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Green Computing: Sustainable Design and Technologies

Sarah Butt

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Supervisor: Dr Mohammad Ahmadi

School of Computing, Engineering and Mathematics
Western Sydney University

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ABSTRACT

The Internet of Things (IoT) has generated increasingly dynamic impacts around the world due to its high-tech mechanisms in the scientific discipline. IoT is an intelligent infrastructure of numerous technologies which connect small to large scale devices to the Internet for the purpose of communication. Alternatively, with the appreciation of such an advancement, there have also been numerous environmental issues raised from the operations of IoT. Green IT/IoT is a notion that has been envisioned to reduce, and possibly eliminate the environmental issues caused by IoT through its sustainable designs and approaches. This report proposes four key research questions that will be addressed to evaluate the challenges in IoT, and the solutions of Green IT. Additionally, a variety of literature reviews will be provided that will focus on the research questions proposed for this study. The questions will focus on 1) the challenges in IoT, 2) the characteristics of Green IT, 3) the designs of Green IT, and 4) the process of implementing Green designs as a solution to the environmental challenges. The remaining of the report will then consist of a methodology and comparative analysis. The methodology presented will focus on the aspects of the comparative analysis. Furthermore, a comparison will be made amongst four scholarly sources to identify the best energy-efficient solution through Green IT. The results will indicate that the source classified as the highest value will be the best solution for energy-efficiency in IoT. The report will end by a brief evaluation of the significance of this study, research gaps, and future prospects.

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CHAPTER I: INTRODUCTION

The Internet of Things (IoT) has become one of the most rapidly advancing high-tech mechanism in the Information and Communications Technology (ICT) industry (Ahmed et al., 2019, p.1). IoT is an intelligent network of technology that encompasses an extensive variety of systems which connects small scale to large scale devices to the Internet for the purpose of exchanging and communicating information (Ibid, p.1). The mechanism of IoT systems consist of many elements, such as, identification, monitoring, locating, sensing, tracking, communication, and computation services from all over the world (Ibid, p.1). It is an expansion of an Internet-based network which serves to extend the communications from human and human to human and things or things and things (Al-Turjman et al., 2019). The IoT has envisioned numerous research and scientific disciplines that facilitate connectivity over various objects worldwide (Al-Turjman et al., 2019). Some of the most favorable and productive technologies that has altered our social and economic industries include: Radio-Frequency Identification (RFID) technologies, sensor networks, biometrics, and nanotechnologies (Al-Turjman et al., 2019). These IoT technologies have dramatically altered the way people live and act in their lives by bringing itself into "real implementations" by addressing various applications in smart grid, e-health, and intelligent transportation (Al-Turjman et al., 2019). Alternatively, though IoT has contributed to huge improvements around the world, like any device, these devices also utilize energy and costs to operate and function properly (Ahmed et al., 2019, p.1). The excessive consumption of energy through the vast interconnectivity of IoT devices and systems has generated enormous waste, unnecessary heat, and carbon emissions in the environment (Al-Turjman et al., 2019). Furthermore, the production of IT hardware has posed serious threats to the environment due to the complications raised in the production and disposal processes (Murugesan, 2008, p.3). This leads to the concept of Green IT which serves to reduce the emissions, pollution, and environmental exploitation; as well as enhance the energy-efficiency, power consumption, and minimize operational costs (Al-Turjman et al., 2019). For several years, Green IT has remained a hot topic due to its increasing benefits in its design, production, utilization, and disposal processes (Murugesan, 2008, p.1). According to contemporary research, Green IT is predicted to enhance significant changes in our daily lives as we move ahead to a more "intelligent" world (Al-Turjman et al., 2019). A growing number of business facilities, IT vendors, and users are heading towards Green IT and thereby helping to build a Greener society and economy (Al-Turjman et al., 2019). IoT is an impeccable technology that will dynamically cover the modern technological world. According to recent studies, analysts and business insiders have predicted that out of 34 billion devices, approximately 24 billion devices will be based on IoT in 2020 (Ahmed et al., 2019, p.10). Hence, the vitality of incorporating a "Greener" approach is highly essential to sustain and conserve our environments. The significance of implementing a Greener approach in the distribution and utilization of IoT serves to reduce the negative environmental effects. It also reduces, and in some areas eliminates the threats of human health concerns.

The objective of this research is to provide Green solutions on the negative effects of IoT. A detailed and comprehensive review of literatures will be provided to analyze the challenges in IoT, the characteristics of Green IoT, the designs of Green IT, and finally, a comparative evaluation of IoT and Green IoT will be analyzed to determine the significance of Green IT. To be more specific, this report aims to achieve the following objectives:

- To identify the challenges of implementing IoT in various industries.
- To study the characteristics of Green Computing.
- To identify individual and infrastructural designs to implement a Sustainable Green Design for IoT.
- To propose a solution on how sustainable designs help implement and improve the performance of IoT; as well as protect the eco-system.
- To evaluate the proposed solution of implementing Green IoT into our environments.

Consequently, the objectives will be narrowed down into four main research questions which will be addressed through the literature reviews. These questions will offer comprehensive details regarding the impacts of IoT on the environments, followed by Green solutions. An evaluation will also be presented to negotiate the effectiveness of the sources. The questions that will be considered in this report are:

1) What are the challenges in implementing IoT in various industries?
2) What are the characteristics of Green Computing?
3) What are the design principles required to implement a sustainable design in IoT?

4) How can sustainable designs help improve the performance of IoT and Green Computing?

Finally, a methodology will be conducted for the purpose of providing a comparative analysis on Green solutions to the effects of energy-consumption. The methodology will focus on three main factors of Green IT and the way these techniques offer energy-efficiency. Once these solutions are identified, a comparative analysis will be presented in a tabular form. A classification value will also be added to the sources being compared which will measure the best energy-efficient solution.

The report will begin by addressing the four main questions through numerous literature reviews, followed by an evaluation of the reviews. Furthermore, a methodology will be presented on conducting a comparative analysis on energy-efficient solutions in Green IT. The results section will evaluate the best energy-efficient solution by reasoning against other sources. Finally, an overview and conclusion of this report will be provided to sum up the research.

CHAPTER II: LITERATURE REVIEW

Challenges in Internet of Things (IoT)

The authors of the article "*A Vision of IoT*" address the concept of IoT and some of the key challenges faced in the Internet of Things. The authors state that IoT has created an exceptional impact by producing a huge network of "Things" that communicate with one another (Chen et al., 2014, p.1). These networks of "Things" are constructed in various forms of electronic devices that allow flexible communication, identification, and computing capabilities which can further be embedded into other systems or devices. Furthermore, the growing trend of enabling the small-scale electronic devices that only require batteries provide much flexibility with its size, cost, and durability. In summary, the authors have characterized IoT with the three main functions: 1) Comprehensive perception, 2) Reliable Transmission, and 3) Intelligent Processing (Chen et al., 2014, p.1). However, apart from the enormous benefits served from the Internet of Things, these technologies are facing numerous "technical and application" challenges at the same time (Chen et al., 2014, p.1). Following some lengthy details of China's perspective towards IoT, the paper further elaborates on the challenges of IoT applications (Chen et al., 2014, p.8). The authors claim that though IoT provides many opportunities to the economic and social industry, it lacks "theory, technology architecture and standards" that mixes the virtual and real world in a combined framework (Chen et al., 2014, p.1). The authors argue that for IoT trends to be universal and pervasive, the varying largescale service distribution needs to be organized within a set of standards (Chen et al., 2014, p.9). This seems to be the issue as IoT consists of numerous manufacturers, is spread across various industries, and also differs in application/user scenarios and requirements (Chen et al., 2014, p.9). These issues consequently affect the outcomes of largescale commercial deployment (Chen et al., 2014, p.9). The key challenges of IoT that are listed in the article extensively talk about problems relating the Architecture of IoT, the Technical Challenges, Hardware Challenges, Privacy and Security Challenges, the Standard Challenges, and lastly, Business Challenges (Chen et al., 2014, p.8-9).

