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IoT applications in sustainability and sustainable community development

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Abstract

The Internet of Things (IoT) merges the global network of the Internet with various tangible objects, fostering innovation in information and communication technology. This integration forms a network of interconnected objects that operate on standard communication protocols, shaping future internet trends. IoT encompasses entities with virtual attributes engaging in social, environmental, and user contexts. Sustainability is integral to IoT, preserving the environment through sustainable resource use and renewable energy promotion. Businesses benefit from sustainable development through resource optimization and enhanced stakeholder relationships. IoT solutions aim to streamline processes and improve quality of life, but their proliferation raises concerns about energy consumption. Initiatives like the Green Internet of Things (G-IoT) prioritize energy efficiency and environmental responsibility to mitigate these impacts.

Strategic technological innovation, particularly in maximizing resource use and reducing emissions, is essential for sustainable development. However, effective implementation requires global coordination and a focus on mitigating IoT's negative environmental impacts. The study highlights the urgency of addressing challenges to meet the United Nations' sustainable development goals by 2030, underlining IoT's pivotal role as a game-changer in this endeavor

Keywords: IoT; Sustainability; Community Development; Sustainable Development Goals

1. Introduction

The conception of the Internet of Things (IoT) encompasses both the "Internet" and "Things," offering a broad understanding of IoT (Sunyaev & Sunyaev, 2020). The term "Internet" refers to the TCP/IP application suite, forming a global network of linked computer networks governed by a global communication protocol. On the other hand, "things" lacks a precise definition, referring to various identifiable objects. Consequently, the fusion of these terms fosters a significant level of innovation in ICT and establishes a semantic framework for IoT as a globally interconnected network of uniquely addressable objects, all operating on standard communication protocols (Nasiri, 2016).

Alternative interpretations of this term have been proposed. IoT is described as entities possessing identities and virtual attributes, operating alongside intelligent interfaces for engagement within social, environmental, and user contexts. Emphasizing seamless integration characterizes IoT as interconnected entities pivotal in shaping what may be regarded as the forthcoming internet landscape (Nasiri et al., 2017).

Sustainability, in its essence, embodies a commitment to enhancing and safeguarding the natural environment (Freeman et al., 2014). It involves assessing the population density within a specific area, ensuring it remains within the carrying capacity of the land to support human needs (Wu, J, 2013). Preserving a viable environment for humanity necessitates integrating sustainable use of biological resources, understanding carrying capacity, and promoting sustainable energy practices. Sustainability emphasizes the enduring preservation of production over short-term

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agricultural maximization, often revolving around renewable and inexhaustible energy sources to mitigate the rapid depletion of fossil fuels such as oil and coal. This definition is rooted in the belief that environmental protection is essential for the well-being of future generations and human society as a whole (Brundlandt Commission, 1987).

Sustainable Development offers businesses a plethora of strategic opportunities. These include optimizing human resources utilization, retaining jobs, achieving cost efficiency, preventing pollution, and conserving energy. Furthermore, integrating sustainability into corporate practices can enhance relationships with stakeholders (Molamohamadi & Ismail, 2013).

IoT solutions aim to streamline processes, enhance system performance, and elevate quality of life in various ways. Given society's increasing focus on sustainability, the rapid expansion of IoT technologies offers numerous benefits. Notably, IoT technologies significantly enhance networking capabilities. The demand for the Internet of Things (IoT) is closely linked to ongoing technological advancements and digitization. There is a growing need for more effective services and efficient systems across the board (Nizetic et al., 2020).

Cutting-edge technologies and the evolution of the Internet of Things (IoT) have invigorated research across various domains concerning human life, facilitating ubiquitous access to information anytime, anywhere, and through any device. This remarkable research endeavors of recent years aim to integrate humans, data, processes, objects, organizations, locations, services, and facilities in unprecedented ways (Rymaszewska et al., 2017). Despite the numerous benefits IoT offers to society, the manufacturing, utilization, implementation, and distribution of IoT services and devices entail substantial energy and resource consumption, resulting in perpetual generation of toxic electronic waste. To attain sustainable development goals, both national and international plans are being implemented, taking into record the environmental, social, and economic considerations. Despite the emergence of Green Internet of Things (G-IoT) initiatives, IoT advancements remain limited in many developing nations (Dagnaw & Tsigie, 2021).

