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TOWARDS A SUSTAINABLE INTERNET OF THINGS: BALANCING TECHNOLOGICAL GROWTH WITH ENVIRONMENTAL RESPONSIBILITY

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Abstract

This commentary critically examines the environmental challenges stemming from the rapid expansion of the Internet of Things (IoT), a technological advancement that is reshaping industries and transforming everyday life. As IoT devices become more ubiquitous, they bring about significant environmental concerns, including increased energy consumption, electronic waste, and the depletion of natural resources tied to their production, deployment, and operation in the environment. Drawing on documentary evidence and recent studies, this article evaluates these impacts, underscoring the dual-edged nature of IoT's growth: while it offers substantial benefits in terms of connectivity, efficiency, and automation, these advancements come at a steep ecological cost. The study reveals that current IoT practices often prioritize technological progress over environmental sustainability, resulting in a growing environmental footprint that threatens to undermine global efforts to address climate change and conserve natural resources. To mitigate these negative effects, the commentary proposes several sustainable solutions. These include the development of low-power networks that reduce energy consumption, the design of eco-friendly IoT devices that minimize resource use and waste, and the adoption of circular economy principles within the IoT sector to promote recycling and reuse. The evidence suggests that without a deliberate effort to integrate sustainability into every phase of IoT development and deployment, the environmental consequences of this technology will continue to escalate. Ultimately, this commentary calls for a paradigm shift in IoT development—one that harmonizes technological innovation with environmental stewardship, ensuring that the future of IoT is not only advanced but also sustainable for generations to come.

INTRODUCTION

The rapid growth of the Internet of Things (IoT) has revolutionized technology, embedding smart devices in nearly every aspect of modern life. From home automation systems that streamline daily tasks to industrial sensors that enhance efficiency, IoT has undeniably expanded the frontiers of connectivity and data-driven decision-making. Yet, beneath the surface of these advancements lies a critical issue that is often overshadowed by the excitement surrounding technological progress: the environmental impact of IoT. As billions of devices interconnect to form a vast digital ecosystem, the energy demands of these networks are soaring, contributing to a steadily increasing carbon footprint. Compounding this problem is the alarming rate at which IoT devices become obsolete, generating vast amounts of electronic waste (e-waste) that our current systems are ill-equipped to handle (Chaudhuri, 2018). Without significant changes in how IoT systems are designed, deployed, and managed, the environmental costs of this technological boom threaten to undermine its potential benefits.

Energy consumption is one of the most pressing concerns associated with IoT. Data centers, which are critical for processing and storing the enormous volumes of data generated by IoT devices, are particularly energy-intensive. According to the International Energy Agency (IEA), data centers alone currently account for about 1% of global electricity demand (Okoyeigbo, Olajube, Shobayo, Aligbe & Ibhaze, 2021). However, with the continued expansion of IoT, this figure is projected to rise significantly. By 2030, data centers and data transmission networks could consume up to 8% of the world's electricity if the current growth trajectory persists. This increase in energy consumption is directly tied to the massive amounts of data that IoT devices generate, which is expected to reach a staggering 79.4 zettabytes by 2025. The environmental implications are profound; as energy use rises, so too do carbon emissions, exacerbating the very climate crisis that many IoT applications, such as smart grids and precision agriculture, are designed to combat (Adewale, Ene, Ogunbayo, & Aigbavboa, 2024). The issue of e-waste adds another layer of complexity to the environmental challenges posed by IoT. Many IoT devices are designed with short lifespans, driven by the rapid pace of technological advancements and consumer demand for the latest features. This results in frequent replacements, leading to a significant increase in e-waste. The *Global E-Waste Monitor 2020* reported that 53.6 million metric tons of e-waste were generated worldwide in 2019, a figure that is projected to rise to 74.7 million metric tons by 2030 (Kehinde, Moses, Borishade, Busola, Adubor, Obembe, & Asemota, 2023). IoT devices, with their often limited upgradability and complex material composition, contribute disproportionately to this growing problem. The environmental hazards are compounded by the toxic substances commonly found in electronic components, such as lead, mercury, and cadmium. When improperly disposed of, these materials can leach into the soil and water, posing serious health and environmental risks. Addressing the e-waste problem requires not only better waste management practices but also a fundamental shift in how IoT devices are designed and consumed.