To begin with the first issue, of "IoT Architecture", the authors argue that IoT devices incorporate a large number of smart interconnected devices and sensors (Chen et al., 2014, p.8). These devices and sensors could include biometrics, cameras, and physical and chemical sensors that are either invisible or nonintrusive (Chen et al., 2014, p.8). And as these devices are expected to provide communication services at anytime and anywhere, these communications are in a "wireless, automatic, and *ad hoc* manner" which makes them complex and decentralized (Chen et al., 2014, p.8). Hence, with an arrival of a severe complex situation, data integrations over varying environments become difficult and require the support of modular interoperable units (Chen et al., 2014, p.8). This prompts further complexities as infrastructure solutions will require the combination of extensive volume of data from various other sources to determine the relevant features, data, and their relationships to support in decision-making (Chen et al., 2014, p.8). With this problem arises the necessity of a single reference architecture that is heterogeneous and can co-exist in IoT (Chen et al., 2014, p.8). This would extinguish the restriction for users to use "end-to-end" solutions and provide a much more flexible approach for cases of identification, intelligent devices, and smart objects (Chen et al., 2014, p.8). With the issue of IoT architecture arises the issues of "Technical" complexities. As the IoT consists of a vast networking arena, there also exists “legacy heterogeneous architectures” in the existing technologies and application systems (Chen et al., 2014, p.8). The authors state that regardless of the differences in communication technologies, which are either fixed, wireless, or mobile communication systems, they all should be of low-cost with efficient and reliable connectivity (Chen et al., 2014, p.8). Furthermore, the differences in technological requirements also demand their own security and technical solutions. This would lead to unnecessary rivalries and deployment restrictions in markets - this could further lead to restraints from dependencies in providing the migration of IoT systems on efficient economic platforms (Chen et al., 2014, p.8).

Hardware Challenges have also been a critical point of view to consider as smart devices with enhanced inter-device communication systems lead to a great value of intelligence (Chen et al., 2014, p.9). According to the authors, hardware researches are directing their designing to enable wireless identifiable systems that contain low sizes and costs (Chen et al., 2014, p.8). However, hardware requirements are also diverging as the bandwidth of IoT could alternate from kbps to mbps (Chen et al., 2014, p.8). There have been difficulties in designing a hardware and protocol co-design for sleeping times while researchers consider the essentials of low power consumption and ultra-low cost in sleep mode or less active times. Low-cost performances would require longer processing latency which eventually ends up to higher energy use. Furthermore, low-cost alternatives do not guarantee a higher performance rate which continues to be a challenge.

With the growing spectrum of IoT, Privacy and Security issues have also been a major concern. Unlike traditional networks, IoT includes a vast combination of things, services, and networks which require extended security management (Chen et al., 2014, p.9). The authors claim that existing security architectures are constructed from the perspective of "human communication" and may not be appropriate when directly applied on IoT systems (Chen et al., 2014, p.9). Improvements in technical areas to adapt a low-cost and M2M-oriented solution is vital (Chen et al., 2014, p.9). The challenge of "Standard" is also viewed to play a significant role in "forming" IoT (Chen et al., 2014, p.9). The notion of developing a standard that allows all actors to equally access and use IoT systems shall promote sufficient developments in IoT infrastructures, devices, and applications (Chen et al., 2014, p.9). This has been suggested to be done in a way where cooperation between multi-parties to develop a standard with information models and protocols are to be open to all participants and publicly available (Chen et al., 2014, p.9). Lastly, IoT has been a "Business" challenge as technical requirements become a considerable notion. There are numerous uncertainties in business models and application scenarios (Chen et al., 2014, p.9). Hence, it is ineffective regarding "business-technology alignment"; as one solution will not fit potentially for all. Though small-scaled applications have said to be profitable in some industries, it is hard to assume the same when extended to other industries (Chen et al., 2014, p.9).

The Internet of Things is widely understood to be a new technology paradigm of computing devices that are capable of globally connecting "Things" and humans with each other (Lee and Lee, 2015, p.1). The authors state that IoT has been recognized as a significant factor that has become highly popular for its use in various industries (Lee and Lee, 2015, p.1). The value of IoT for enterprises is recognized by its ability to communicate and integrate vendor-managed inventory systems, business intelligence applications and analytics, as well as customer support systems (Lee and Lee, 2015, p.8). Though the benefits are considered to a great extent, the authors also touch base on five technical and managerial challenges present in IoT. These challenges are Data Management, Privacy, Security, Data Mining, and Chaos (Lee and Lee, 2015, p.2).

The authors of the article have evaluated surveys of IoT practices and discussed the aforementioned challenges in the development of IoT by enterprises (Lee and Lee, 2015, p.8). According to research, the overpowering value of data generated by IoT machines will most possibly cause data centers to face numerous challenges with consumer privacy, security, data itself, storage management, server technologies, and data center networking (Lee and Lee, 2015, p.8). Similar to the arguments of the previously mentioned article, the architecture of IoT is problematic for reliable data management. Data management tends to challenge IoT sensors and devices as they generate enormous amount of data that needs to be processed and stored (Lee and Lee, 2015, p.9). Considering the huge volume of data transmission, the current architecture of the data center is not equipped enough to deal with the "heterogenous nature" of personal and enterprise data (Lee and Lee, 2015, p.9). This leads to only few enterprises who can invest in data storage that is efficient to house all IoT data collected from their networks. Therefore, they will arrange and prioritize data for procedures based on necessity and value (Lee and Lee, 2015, p.9).