Green Internet typically refers to "planning and investing in a technology infrastructure that meets present needs while conserving energy and reducing costs" (Dagnaw & Tsigie, 2021). The concept of the Green Internet of Things centers on energy efficiency and the reliability of IoT principles. "Green IoT" is characterized by energy-efficient practices within IoT aimed at mitigating or eliminating the greenhouse gas emissions produced by current applications. Green IoT involves the efficient production, development, disposal, and utilization of computers, servers, and associated subsystems (such as printers, displays, communication equipment, and storage devices), with significantly minimized negative effects on society and the environment (Sarath & Sathiyabama, 2022).

1.1. Need of Internet of Things

The Internet of Things (IoT) emerged as a groundbreaking concept that has transformed the global landscape by connecting billions of IoT devices (Sharma et al., 2019). These devices operate by sensing, gathering, and transmitting crucial information from their surroundings. However, like a coin having opposite two sides, IoT has also introduced certain challenges to the environment, notably including the rise in electronic waste volume, energy consumption, and CO_2 emissions (Pershaanaa et al., 2023).

Addressing the potential adverse effects of recent advancements in IoT technology on both society and the environment has become imperative. These challenges predominantly encompass increased energy consumption, electronic waste generation, greenhouse gas emissions—particularly CO_2, utilization of non-biodegradable materials in IoT devices, and reliance on non-renewable natural resources. This urgency has underscored the necessity for the adoption of Green IoT (G-IoT), an evolving technological paradigm aligned with environmentally friendly practices and economic principles. G-IoT endeavors to significantly enhance environmental and human well-being through sustainable technological innovations, effectively shrinking the world's ecological footprint (Zhu et al., 2015). G-IoT has become essential and holds the potential to revolutionize human society while simultaneously improving environmental health (Dalal & Solanki, 2021). Its primary focus is twofold: firstly, developing IoT computing devices, communication protocols, and networking architectures that prioritize energy efficiency; secondly, leveraging IoT technologies to mitigate emissions of greenhouse gases, radiation, and pollution. Harnessing the advancements in IoT, Green IoT stands poised to bolster environmental and economic sustainability. Consequently, green technologies and processes emerge as pivotal pillars in fostering sustainable development and shaping a smarter world.

Green IoT, in simple terms, refers to "planning and investing in a technology network that meets present and future needs while prioritizing energy conservation and cost savings." The Green Internet of Things aims to achieve energy efficiency and enhance the reliability of IoT principles. "Green IoT" is described as the energy-efficient approach within IoT to minimize or eliminate the greenhouse effect caused by existing applications. It involves efficiently producing,

developing, and disposing of computers, servers, and associated subsystems (such as printers, displays, communication equipment, and storage devices), with a reduced negative impact on society and the environment. Transitioning to green IoT necessitates new resources to mitigate the adverse effects of IoT on human health and the climate. The primary objective of Green IoT is to reduce CO_2 emissions and waste, promote environmental conservation, and address the high costs associated with operating equipment and power consumption. Decreasing the energy consumption of IoT devices is crucial for creating a healthier and more sustainable world. Green IoT presents a significant opportunity to achieve new economic heights and foster a highly sustainable environment through the advancement of eco-friendly ICT technologies (Dalal, S, 2021).

2. IoT for Sustainable Community Development

A decade ago, various United Nations committees defined sustainable development as a concept that "meets present needs without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). Building on the work of scholars and international development organizations, this original framework has evolved to encompass inclusive well-being, ensuring that overall living standards for all individuals, both now and in the future, are maintained or improved over time.

As previously mentioned, nearly all United Nations Member States committed in September 2015 to the 17 Sustainable Development Goals (SDGs), which outline specific commitments and timelines for enhancing well-being. Sustainable development is integral to technological advancement, with innovation being identified as one of the SDGs and a means to achieve others. Information Technology (IT) encompasses a wide range of tools, techniques, processes, and activities that can be utilized to achieve social objectives in a consistent and replicable manner. Concurrently, innovation serves as a mechanism for developing, creating, formalizing, and implementing technology. Innovation occurs within various innovation systems, which can be viewed as interconnected networks of individuals and organizations that drive innovation forward (Klement et al., 2020).