The current model of IoT development, which prioritizes rapid innovation and market growth, is clearly unsustainable. Without a deliberate focus on sustainability, the environmental costs will likely overshadow the benefits of IoT. This commentary argues that a more sustainable approach to IoT is not just desirable but essential. To mitigate the environmental impact of IoT, several strategies must be implemented. These include the development of low-power networks that reduce the energy demands of IoT devices, the adoption of eco-friendly designs that prioritize durability and recyclability, and the application of circular economy principles that minimize waste throughout the product lifecycle (Nnadi, & Idachaba, 2018). Low-power networks, such as those based on the LoRaWAN and Sigfox protocols, offer a promising solution to the energy consumption problem. These networks are designed to operate efficiently over long distances while consuming minimal power, making them ideal for IoT applications that require widespread connectivity without the energy burden of traditional networks. By reducing the energy demands of IoT devices, low-power networks can significantly decrease the carbon footprint of IoT ecosystems (Kehinde, 2025). However, the adoption of these networks is still in its early stages, and broader implementation will require collaboration between industry, policymakers, and technology developers. In addition to addressing energy consumption, sustainable IoT development must also focus on reducing e-waste (Vermesan, & Friess, 2022). This can be achieved through eco-friendly device design, which emphasizes durability, repairability, and recyclability. By designing devices with longer lifespans and making them easier to repair and upgrade, manufacturers can reduce the frequency of replacements and, consequently, the volume of e-waste. Furthermore, the use of sustainable materials, such as biodegradable plastics and non-toxic components, can mitigate the environmental impact of IoT devices at the end of their lifecycle. Adopting these design principles will require a shift in industry practices, but the long-term environmental benefits make this an essential step toward a sustainable IoT.

The circular economy offers a comprehensive framework for achieving sustainability in the IoT sector. By promoting the reuse, refurbishment, and recycling of products, the circular economy aims to keep materials in use for as long as possible, reducing waste and conserving resources. In the context of IoT, this means designing devices that can be easily disassembled and repurposed, as well as creating systems for collecting and recycling old devices. Implementing circular economy principles in the IoT sector will require coordinated efforts across the supply chain, from manufacturers to consumers(Gao, Wang, Hu, & Martinez, 2023). However, the potential to drastically reduce e-waste and resource consumption makes this approach a crucial component of any sustainable IoT strategy. The World Economic Forum predicts that the number of IoT devices will surpass 25 billion by 2030, up from 7.6 billion in 2019. While this expansion offers significant opportunities for advancements in areas like smart cities, healthcare, and industrial automation, it also presents substantial environmental challenges (Bango, Misra, Jonathan, & Ahuja, 2022). The energy required to power billions of devices, the resources needed for their production, and the waste generated at the end of their life cycles all contribute to a growing environmental footprint. These issues must be addressed if IoT is to fulfill its promise of creating a more efficient and connected world without undermining environmental sustainability (Nguyen, Le, Pham, Nguyen, Balasubramaniam, & Hoang, 2021). Despite the clear need for a more sustainable IoT, some argue that the environmental impact of IoT is outweighed by its benefits. Proponents highlight the potential of IoT to drive innovation, improve efficiency, and address global challenges such as climate change and resource scarcity. For example, smart grids and precision agriculture are often cited as key applications of IoT that can help reduce energy consumption and optimize resource use. While these benefits are real, they do not negate the environmental costs associated with IoT. The energy savings achieved through smart grids, for instance, may be offset by the energy required to power the IoT devices themselves. Similarly, the environmental benefits of precision agriculture must be weighed against the e-waste generated by outdated or obsolete IoT devices (He, Almasifar, Mehbodniya, Javaheri, & Webber, 2022). Thus, a balanced approach that recognizes both the benefits and the costs of IoT is essential for sustainable development. While IoT has the potential to drive significant technological advancements, its environmental impact cannot be ignored. The evidence clearly shows that the current trajectory of IoT development is unsustainable, with rising energy consumption and increasing e-waste posing significant environmental risks. To address these challenges, a holistic approach is needed—one that prioritizes sustainability across the entire lifecycle of IoT devices. This includes the adoption of low-power networks, eco-friendly designs, and circular economy principles (Vermesan, Friess, Guillemin, Giaffreda, Grindvoll, Eisenhauer, & Tragos, 2022). Furthermore, policymakers and industry leaders must work together to create a regulatory framework that encourages sustainable practices in the IoT sector. Only by balancing technological growth with environmental responsibility can we ensure that the benefits of IoT are realized without compromising the health of our planet.