Another challenge outlined in the article is the "Data Mining" challenge (Lee and Lee, 2015, p.9). As more data becomes available for processing and analysis, there is sufficient need of more efficient and quantitative data mining tools (Lee and Lee, 2015, p.9). The increasing amount of not only traditional discrete data, but also streaming data that is produced by digital sensors, require more data mining tools (Lee and Lee, 2015, p.9). These streaming data are very specific and higher in volume, such as, locations, movements, temperature, chemical changes, humidity, etc. (Lee and Lee, 2015, p.9) The shortage of competent data analysts requires the critical need of data mining tools that can provide corrective process to organize significant operational issues. This method would further allow business executives to be informed of information regarding competitors, strategic motives, and customer preferences that will impact their business activities (Lee and Lee, 2015, p.9). “Privacy and Security” issues remain a constant and contemporary challenge in the arena of IoT. As many business, health, and economic industries are reliable on the services of IoT, protecting privacy still remains counterproductive as the streamlining operations provide cost and health risk deficiencies (Lee and Lee, 2015, p.10). Similarly, the variety of connected IoT devices and networks also contain potential security threats which only continue to escalate (Lee and Lee, 2015, p.9). Though IoT serves to improve the productivity of companies and peoples’ lives, it is also more prone to hackers that aim to target the privacy and security of individuals (Lee and Lee, 2015, p.9). According to the authors’ research, 70% of the most frequently used IoT devices are vulnerable to serious threats (Lee and Lee, 2015, p.9). These insecurities are derived from the lack of transport encryption, weak web interfaces, unreliable software protection, and insufficient authorization (Lee and Lee, 2015, p.9). There is an immediate need of security solutions such as “intrusion prevention systems, firewalls” in IoT products, as well as encouraging users to apply the security features when utilizing their devices (Lee and Lee, 2015, p.9).

Lastly, the challenge of "Chaos" is the most crucial issue to be considered as it is prompted and led by the challenges mentioned above. The evolution of IoT technologies, such as, microchips, wireless networking technologies, and sensors have created a hyper-accelerated innovation cycle (Lee and Lee, 2015, p.9). This hyper-accelerated cycle is much faster than the "typical consumer product" innovation cycle (Lee and Lee, 2015, p.9). At the same time, the IoT sector still faces competing standards, security and privacy issues, complex communications, and poorly tested devices which could lead to severe and fatal consequences (Lee and Lee, 2015, p.9). If these issues are not soluble, these devices and applications hold the capacity of turning lives into chaos (Lee and Lee, 2015, p.9). The IoT world is extremely hyper-connected, and one error in a small part of any system can cause major disorders throughout the whole process of the application or system (Lee and Lee, 2015, p.9-10). Some examples include attackers accessing web applications and trackers, failures or disorders in medical devices, and smart home kits such as residential power meters breaking down by attackers (Lee and Lee, 2015, p.9-10). The IoT is like an interconnect chain reaction where one small disorder could lead to chaotic outcomes. To prevent such dangers, it is vital for businesses to make effort to reduce the problems of connected systems and enhance the security standardization of IoT applications (Lee and Lee, 2015, p.9-10).

The advancement of smart homes, smart devices, and "smart everything" in the Internet of Things has become one of the most incredibly effective tools of growth, potential, and advancement (Khan and Salah, 2017, p.1). However, as agreed by majority of the researchers, these IoT devices are still limited in storage, compute, and network capacities which make them vulnerable to threats (Khan and Salah, 2017, p.1). The authors have structured an extensively analytical paper that discusses major architecture and security issues. They further categorize the most popular security challenges in relation to the IoT architecture, the protocols used for networking, communication, and management (Khan and Salah, 2017, p.3). However, this summary will focus on the key security challenges to give an overall view of the paper.

There are major security threats linked with Wireless Sensor Networks (WSNs), Machine-to-Machine (M2M), and Cyber Physical Systems (CPS) as their IP protocol is used as the main source for connectivity (Khan and Salah, 2017, p.3). The authors state that the "Security" challenges mentioned requires significant security preservations in its architecture (Khan and Salah, 2017, p.3). Insecure web connections and services may pose threat to user privacy, integrity, or confidentiality of data (Khan and Salah, 2017, p.3). Furthermore, the nature of "IoT Architecture", such as, its interconnected networks and heterogenous devices makes it more prone to the security threats of hacking, manipulation, and external monitoring. Some of these small interconnected devices, such as sensors, contain limited power and memory which make them more prone to security threats (Khan and Salah, 2017, p.3). Therefore, the security solutions need to be improved to the constrained IoT architectures.

The authors have asserted the vitality of restricting the IoT architecture to create a more secure communication and network system. As IoT data is transmitted via numerous hops in a network, a reliable encryption mechanism is essential to guarantee the privacy and security of data (Khan and Salah, 2017, p.6). Due to the vast integration of services, devices, and networks, the data stored on a device is susceptible to privacy violation as it compromises nodes that exist in an IoT network. This could lead to an attacker modifying information for their own vicious purposes (Khan and Salah, 2017, p.6). There is also a threat of privileged communication in IoT as the need for reliable authentication and authorization needs improvement. The widespread diversity of authentication mechanisms in IoT exists due to the heterogenous architectures and environments which support the devices (Khan and Salah, 2017, p.6). These diverse environments create challenges for "defining standard global protocol" for authorization in IoT (Khan and Salah, 2017, p.6). Furthermore, attacks on IoT devices are likely to interfere the provision of services through a predictable Denial-of-Service attack (p.6).

Lastly, the challenge of "Energy-efficiency" also serves to impact the architecture of IoT devices. IoT devices are usually resource-constrained and constructed with low power and storage. An increase of energy consumption could possibly flood the network and exhaust the IoT resources through forged service appeals (Khan and Salah, 2017, p.6). Continuous developments of heterogenous networks in the IoT infrastructure can potentially expose enormous amount of single-points-of-failure which can weaken the services of IoT (Khan and Salah, 2017, p.7). Such problems require the development of a "tamper-proof" environment for greater number of IoT devices, as well as implement an alternate option for fault-tolerant networks (Khan and Salah, 2017, p.7).

Characteristics of Green Computing

In this article, Murugesan (2008) discusses the importance of Green IT, and its significance in creating a much more productive and secure IT infrastructure and eco-system. Murugesan argues that though IT has created an enormously beneficial arena, it has also been contributing to environmental problems (Murugesan, 2008, p.1). Computers and other IT infrastructures consume large volumes of electricity which creates heavy burdens on electric grids; further leading to greenhouse gas emissions (Murugesan, 2008, p.1). Moreover, IT hardware cause severe environmental issues during its production and disposal processes (Murugesan, 2008, p.1). Murugesan further asserts the crucial necessity of implementing Green IT practices. He states that we must "green" IT products, applications, services, and practices (Murugesan, 2008, p.1). The author addresses key issues of IT, followed by giving extensive information about the principles and practices of Green IT.

Murugesan defines Green IT as "environmentally sound IT" (Murugesan, 2008, p.2). There are numerous characteristics of IT, all which promote sustainable attributes. Green IT is defined as the practice of "designing, manufacturing, using, and disposing of computers, servers, and associate subsystems…efficiently and effectively with minimum or no impact on the environment" (Murugesan, 2008, p.2). Some of Green IT characteristics are evident in its benefits which serve to enhance the environment by improving energy-efficiency, reducing greenhouse gas emissions, reducing the use of harmful materials, and following the "Three R's" strategy of reuse, refurbish, and recycle (Murugesan, 2008, p.2 & p.8). Green IT also endeavors to achieve economic viability and improves system performances and use by abiding the social and ethical responsibilities (Murugesan, 2008, p.2). The benefits and characteristics of Green IT spans extensively across a number of significant areas and activities. These include design for environmental sustainability, energy-efficient computing, cost-efficient power management, data center design, layout and location, server virtualization, disposal and recycling, regulatory compliance and green metrics, environment related risk alleviation, utilization of renewable energy sources, and eco-labelling of IT products (Murugesan, 2008, p.3-4).

