT devices and data volumes grow exponentially, there is a shift towards distributed computing models. Network administrators now face the challenge of creating scalable systems that can automatically manage identification, classification, and policy enforcement, alongside ensuring standard connectivity and security.

Wireless technologies used in GloT include:

- RFID (Radio-Frequency Identification) tags, which respond to queries from a reader, are integral to GloT. These tags can be:
 - Active (battery-powered)
 - Passive (without a battery)
- Microcontroller Units (MCUs) and Integrated Circuits (ICs) serve as cost-effective, standalone processing units within these systems, supporting the efficient functioning of GloT technologies.

Green IOT Technology



[The Green Internet of Things General Components.](#) | [Download Scientific Diagram](#)

Green cloud computing

- Green cloud computing is the practice of optimizing cloud data centers, services, and operations to reduce their environmental impact, particularly by minimizing power usage, using renewable energy, and reducing e-waste

Objectives of Green Cloud Computing

- **Reduce Energy Consumption:** Lower the power used by data centers, servers, and networking devices.
- **Minimize Carbon Emissions:** Use renewable energy sources and efficient infrastructure to cut greenhouse gas emissions.
- **Optimize Resource Utilization:** Avoid over-provisioning by using techniques like virtualization, auto-scaling, and server consolidation.
- **Promote Sustainability in IT:** Encourage environmentally responsible choices in hardware, software, and operations.



How It Works:

- Virtualization allows multiple applications to run on a single physical server, reducing the number of machines needed.
- Dynamic resource allocation ensures that computing power is provided based on demand, avoiding idle energy usage.
- Green data centers use energy-efficient cooling, power management, and hardware.
- Renewable energy sources like solar and wind are used to power data centers.
- Carbon-aware cloud platforms let users monitor and manage the environmental impact of their computing tasks.



Benefits of Green Cloud Computing

- Environmental Protection – Reduces carbon footprint and electronic waste.
- Cost Savings – Energy-efficient operations mean lower electricity bills.
- Improved Resource Management – Efficient workload distribution reduces hardware stress.
- Corporate Responsibility – Aligns with sustainability goals and green certifications.

What is Green Software Design?

- Green software design refers to creating software in a way that minimizes its environmental impact, especially in terms of energy consumption. This includes the entire lifecycle of the software—from development and deployment to usage and disposal.
- If the software is designed in such a way that it takes into account the energy and environmental resources it uses, and optimizes them to reduce waste and consumption, then it is called green software.



Goals of Green Software:

- Reduce energy usage: Green software is built to perform tasks efficiently using as little computing power and electricity as possible.
- Use hardware more effectively: It ensures that hardware components (like servers, processors, and storage) are not overused or left running unnecessarily.
- Minimize carbon footprint: The goal is to reduce the greenhouse gas emissions associated with the operation of software systems.

How Does Green Software Work?

- One technique used in green software is the integration of an Orchestration Agent (OA).

What is an Orchestration Agent (OA)?

- An OA is a piece of software installed on devices at the user's location (client side). Its job is to choose the most energy-efficient server to perform a task.

How does it work?

- The OA monitors the energy consumption profile of various servers.
- It then intelligently routes tasks to the servers that will consume the least amount of energy for that specific task.
- This helps in reducing the overall energy usage and ensures the software runs in the greenest way possible.

References

1. ALBREEM, M. A. (2021). Green Internet of Things (GloT): Applications, Practices, Awareness, and Challenges.
2. Butt, S. (2020). Green Computing: Sustainable Design and Technologies. *IEEE*, 1-7.
3. Cloud, A. (2015). Green Computing- The Environmental Benefit.
4. GAUR, R. (2023). GREEN COMPUTING: APPROACHES, TECHNIQUES AND ITS IMPLEMENTATION. *JSDR*, 1-5.
5. Pazowski, P. (2015). GREEN COMPUTING: LATEST PRACTICES AND TECHNOLOGIES FOR ICT SUSTAINABILITY. *Joint International* , (pp. 1-8).