Energy Efficiency and Circular Economy in IoT

As the Internet of Things (IoT) continues to expand, concerns about the environmental impact of these technologies are growing. A critical area that needs urgent attention is energy efficiency in IoT devices, which is intrinsically linked to the principles of the circular economy. Energy efficiency in IoT is crucial because the sheer number of connected devices worldwide is staggering. Estimates suggest that by 2030, there could be over 25 billion IoT devices in use globally (Albreem, Sheikh, Bashir, & El-Saleh, 2023). Each of these devices requires energy to operate, and cumulatively, they contribute to a substantial amount of global energy consumption. For instance, a study by Ericsson estimated that the total electricity consumption of IoT devices could reach 3,000 TWh by 2025, equivalent to nearly 11% of the world's total electricity usage. This level of consumption not only raises concerns about sustainability but also underscores the need for more energy-efficient IoT solutions (Kehinde, Moses, Taiye, Oladele, Simon-Ilogho, Adebukola, & Kehinde, 2024). The circular economy offers a framework for addressing these challenges. By adopting circular economy principles, IoT manufacturers can design devices that are not only energy-efficient but also durable, repairable, and recyclable (Kehinde, 2025). This approach helps to minimize waste and reduce the need for new raw materials, which are often sourced from environmentally damaging mining operations. For example, companies like Fairphone are already pioneering the use of modular design in smartphones, allowing users to easily replace parts and extend the device's lifespan. A similar approach could be applied to IoT devices, where components such as batteries, sensors, and processors could be easily swapped out, rather than requiring the replacement of the entire device. Moreover, the circular economy encourages the recycling and repurposing of materials at the end of a device's life (Nižetić, Šolić, Gonzalez-De, & Patrono, 2020). Currently, electronic waste (e-waste) is one of the fastest-growing waste streams globally, with over 50 million metric tons generated in 2020 alone. IoT devices contribute to this problem, as many are not designed with end-of-life disposal in mind. By rethinking the lifecycle of IoT devices through the lens of the circular economy, manufacturers can ensure that these devices have a second life, either through refurbishment, reuse, or recycling of components (Chima, Babajide, Adegboye, Kehinde, & Fasheyitan, 2021). To truly make IoT sustainable, energy efficiency and circular economy principles must be integrated from the very beginning of the design process (Dong, & Ullah, 2023). This means prioritizing low-power components, optimizing software to reduce energy consumption, and designing devices that are easy to disassemble and recycle. Governments and industry standards bodies can also play a role by setting regulations and guidelines that encourage sustainable practices. For example, the European Union's Ecodesign Directive already sets energy efficiency standards for various electronic devices, and expanding this to include IoT could drive significant improvements.