In order to comprehensively focus on the environmental impacts of IT, a holistic approach to Green IT is a productive solution. Green IT addresses four complementary issues of IT:

Green Use: This practice reduces the energy consumption of computers and other information systems by using them in an environmentally sound manner (Murugesan, 2008, p.5). A significant "green" objective in using IT materials is to reduce their energy consumption, thus, preventing excessive greenhouse gas emissions (Murugesan, 2008, p.5-6). There are many ways to reduce the energy consumption of computers during their use. Enabling power management techniques can significantly help reduce power consumption. Computers tend to generate a lot of heat and require cooling which leads to more power consumption and costs for enterprises. There are even options to automatically power down to an "energy-saving" mode when computers are not in use. A combined approach of shutting down or hibernating computers when not in use can significantly reduce PC energy consumptions (Murugesan, 2008, p.5-6). There is a software known as Surveyor from Verdiem that allows network-level control over computers. It positions the PC into low power-mode or standby when they aren't being used. Users can then wake the PCs for software upgrades of backup without having to wait for the re-boot process (Murugesan, 2008, p.6).

Green Disposal is the refurbishment and reuse of old computers. It is also the practice of recycling unwanted computers and electronic equipment properly, without causing environmental damage (Murugesan, 2008, p.5). Electronic components consist of many toxic materials like lead, chromium, cadmium, and mercury which could leak harmful chemicals and materials into the environment and waterways if buried in landfills (Murugesan, 2008, p.8). Also, burning such materials would cause toxic gases into the air making it highly dangerous for people to breathe into. Unwanted electronics must not be thrown away as they cause severe environmental damage. Instead, using a Greener approach of reusing, refurbishing, and recycling can help sustain the eco-system, as well provide cost-efficiency.

Reusing old computers is a strategic way to fulfill requirements of efficient use and sustainability. We could also provide old computers to others who may need it for its functional components, or overall use. (Murugesan, 2008, p.8). Using the hardware for a longer period reduced the environment "footprint" produced by PC manufacturing and disposal (Murugesan, 2008, p.8). Refurbishing and upgrading old computer devices to almost as new products is also a cost-efficient and eco-friendly way of practicing Green IT. Refurbishing electronic devices by purchasing specific parts and adjoining them with the old parts can also be as productive as a new product (Murugesan, 2008, p.8). Lastly, if refurbishing is not an option, electronics must be recycled in environmentally friendly ways which do not end up landfills or waterways.

Green Design are energy-efficient and globally sound components, servers, electronics, and cooling equipment (Murugesan, 2008, p.5). The rapid increase of Internet and web application is rising the growth of data centers (Murugesan, 2008, p.7). The installations of more servers and computers had increased six-fold to thirty million in the last decade (Murugesan, 2008, p.7-8). Availability of electricity has become a worrying issue for many enterprises as each server draws extensive amount of electricity (Murugesan, 2008, p.7). However, Green IT has provided a solution to improve data center efficiency by implementing energy-efficient tools, improvising airflow to cut down cooling requirements, and adopting environmentally friendly designs (Murugesan, 2008, p.8).

Energy conservation methods, such as, utilizing liquid cooling, nanofluid cooling systems, and in-row cooling technologies are now being implemented (Murugesan, 2008, p.7). Also, using high-density servers, hydrogen fuel cells as optional green power sources, and implementing virtualization technologies also serve to reduce power consumption of servers, as well as lower the heat production (Murugesan, 2008, p.7).

Eco-friendly designs are also highly beneficial for data centers as they use a “synthetic white rubber roof, paint, and carpet” that consists of low volatile organic compounds, energy-efficient electrical systems, and countertops produced of recycled materials (Murugesan, 2008, p.7). Eco-friendly designs also make sufficient use of natural light and green power electricity that is generated from solar or wind energy (Murugesan, 2008, p.7).

Lastly, virtualization is another key alternative to reduce power consumption in data centers. Virtualization allows one physical server to host multiple virtual servers

(Murugesan, 2008, p.7-8). It also permits data centers to combine their physical server infrastructure by holding numerous other virtual servers on a smaller number of more powerful servers, utilizing less electricity. Instead of getting a better hardware usage, virtualization also decreases data center floor space, makes productive use of computing power, and reduces energy demands (Murugesan, 2008, p.8).

Green Manufacturing is the production of electronic components, and other subsystems with minimum or no impact on the environment (Murugesan, 2008, p.5). Green manufacturing methods aim to prevent any environment impact of IT devices by adopting to new technologies and techniques (Murugesan, 2008, p.9). According to the author, many computer manufacturers are implementing processes of creating green PCs by using nontoxic materials. These new PCs are efficiently upgradable and consume less electrical power (Murugesan, 2008, p.5). The shift from single code to dual and quadcore processors conserve power, while also increasing processing performance (Murugesan, 2008, p.5). Other alternatives include dividing the cache into segments that are only power-driven when required. Further power reduction techniques include darkening the backlight of screens (Murugesan, 2008, p.9).

These four components mentioned above have been labeled as some of the most effective ways that Green IT can be implemented. Murugesan states that Green IT is and continues to be a necessity; not an option (Murugesan, 2008, p.11).

Sustainable Design Principles to Implement Green Internet of Things (G-IoT)

The article *"Green Internet of Things for Smart World"* targets to achieve a sustainable smart world by envisioning Green IoT designs and their principles (Zhu et al., 2015, p.1-2). The authors focus on Green ICTs that serve to reduce the energy consumption of IoT (Zhu et al., 2015, p.1). Some of the "hot Green" ICTs discussed are as follows: Green Radio-Frequency Identification (RFID), Green Wireless Sensor Network (WSN), Green Cloud Computing (CC), Green Machine-to-Machine (M2M), and Green Data Center (DC) (Zhu et al., 2015, p.1-2). The authors also review the latest Sensor-Cloud development and further envision a future Green Sensor-Cloud (Zhu et al., 2015, p.1-2). In order to enable a sustainable smart world, the authors state that IoT should be characterized by its energy-efficiency (Zhu et al., 2015, p.3). Since most of the IoT devices in a smart world are equipped with additional sensory and communication add-ons, they require extra energy (Zhu et al., 2015, p.3). Furthermore, the growing interest and adoption from numerous organizations have greatly increased the energy demands which pose significant concerns for the environment (Zhu et al., 2015, p.3). Though the authors do not propose brand new technologies in replacement of existing IoT technologies, they do suggest alterations of its use by providing Green solutions to their existing structures and designs. The focus on this article will be based on three main ICT technologies: RFID, WSN, and CC; and their proposed Green design for its sustainable use.