The rapid emergence of smart and IoT-driven technologies has swiftly ushered in a plethora of technical possibilities across different facets of life. IoT solutions aim to streamline processes, boost system performance—whether technological or individual processes—and ultimately enhance quality of life. As society increasingly prioritizes sustainability, the dynamic expansion of IoT technologies offers numerous benefits. Nevertheless, from an environmental standpoint, this exponential growth necessitates careful regulation and scrutiny to ensure the prudent utilization of limited global resources and mitigate adverse repercussions (Nizetic et al., 2020)

Figure 1 Application Areas of IoT Technologies (Nizetic, 2020)

The necessity for the Internet of Things (IoT) stems directly from ongoing technological advancements and the process of digitization. There's a need to connect various electronic devices in a practical manner. Overall, there's a demand for

more efficient services and systems, which can be achieved through the successful integration of IoT technologies. These innovations have yielded a range of valuable assets and intelligent networking capabilities, software enhancements, and systems capable of generating synergies and benefits. One of the most significant advantages of IoT technologies is their enhancement of networking capabilities. Various benefits are conceivable, which will eventually find their way into people's lives across multiple application domains in the future (Nizetic et al., 2020). The IoT technology fields are different and based on existing technical solutions. The most represented application industries are shown in figure 1.

3. Contributions of IoT to Sustainable Development Goals (SDGs)

Sustainability stands as a crucial factor in unveiling the digital future, with the Internet of Things (IoT) emerging as a pivotal enabler of this sustainable digital transformation and community development. Here, "community" refers to any geographical area operating under a structured framework with available resources to meet both present and future needs, with sustainability contingent upon risk tolerance. Industrial IoT, combined with public and consumer IoT, is expected to generate an economic value of more than $15 trillion per year by 2030, according to the Sustainable Development Impact Summit (SDSI, 2019). In addition, IoT's integration with other technologies such as AI, blockchain, cluster and cloud computing offers tremendous opportunities for sustainable community growth. The Sustainable Development Goals (SDGs) were introduced in 2015 by the UN General Assembly in Resolution 70/1, with 2030 as its target year. The SDGs were developed with community involvement, including academia, governments and the private sector. The SDGs cover three main dimensions of sustainability: environmental protection; social diversity and inclusion; and economic growth. The SDGs have become accepted and accepted as the standard system of achieving sustainable community development. In the context of the IoT paradigm, sustainability indicators play a key role in enhancing sustainability and social impact (Moldan, T.B., J, 2019). Sustainability indicators are valuable tools for defining the minimum and current requirements for sustainability. IoT, together with technology, is expected to be a game changer in the near future. IoT offers a comprehensive, commercializable, widely available and accepted technology to achieve these goals with many social and economic benefits, at regional, national and wider community levels. IoT is capable of sensing and communicating through interconnected systems in a variety of environments (Moldan *et al*., 2012). Consequently, they enable the evaluation of management policies and actions to make reliable forecasts of future changes.

Sustainability indicators, however, are not the end-all and be-all for achieving sustainable objectives. Action needs to be taken at the appropriate levels, and this action needs to be accompanied by policy action. For example, the surface water quality (WQ) indicators provide only local data over a limited period of time, so they need to be extrapolated for better decision-making. The Internet of Things (IoT) holds promise for sustainable community development by facilitating the creation of engineered systems that promote sustainability while safeguarding natural and environmental systems (Salam, 2020). Leveraging interconnected systems, sensing technologies, and communication capabilities, IoT for sustainability aims to establish a paradigm that balances the community's need for ecological and environmental protection with the maintenance of a resilient economic society.

The significant correlation between the Internet of Things (IoT) and sustainability is undeniable (Salam, 2020). For instance, an IoT solution for monitoring floods, sewage, and storm overflow, utilizing sensing and communication technologies, contributes to sustainable communities (SDG 11) by mitigating water-related disasters and minimizing economic losses (Salam & Shah, 2019). Similarly, an IoT system for condition-based maintenance of smart grids supports infrastructure development (SDG 9), while city-wide smart lighting IoT initiatives promote energy efficiency enhancements (SDG 7). The evolution of next-generation wireless IoT holds promise for progress across various fronts to address the escalating demands of commercial applications, scientific endeavors, governmental agencies, and the public, facilitating enhanced and broader connectivity (SDG 9).