Materials Sourcing, Resource Depletion, and E-Waste in IoT

The rapid proliferation of IoT devices has brought about an increased demand for raw materials, leading to significant environmental concerns related to resource depletion and electronic waste (e-waste). The production of IoT devices relies heavily on specific raw materials, many of which are rare and finite. For example, the production of semiconductors, essential components in IoT devices, requires materials like silicon, cobalt, and rare earth metals (Omar, 2024). The mining and extraction of these materials often result in severe environmental degradation, including deforestation, water pollution, and loss of biodiversity. Moreover, many of these materials are sourced from regions with lax environmental regulations and poor labor practices, further exacerbating the negative impact of IoT production. A striking example is cobalt, a critical component in lithium-ion batteries used in IoT devices. The Democratic Republic of Congo, which supplies over 60% of the world's cobalt, has been at the center of controversies over child labor and environmental destruction linked to mining activities (Haseeb, Din, Almogren, Ahmed, & Guizani, 2021). As demand for IoT devices increases, so too does the demand for cobalt, leading to more intensive mining operations and greater environmental harm. This situation highlights the need for more sustainable sourcing practices and the development of alternative materials that can reduce the reliance on such scarce resources. In addition to the challenges posed by material sourcing, the issue of e-waste is becoming increasingly pressing (Segun, Moses, Taiye, Oladele, Ogunnaike, Itai, & Kehinde, 2024). E-waste is one of the fastest-growing waste streams globally, and IoT devices contribute significantly to this problem. Many IoT devices have relatively short lifespans and are often difficult to repair or upgrade, leading to a high turnover rate and a growing pile of discarded electronics (Vermesan, & Friess, 2013). In 2020, the world generated 53.6 million metric tons of e-waste, of which only 17.4% was recycled, according to the Global E-Waste Monitor. The remaining e-waste often ends up in landfills or is improperly disposed of, leading to environmental contamination from toxic substances like lead, mercury, and cadmium. Addressing these issues requires a multi-faceted approach (Joseph, Kehinde, Ogunnaike, Mercy, Adebayo, Deborah, & Tola, 2025). First, manufacturers need to adopt more sustainable materials sourcing practices, including using recycled materials and developing alternatives to rare and environmentally damaging elements. For instance, companies like Apple are investing in recycling programs to recover valuable materials from old devices, and research is ongoing into the development of biodegradable electronic components. Second, the design of IoT devices must prioritize longevity and reparability (John, Ucheaga, Olowo, Badejo, & Atayero, 2016). This can be achieved through modular design, which allows for easy replacement of parts and upgrades, thus extending the device's lifespan and reducing the need for new materials. Additionally, policies promoting extended producer responsibility (EPR) can incentivize manufacturers to take back and recycle their products, reducing the environmental impact of e-waste.