It has become a great necessity to convert Green IoT as our focus to implement sustainable methods. The core components of sustainable designs target the energy-efficiency and energy consumption value of a "thing". The authors claim that in order to reduce the impacts of Greenhouse effects of IoT, “The entire life cycle of green IoT should focus on green design, green production, green utilization and finally green disposal/recycling to have no or very small impact on the environment.’’ (Zhu et al., 2015, p.3) To propose a Green design for the aforementioned IoT, the authors begin with the most commonly used device: RFID tags. The basic purpose of RFID tags is the storage of information regarding the objects and things they are attached to (Zhu et al., 2015, p.5). The process of the RFID tag is to transmit the information of the things or object through query signals, followed by a response from nearby RFID tags (Zhu et al., 2015, p.5). Normally, the transmission ranges of RFID systems are low, and go as far as a few meters (Zhu et al., 2015, p.5). Additionally, the tags utilize various bands from low to ultra-high frequencies at 860-960MHz to perform transmission (Zhu et al., 2015, p.5). As there are two types of commonly known RFID tags, active and passive, the passive tags tend to harvest energy from reader signals with the principle of induction (Zhu et al., 2015, p.5). By substituting to a Green RFID alternation, reducing the sizes of RFID tags would decrease the quantity of nondegradable material utilized in their production (for example, biodegradable RFID tags, printable RFID tags, paper-based RFID tags) as the tags are problematic and difficult enough to recycle (Zhu et al., 2015, p.6). Additionally, energy-efficient algorithms and protocols can be used to enhance tag estimation, regulate transmission power levels, reduce tag collision, and avoid overhearing (Zhu et al., 2015, p.6).

Another Green alternative suggested by the authors focuses on WSNs. WSNs are usually consisted of a number of sensor nodes and a Base Station (BS) (Zhu et al., 2015, p.6). Though the sensor nodes are with low processing, low power, and storage capacity, the BS remains a powerful source (Zhu et al., 2015, p.6). When the sensor nodes are equipped with multiple on-board sensors, they take readings of the temperature, humidity, acceleration, or anything from the surroundings (Zhu et al., 2015, p.6). Then the data is transferred to the BS where the information is stored. The authors have suggested a commonly used commercial WSN solution which is based on the IEE 802.15.4 standard, which covers physical and medium access control layers for low power and low-bit communications (Zhu et al., 2015, p.6). Additionally, to allow a Green solution, the sensor nodes should only be active when necessary, while the remaining time they should be left on sleep mode to reduce energy consumption (Zhu et al., 2015, p.6). Further techniques to be considered are:

- For energy depletion, energy can be utilized from natural resources such as the sun, kinetic energy, vibration, temperature…etc. This would also increase the lifespan of WSNs and microprocessors by maximizing their performance (Zhu et al., 2015, p.6).

- Radio optimization techniques involve transmission power control, modulation optimization, directional antennas, and energy-efficient Cognitive Radio (CR) (Zhu et al., 2015, p.6)

- Data reduction mechanisms include techniques such as: compression, aggregation, and sampling of data (Zhu et al., 2015, p.6).

- Finally, energy-efficient routing techniques include multipath routing, cluster architectures, node mobility…etc. (Zhu et al., 2015, p.6).

The final Green alteration to be suggested is for Cloud Computing. Cloud Computing is known to offer various high-performance computing resources and storage to its users (Zhu et al., 2015, p.6). With the increasing applications that rely on Cloud, more resources need to be deployed and more power is consumed which causes environmental issues due to carbon dioxide emissions (Zhu et al., 2015, p.6). A Green solution offers the adoption of hardware and software that decrease the energy consumption (Zhu et al., 2015, p.6). Hardware solutions should aim to design and manufacture devices which consume less energy. Whereas, software solutions should offer efficient designs that consume less energy with minimum source utilization, such as, power-saving Virtual Machine techniques (VM), energy-efficient allocation mechanisms, effective models, and evaluation tactics regarding energy-saving policies and Green Cloud Computing schemes based on Cloud supporting technologies (Zhu et al., 2015, p.6).

There are many Green ICT principles that have also been briefly discussed by the authors which serve to reduce the increasing energy consumption from IoT. These principles focus on the following points:

- Turning off facilities that are not needed.
- Only send data that is highly essential and needed.
- Minimize the length of data path.
- Minimize the length of wireless data path.
- Trade-off processing for communications, combine data from multiples sources, data fusion.

- Advanced communication techniques, Multiple-Input, Multiple-Output (MIMO) techniques establish enhanced spectral efficiencies in multipath fading environments relative to their single-input single-output counterparts.

Renewable Green power sources such as oxygen, fresh water, solar energy, time, and biomass are resources which are replaced naturally and can be used again. This will reduce the dependency on oil and emissions of carbon dioxide (Zhu et al., 2015, p.6-7).

With a highly similar approach, Nandyala and Kim (2016) have also proposed Green IoT applications to architectures that enable Green components. The focus of this article will be on reviewing the improved “Green” Machine-to-Machine (M2M) and Data Center (DC) infrastructure (Nandyala and Kim, 2016, p.2). When looking into the M2M structure, enormous M2M nodes intelligently collect monitored data and deploy them into the M2M domain (Nandyala and Kim, 2016, p.9). The BS further connects numerous M2M applications over the network in the application domain (Nandyala and Kim, 2016, p.9). When evaluating the whole process, a lot of energy is consumed from the enormous machines, specifically in the M2M domain. When observing the process from a Green M2M perspective, there are alternative methods that can be adapted to increase energy-efficiency (Nandyala and Kim, 2016, p.9).

- Adjust the transmission power to a minimum level that is necessary.
- Design competent and effective communication routing protocols with the application of algorithmic and distributed computing techniques.

- Manage activity scheduling in which the aim is to switch some nodes to low-power or sleeping mode to enable only a subset of connected nodes to remain active for the functionality of the original network.

- Conduct joint energy-saving mechanisms with overload protection and resource allocation.

- And finally, conduct energy harvesting and the benefits of CR (for example, spectrum sensing and management, interference mitigation, and power optimization) (Nandyala and Kim, 2016, p.9).

The final sector to discuss that contributes majorly towards the infrastructure of IoT is Data Center (DC). A Green Data Center solution has also been proposed to enable a potential sustainable solution. As it is understood, the primary job of DCs is to store, manage, process, and distribute extensive data and applications that are constituted by users, things, and systems (Nandyala and Kim, 2016, p.9-10). When dealing with large amounts of data and applications, DCs consume a high value of energy with high operational costs and large carbon dioxide footprints (Nandyala and Kim, 2016, p.9). The increasing generation of large data by things and objects in the smart world tends to create problems with the DCs' energy-efficiency (Nandyala and Kim, 2016, p.10). However, there is potential to reducing this risk of high energy consumption by following the techniques below:

- Utilize renewable or natural Green sources of energy, such as, wind, water, solar energy, etc.

- Use dynamic power-management technologies, such as, Turbo boost.

- Design more energy-efficient hardware techniques that exploits the advantages of dynamic voltage and frequency scaling; also, implement Vary-On/Vary-Off (VOVO) techniques.

- Design energy-efficient DC architecture, for example, Nano DCs that assist in power conservation.

- Design energy-aware routing algorithms to manage traffic flows to a subset of the network, also, switch off idle devices.

- Construct effective DC power models.

- Finally, enable support from communication and computing techniques, such as, optical communication, virtual machine migration…etc. (Nandyala and Kim, 2016, p.10).

Below is a table that summarizes Green ICT enabling Green IoT techniques. **Table 1** summarizes the main IoT technologies discussed in both articles.