Figure 2 The UN 17 Sustainable Development Goals (Internet of Things Guidelines for Sustainability, 2018)

In the area of human health (SDG 3), instead of relying on a single major technological breakthrough, communities can leverage a combination of key IoT technologies. Wireless data collection IoT technologies provide real-time access to crop and soil moisture data, supporting effective decision-making in water management (SDG 2 and 12). Furthermore, early warning systems for drought stress in digital forest management enable proactive and prioritized actions (SDG 13), while detection of forest soil moisture guides recovery strategies. These illustrations clearly show that sustainable community development is the greatest benefit of the Internet of Things. Researchers have investigated the correlation between the Internet of Things and sustainability (Saengchai & Jermsittiparsert, 2019). Specifically, they examined 640 distinct Internet of Things projects in comparison with the 17 Sustainable Development Goals (SDGs) to analyze their interrelationship (Salam, 2020). The analysis revealed that 84% of the IoT projects studied demonstrated a heightened potential to achieve these goals. Moreover, 75% of the projects emphasized five specific SDGs (SDG# 3, 7, 9, 11, and 12). The IoT contributes to sustainable development in the following areas:

- Ecological Engineering: The IoT facilitates sustainable development in ecological engineering, such as the restoration and enhancement of ecological functions within natural systems and natural capital (Schneider, 2019).

Earth Systems Engineering: Sustainable IoT development supports the monitoring of earth systems, such as greenhouse gas emissions. It holds significant promise for guiding adaptation to changing climates, forestry practices, mining operations, energy systems, and other global-scale concerns through the development of decision support systems (Li *et al.* 2014).

Industrial Ecology: The IoT promotes progress and innovation in industrial ecology, including the refinement of life cycle assessment methods, economic models, and metrics for sustainable systems (Zhu & Zhao, 2018).

Environmental Sustainability and Green Engineering: The IoT paradigm offers substantial potential to enhance the sustainability of infrastructure, such as water management and the recycling and reuse of drinking water, stormwater, and wastewater, as well as climate assessment (Maksimovic, M., 2018). As a result, the IoT drives innovation and growth strategies in distribution and collection systems through its sensing and monitoring capabilities.

4. Conclusion

The review conducted in this research concludes that all efforts in the IoT sector aimed at designing and developing IoT devices, software, and techniques may not yield long-term societal benefits unless there is a focus on Green IoT. Green IoT is identified as a crucial foundation for achieving sustainable development goals. Survey findings reveal that 65-80% of researchers and educators advocate for a shift from IoT developments to Green IoT developments for sustainable benefits in the long run. However, it's important to note that the limitations of this study include the use of a moderate-sized sample population, suggesting the need for larger-scale studies to generalize the results.

In fostering a sustainable future, it's imperative to make informed decisions regarding technological innovations at the outset of development. Technology plays a vital role in sustainable development as it can be harnessed to manage natural assets in a well-planned and organized manner. This approach can lead to cleaner and more affordable energy, access to clean water, the ability to thrive in less polluted environments, and effective environmental governance.

To realize a vision of a sustainable world, it's crucial to make appropriate choices early on and engage in thorough technological research and innovation. The judicious use of technology is essential, as it can serve as a vital tool for sustainable development. There are numerous areas where technology can prove beneficial, such as maximizing the use of raw materials, reducing greenhouse gas emissions and waste, and preserving natural resources. The concepts of IoT and Green IoT, supported by specifically designed products and services for environmental sustainability, have the potential to transition traditional development practices into sustainable ones.

Effective implementation of IoT for sustainable development can only yield results when efforts are coordinated globally, nationally, regionally, and individually. Green IoT plays a critical role in maintaining a clean and environmentally friendly environment by mitigating the negative impacts of IoT on nature. Through surveys, this paper has highlighted urgent issues and challenges that need to be addressed to achieve the sustainable development goals outlined by the United Nations by 2030. The analysis of survey results underscores the importance of IoT as a crucial element and game-changer in the pursuit of sustainable development goals, thus emphasizing its essential and indispensable nature.

4.1. Future Prospects and Emerging Challenges

This research makes significant contributions to the fields of IoT and sustainability. As a result, it offers a thorough and focused evaluation, analyzing sustainability and its implications across various aspects of IoT technology, Engineering and application. Further study and research are necessary to delve deeper into the novel essence of this field. Establishing a standardized framework for IoT is vital for future research endeavors, enabling a better understanding of the level of digitalization across different sectors, industries, or businesses. In my opinion, there is a need for additional multidisciplinary research to explore the relationship between IoT and sustainability. Such interdisciplinary studies provide diverse perspectives and insights, offering multiple solutions to complex issues. These solutions promote both social and environmental sustainability, fostering a clean, safe, and environmentally friendly living environment for individuals.

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