Sustainable Manufacturing and Climate Change in IoT

The intersection of sustainable manufacturing practices and the role of IoT in addressing climate change presents both opportunities and challenges. As IoT devices become increasingly integrated into various sectors, the way these devices are produced and their contribution to climate change must be carefully considered. Sustainable manufacturing refers to the creation of products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources (Vermesan, Friess, Guillemin, Gusmeroli, Sundmaeker, Bassi, & Doody, 2022). For the IoT industry, this means rethinking how devices are designed, produced, and assembled. Traditionally, the manufacturing of electronic devices has been resource-intensive and environmentally damaging, involving energy-consuming processes and the use of hazardous chemicals (Daniel, Babalola, Falola, Kehinde, & Mikémina, 2025). The shift towards sustainable manufacturing in IoT aims to change this narrative by adopting greener production techniques and materials. One significant advancement in this area is the adoption of additive manufacturing, commonly known as 3D printing. Additive manufacturing allows for precise control over material usage, reducing waste and enabling the use of environmentally friendly materials (Akram, 2024). For example, some companies are exploring the use of bioplastics, which are derived from renewable sources and are biodegradable, as an alternative to traditional plastics in IoT devices. This shift not only reduces the environmental impact of the manufacturing process but also contributes to the reduction of waste when these devices reach the end of their lifecycle. Furthermore, sustainable manufacturing practices can significantly reduce the carbon footprint of IoT devices. Manufacturing is a major contributor to global greenhouse gas emissions, accounting for approximately 20% of global emissions, according to the World Resources Institute. By optimizing manufacturing processes to be more energy-efficient and by using renewable energy sources, IoT manufacturers can play a crucial role in reducing emissions (Mbonu, Kilanko, Kilanko, & Babalola, 2022). For instance, companies like Tesla and Apple are investing heavily in renewable energy to power their manufacturing facilities, setting an example for the broader industry. In addition to sustainable manufacturing, IoT itself holds significant potential in the fight against climate change. IoT devices can be deployed to monitor and manage environmental conditions, providing real-time data that can be used to reduce energy consumption and improve resource management. For example, IoT sensors in smart buildings can optimize heating, cooling, and lighting systems based on occupancy and environmental conditions, leading to significant energy savings. A study by the American Council for an Energy-Efficient Economy (ACEEE) found that smart buildings equipped with IoT technology can reduce energy use by up to 30%. Moreover, IoT can aid in climate change adaptation by providing data and tools that help communities respond to environmental challenges (Tiwari, Rosak-Szyrocka & Żywiołek, 2022). For instance, IoT-based early warning systems can monitor weather patterns and provide alerts for natural disasters like floods, hurricanes, and wildfires, helping to mitigate their impact. In agriculture, IoT sensors can monitor soil moisture levels, enabling farmers to use water more efficiently and reduce the stress on local water resources, which is crucial in regions facing drought due to climate change.

Evidence and Logical Reasoning

The proliferation of IoT devices has led to a surge in energy consumption, which poses a significant environmental challenge. According to a report by the International Energy Agency (IEA), data centers and data transmission networks currently account for 1% of global electricity consumption, a figure that could rise to 8% by 2030 if IoT adoption continues unchecked. This rise in energy demand is driven by the need to power billions of IoT devices, as well as the data centers that process and store the vast amounts of data these devices generate (Okokpujie, Okokpujie, Ogundipe, Anike, Asaboro, & Vincent, 2023). The energy consumption of IoT devices is not merely a technical concern; it is intrinsically linked to carbon emissions, which contribute to climate change. A 2018 study published in *Nature* estimated that by 2025, information and communication technology (ICT) systems, including IoT devices, could account for up to 20% of global electricity use, contributing to 5.5% of the world's carbon footprint. These data illustrates the unsustainable trajectory of IoT development, where the environmental costs threaten to outweigh the benefits. Logical reasoning further reinforces the argument for sustainable IoT development. The relationship between IoT growth and environmental degradation is not merely a correlation; it is causal. The design and deployment of IoT devices often prioritize technological advancement and market expansion over environmental sustainability(Paridhi, Monika & Ritika, 2024). For instance, many IoT devices are designed with short lifespans to encourage rapid turnover, leading to increased electronic waste (e-waste). The *Global E-Waste Monitor 2020* reported that 53.6 million metric tons of e-waste were generated worldwide in 2019, with only 17.4% of this waste being recycled. The remaining 82.6% ended up in landfills or was improperly disposed of, leading to the release of hazardous substances into the environment. The proliferation of IoT devices, many of which are disposable or difficult to recycle, contributes significantly to this growing problem (Zeeshan, Hämäläinen, & Neittaanmäki, 2022). This evidence underscores the need for a paradigm shift in IoT development, one that prioritizes sustainability from the outset. In addition to energy consumption and e-waste, the materials used in IoT devices also pose environmental challenges. Many IoT devices contain rare earth elements and other materials that are environmentally damaging to extract and difficult to recycle (Lăzăroiu, & Harrison, 2021). A 2021 report by the European Commission highlighted that the extraction and processing of these materials contribute to environmental degradation, including deforestation, habitat destruction, and pollution. Moreover, the geopolitical concentration of these resources raises concerns about supply chain sustainability and environmental justice (Nižetić, Šolić, Gonzalez-De, & Patrono, 2020). The evidence clearly indicates that the current approach to IoT development is not only environmentally unsustainable but also ethically questionable. Addressing these challenges requires a holistic approach that considers the entire lifecycle of IoT devices, from design and manufacturing to deployment and disposal.