TABLE 1. A summary of green ICT enabling green IoT (Nandyala and Kim, 2016)

Scheme	Techniques
Green RFID	1) Reduce the sizes of RFID tags to decrease the amount of nondegradable material used in their manufacturing; 2) Energy-efficient algorithms and protocols for optimizing tag estimation, adjusting transmission power level dynamically, avoiding tag collision, avoiding overhearing, etc.
Green WSN	1) Make sensor nodes only work when necessary, while spending the rest of their lifetime in a sleep mode; 2) Energy depletion (e.g., wireless charging, energy harvesting mechanisms which generate power from the environment (e.g., sun, kinetic energy, vibration, temperature differentials, etc.)); 3) Radio optimization techniques (e.g., transmission power control, modulation optimization, cooperative communication, directional antennas, energy-efficient cognitive radio (CR)); 4) Data reduction mechanisms (e.g., aggregation, adaptive sampling, compression, network coding); 5) Energy-efficient routing techniques (e.g., cluster architectures, energy as a routing metric, multipath routing, relay node placement, node mobility).
Green CC	1) Adoption of hardware and software that decrease energy consumption; 2) Power-saving virtual machine (VM) techniques (e.g., VM consolidation, VM migration, VM placement, VM allocation); 3) Various energy-efficient resource allocation mechanisms (e.g., auction-based resource allocation, gossip-based resource allocation) and related task scheduling mechanisms; 4) Effective and accurate models and evaluation approaches regarding energy-saving policies; 5) Green CC schemes based on cloud supporting technologies (e.g., networks, communications, etc.).
Green M2M	1) Intelligently adjust the transmission power (e.g., to the minimal necessary level); 2) Design efficient communication protocols (e.g., routing protocols) with the application of algorithmic and distributed computing techniques; 3) Activity scheduling, in which the objective is to switch some nodes to low-power operation ("sleeping") mode; 4) Joint energy-saving mechanisms (e.g., with overload protection and resources allocation); 5) Employ energy harvesting and the advantages (e.g., spectrum sensing, spectrum management, interference mitigation, power optimization) of CR.
Green DC	1) Use renewable or green sources of energy (e.g., wind, water, solar energy, heat pumps, etc.); 2) Utilize efficient dynamic power-management technologies (e.g., Turboboost, vSphere); 3) Design more energy-efficient hardware (e.g., exploiting the advantages of DVFS (dynamic voltage and frequency scaling) techniques and VOVO (vary-on/vary-off) techniques)); 4) Design novel energy-efficient data center architectures (e.g., nano data centers) to achieve power conservation; 5) Design energy-aware routing algorithms to consolidate traffic flows to a subset of the network and power off idle devices; 6) Construct effective and accurate data center power models; 7) Draw support from communication and computing techniques (e.g., optical communication, virtual machine migration, placement optimization, etc.).
General green ICT	1) Turn off facilities that are not needed (e.g., sleep scheduling); 2) Send only data that are needed (e.g., predictive data delivery); 3) Minimize length of data path (e.g., routing schemes, network working mechanisms); 4) Minimize length of wireless data path (e.g., energy-efficient architectural designs, cooperative relaying); 5) Trade off processing for communications (e.g., data fusion, compressive sensing); 6) Advanced communication techniques (e.g., multiple-input multiple-output (MIMO), CR); 7) Renewable green power sources (e.g., oxygen, fresh water, solar energy, timber, biomass).

Proposed Solution of Implementing Green Internet of Things (G-IoT)

The exceptional developments in the field of Internet of Things (IoT) has dramatically transformed the way people live and work. IoT has led to exponential benefits worldwide due to its services and flexibility. Although the enormous benefits of IoT has enriched the society, it must be understood that IoT consumes a high level of energy, causes toxic pollution, and E-waste (Alsamhi et al., 2018, p.1). These issues place great stress on the environments and smart world (Alsamhi et al., 2018, p.1). The authors claim that in order to increase the benefits and prevent the harm of IoT, there is a vital necessity to move towards Green Computing (Alsamhi et al., 2018, p.1). In order to comprehensively focus on the environmental impacts of IT, a holistic approach to Green IT is a productive solution. Green Computing (Green IoT) strives to work for measures to reduce carbon footprint, preserve resources, and encourage energy-efficient techniques of electronic usage (Alsamhi et al., 2018, p.2). The authors provide extensive solutions for reducing carbon emission and energy-efficiency in IoT by implementing "Green IoT" techniques to alter existing designs.

Green Computing or Green IoT refers to the technologies that convert the existing IoT environment into an eco-friendlier way by making use of services and storages that allow subscribers to gather, store, access, and manage information (Alsamhi et al., 2018, p.1-2). The enabling technologies for Green IoT are called Information and Communication Technology (ICT) (Alsamhi et al., 2018, p.2). Alsamhi et al. (2018) claim that the increasing applications of ICT has drawn an increasing amount of energy consumption, carbon emission, and E-waste (Alsamhi et al., 2018, p.2). Hence, Green IoT is a sustainable practice that manufactures, designs, and disposes computers, servers, and other associated subsystems more efficiently with a reduced effect on the environment (Alsamhi et al., 2018, p.2-3). The following technologies have been discussed by the authors, in which they have implemented Green ICT technologies to reduce the environmental stress: Green Radio-Frequency Identification (GRFID), Green Wireless Sensor Network (GWSN), Green Machine-to-Machine (GM2M), Green Cloud Computing (GCC), and Green Data Center (GDC) (Alsamhi et al., 2018, p.2). RFID and WSN are two complementary technologies that qualify the identification of every object in IoT. Hence, IoT can only become G-IoT if substantial alterations are made in making RFID and WSN "Greener" (Alsamhi et al., 2018, p.2-3). The focus of this review will remain only on RFID and WSN technologies to highlight the way sustainable designs improve the performance of IoT.

RFID is known to be one of the most promising wireless communication systems used to enable IoT (Alsamhi et al., 2018, p.3). RFID is a low-cost and flexible technology used in applications to track people, objects, or things in real-time (Alsamhi et al., 2018, p.3). It is also one of the fastest growing wireless technologies that provides immense benefits due to its features and potentials (Alsamhi et al., 2018, p.3). There has been a Green approach with the manufacturing of RFID tags to eliminate its negative influences on the environment. The authors have proposed a design where novel materials can be used for manufacturing biodegradable RFID tags. Some of the materials suggested for designing the tags include conductive, adhesive, plastics, etc., whereas, alternative processing approaches include chip less RFID tags and passive wireless RFID sensors (Alsamhi et al., 2018, p.3). There has also been a proposal that focuses on enhancing the lifespan of the UAV battery and RFID reader detection range (Alsamhi et al., 2018, p.3). UAV is utilized for information collection from RFID sensors by scattering throughout the area using downloading measuring data. UAV localization and tracking are being considered to implement cost-efficiency (Alsamhi et al., 2018, p.3). Other techniques include reducing the size of RFID tags to allow easy recycling, and, energy-efficient techniques and protocols are encouraged to avoid overheating, estimation, and tag collision (Alsamhi et al., 2018, p.3).