Addressing Counterarguments and Alternative Views

Despite the compelling evidence of the environmental impact of IoT, some argue that the benefits of IoT outweigh the costs. Proponents of IoT often highlight its potential to drive innovation, improve efficiency, and address global challenges such as climate change and resource scarcity (Dong, & Ullah, 2023). For example, smart grids and precision agriculture, both of which rely on IoT, are often cited as solutions to energy and food security challenges. While it is true that IoT has the potential to contribute to sustainability in these areas, this argument overlooks the broader environmental costs of IoT. The energy savings achieved through smart grids, for instance, may be offset by the energy required to power the IoT devices themselves. Similarly, the environmental benefits of precision agriculture may be undermined by the e-waste generated by outdated or obsolete IoT devices (Isaac, Moses, Taiye, Salau, Oladele, Mercy, & Kehinde, 2025). Furthermore, some argue that technological advancements, such as the development of low-power networks and energy-efficient devices, will mitigate the environmental impact of IoT. While these innovations are promising, they are not a panacea (Salam, A. (2024). The energy consumption of IoT is driven not only by the devices themselves but also by the data centers and networks that support them. Even with energy-efficient devices, the exponential growth of IoT will continue to drive up energy demand. Additionally, the focus on technological solutions often obscures the need for systemic change in how IoT devices are designed, deployed, and managed. For instance, a shift toward circular economy principles, where devices are designed for longevity, repairability, and recyclability, is essential to reducing e-waste. Without such systemic change, the environmental impact of IoT will continue to escalate. Another counterargument is that regulation and policy can address the environmental challenges of IoT. While regulation is undoubtedly necessary, it is not sufficient on its own (Kehinde, Moses, Borishade, Busola, Adubor, Obembe, & Asemota, 2023). The rapid pace of technological change often outstrips the ability of regulators to keep up, leading to gaps in oversight and enforcement. Moreover, regulatory approaches tend to be reactive rather than proactive, addressing problems after they have already occurred rather than preventing them in the first place. For example, the European Union's Restriction of Hazardous Substances (RoHS) Directive has been effective in reducing the use of certain toxic materials in electronics, but it does not address the broader issue of e-waste. A more proactive approach is needed, one that encourages sustainable design and production practices from the outset.

Conclusion

The rapid expansion of the Internet of Things presents both opportunities and challenges. While IoT has the potential to drive significant technological and social advancements, the environmental costs of its current trajectory are untenable. The evidence clearly shows that the energy consumption, e-waste, and material use associated with IoT are contributing to environmental degradation and climate change. Addressing these challenges requires a holistic approach that prioritizes sustainability across the entire lifecycle of IoT devices. This includes the development of low-power networks, eco-friendly device designs, and circular economy principles. Furthermore, it is essential to adopt a more proactive regulatory framework that encourages sustainable practices in the IoT sector. The significance of this commentary lies in its call for a fundamental rethink of how we approach IoT development. The environmental challenges posed by IoT are not insurmountable, but they require a concerted effort from industry, policymakers, and consumers alike. By embracing sustainability as a core principle of IoT development, we can ensure that the benefits of this technology are realized without compromising the health of our planet. Future research should focus on identifying and scaling up sustainable IoT practices, as well as exploring the ethical and social implications of IoT. Only by balancing technological growth with environmental responsibility can we achieve a truly sustainable Internet of Things.

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