WSNs have also flourished the field of IoT. Though the sensors are a combination of low power and low-cost electronic devices, they measure and collect environmental information, such as, temperature, weather, pollution, agricultural fields, fire detection, etc., then transfer the data to the BS which consumes a high volume of power and energy (Alsamhi et al., 2018, p.4). The idea of Green WSN is supported by studies in which they suggest shifting the sensor nodes in sleeping mode for most of their life to save energy (Alsamhi et al., 2018, p.4). WSNs can be realized when data communication occurs at ultra-low power (Alsamhi et al., 2018, p.2). Sensors can also harvest energy from natural environmental resources such as the sun and temperature (Alsamhi et al., 2018, p.2). This not only reduces the high volume of energy consumption, but also maximizes the lifespan of the sensor node performance (Alsamhi et al., 2018, p.2). Furthermore, the goal of providing sufficient energy in WSNs will be achieved without compromising on the Quality of Service (QoS) (Alsamhi et al., 2018, p.4). The implementation of GWSN will increase energy-efficiency, extend network lifetime, reduce delay nodes, and reduce the overall budget (Alsamhi et al., 2018, p.4).

As the advances in Information and Communication Technology (ICT) have revolutionized a variety of fields, Maksimovic (2017) has also stressed the significance of moving towards a Greener future (Maksimovic, 2017, p.1). Maksimovic (2017) emphasizes on the long-term benefits of a Greener future where the energy consumption, pollution, and usage of raw and non-renewable resources will be reduced (Maksimovic, 2017, p.1). The author summarizes by asserting that ICT can be considered as a mechanism for addressing environmental issues, and Green IoT is known to take one of the most important roles to create a “green and sustainable place for living” (Maksimovic, 2017, p.1).

The practice of Green IoT (G-IoT) is the outcome of efforts to enhance the quality of life through environmental protection and sustainability using developed technology (Maksimovic, 2017, p.2). The establishment of a system of systems by linking and joining billions of devices, vehicles, and infrastructure in a city enables stakeholders to reduce energy consumption, water consumption, and carbon emission (Maksimovic, 2017, p.2). Additionally, it increases safety-efficiency and human well-being, which is possible through an envisioned G-IoT structure of devices combined with Big Data Analytics (Maksimovic, 2017, p.2-3). G-IoT consists of two main aspects:

1) Design and production of Green devices, networking architectures, and communication systems with optimized power consumption and maximized bandwidth utilization.

2) The usage and disposal of Green devices and technologies to prevent carbon emissions and pollutions, while enhancing energy-efficiency (Maksimovic, 2017, p.2).

Following the above points, G-IoT's vision considers the involvement of the most important and hot Green ICTs, such as, Wireless Sensor Networks (WSNs), Cellular Networks, Radio-Frequency Identification (RFID), energy harvesting devices, Machine-to-Machine (M2M) communication, Cognitive Radio (CR), Big Data Analytics, and biometrics (Maksimovic, 2017, p.2). These complimentary technologies should be established on Green design to allow Green communication, Green processing, Green utilization, and Green disposal (Maksimovic, 2017, p.3). Though most of the designs have been elaborated in the above reviews, Maksimovic (2017) summarizes the following required tasks in order to realize the vision and impact of G-IoT:

1) Implementing eco-friendly designs and bio-products in manufacturing processes of G-IoT components.

2) Cutting down energy usage and operational costs through designs.

3) Shutting down or enabling sleep scheduling algorithms to increase the efficiency of DC, cooling, and power supplies.

4) Utilizing renewable Green power sources, such as, wind, sun, oxygen, geothermal, etc.

5) Transmitting data only when necessary.

6) Minimizing the length of data path and length of wireless data path.

7) Adjusting processing for communication (compressive sensing).

8) Finally, implementing advanced communication techniques, such as, MIMO (Maksimovic, 2017, p.4).

The aforementioned qualities present effective QoS and benefits from G-IoT compared to IoT. G-IoT provides the benefits to be more energy-efficient and reduces the amount of waste and Greenhouse gas emissions (Maksimovic, 2017, p.4). It also leads to insignificant or no harmful impacts on the human lives or environment (Maksimovic, 2017, p.4).

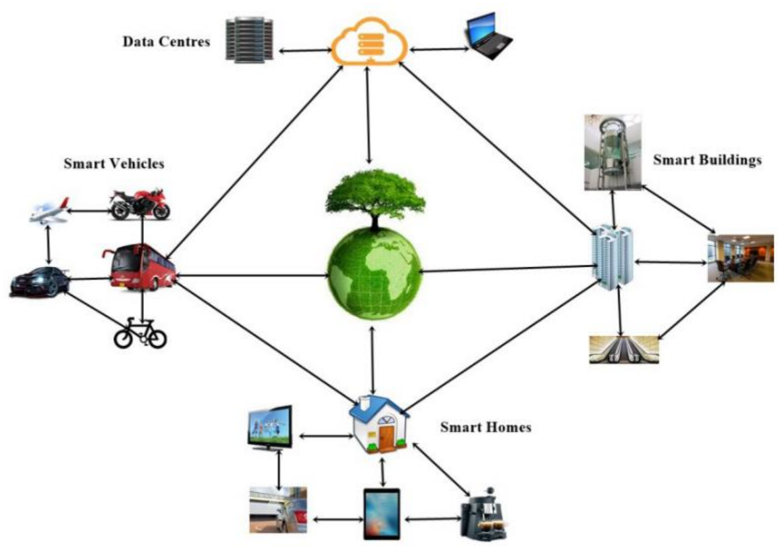

FIGURE 1. Green Internet of Things (Arshad et al., 2017).

CHAPTER III: METHODOLOGY

Green IT has been envisioned to promote one of the best solutions to the issues of energy consumption in IoT. Green IT serves enormous benefits to the sustainability of environments, in which energy-efficiency ranks as one of the most considered factors. In order to identify the best energy-efficiency approaches in Green IT, a comparative analysis will be conducted which will evaluate a number of existing data in scholarly papers. The scholarly papers will be collected from the Western Sydney University Library and Google Scholar. The criteria of this scope will also be obtained based on the important information extracted from the scholarly sources. Once the data is collected and critically analyzed, a table of the criteria and their comparisons will be created. The purpose of this comparison will focus on the energy-efficient methods in Green IT. To be more specific, the comparative analysis criteria will focus on three key factors, such as, Green Designs and Production, Green Power Sources, and Green Use. Green Designs will include details of manufacturing products that can be used for production, while preserving the safety of the environment. Green Power Sources will consider natural energy consumption alternatives such as kinetic and solar energy; this reduces the stress upon data centers and reduces carbon emission. Finally, Green Use will focus on everyday practices that can be adapted to reduce excessive energy use when dealing with IoT. Once the information of these criteria is extracted from various sources, they will be executed into a tabular structure, and a comparison will be drawn that will compare the processes, products, efficiency, and reliability of each criteria of the scope. A discussion on the trade-offs will also be considered which is highly significant in simplifying and highlighting the strengths and weaknesses of each criteria. Finally, each criterion will be measured by a value classification that will indicate the best approach of energy-efficiency.

For this scenario, a comparative analysis is highly significant to compare and measure varying methods and techniques of energy-efficiency in Green IT. This method of comparison is particularly suitable for the objective of identifying the best energy-efficient technique as it contributes to an in-depth understanding of knowledgeable sources. Alternatively, an acknowledgment of the strengths and weaknesses of each criteria can easily be measured through the comparison of different approaches. It also preserves extra research time to collect, structure, and compare data of contemporary and past sources. The expected outcomes of this comparative analysis are to classify the best energy usage and energy conservation approaches through Green IT.

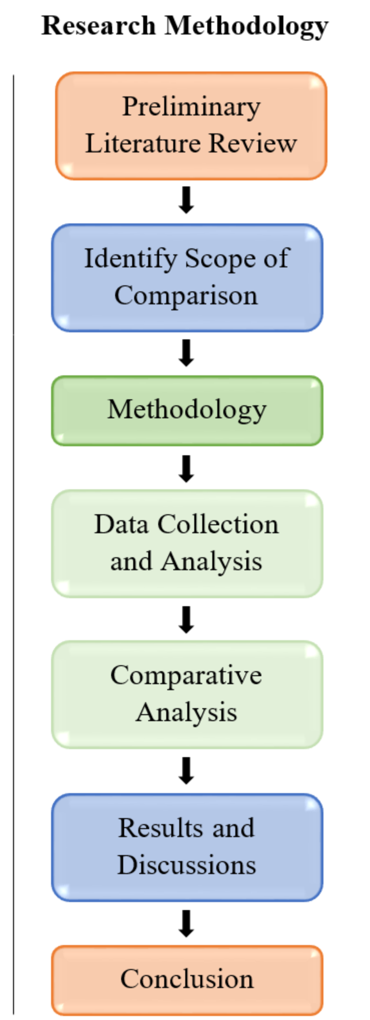

FIGURE 2. Process Model Diagram of Research Methodology.

CHAPTER IV: PROGRAM WORK

Timeline

Task	Start Date	End Date
Preliminary Literature Review	8/12/2019	8/31/2019
Identify Scope of Comparison	9/1/2019	9/21/2019
Methodology	9/22/2019	9/28/2019
Data Collection and Analysis	9/22/2019	9/28/2019
Comparative Analysis	9/22/2019	9/28/2019
Results and Discussions	9/22/2019	9/28/2019
Conclusion	9/22/2019	9/28/2019

FIGURE 3. Timeline of the Research Plan.

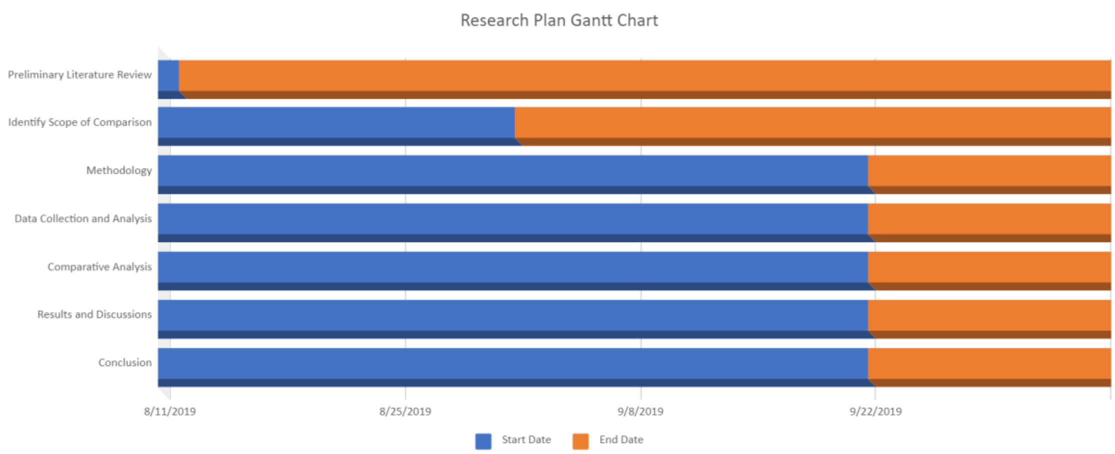

FIGURE 4. Gantt Chart of the Research Plan.

Resource Requirements

TABLE 2. Resource Requirements used to carry out the Research

Resource Type	Source	Skill Level	Quantity	Hours	Controlled by
Supervisor	Internal	Task managing skills, Critical thinking and problem-solving skills, Decision-making skills	1	7	Researcher
Google Scholar (Articles, Journals)	External	Peer-reviewed, high number of citations, up to date	14-18	140	Researcher
Books	Internal/ External	Preferably up to date	1-4	140	Researcher

CHAPTER V: COMPARATIVE ANALYSIS

In this section, an evaluation of different sources and their approaches have been listed in **Table 3** based on the devised scope and criteria. The scope of comparison was to identify the best approach of energy-efficient methods through the criteria of Green Designs and Production, Green Power Sources, and Green Use (Murugesan, 2008, p.7-8). Green IT provides a solution to reduce carbon emissions caused by excessive power consumption and heat. Green Designs utilize energy-efficient tools to manufacture non-toxic products, improve airflow facilities, and cut down cooling requirements for data centers (Murugesan, p.7). In addition, Green Power Sources utilize natural energy such as solar and kinetic energy to consume power. The final aspect of 'Green Use' is a practice that reduces the energy consumption of electronics by implementing "Green methods" in daily lives (Ibid, p.7-8). Such methods focus on enabling power management techniques that can significantly reduce power consumption (Ibid, p.7-8). A discussion on the trade-offs is also considered which is a highly significant aspect as it highlights the benefits or deficiencies of each criteria. It also simplifies the identification of the most suitable energy-efficient approach. Following the evaluation of all sources, a classification will also be added to weigh the value of each source to determine their significance.

TABLE 3. Comparison of sources for Green energy-efficiency approaches

Sources	**Green Designs**	**Green Power Sources**	**Green Use**	**Trade-offs**	**Classification/ Value**
Harnessing Green IT: Principles and Practices **(Murugesan, 2008)**	Utilization of non-toxic materials AND dual/quad-core processors.	Solar panels for power consumption	Sleep scheduling of IT devices	Easy to implement AND conserves power energy.	Good
Green Internet of Things for Smart World **(Zhu et al., 2015)**	Produce smaller sized RFID tags OR paper-based and printable RFID tags.	For RFID: Utilize energy-efficient algorithms and protocols to regulate transmission power levels. For WSN: Base Stations should utilize natural energy from the sun, wind, temperature, etc.	For RFID: Utilize smaller RFID tags or use paper-based tags to decrease nondegradable material. For WSN: Implement sleep scheduling	For RFID: Reduction in signal collision. For WSN: Natural energy enhance lifespan of systems and devices.	Very Good
Green IoT Agriculture and Healthcare Application (GAHA)	Design energy-aware routing algorithms	Utilize natural energy	Sleep scheduling	Complex designing process	Medium

(Nandyala and Kim, 2016)					
Greening Internet of Things for Smart Everythings with A Green Environment Life: A Survey and Future Prospects **(Alsamhi et al., 2018)**	N/A	Harvest energy from the natural environment.	Sleep scheduling of sensor nodes	Easy to implement	Medium

CHAPTER VI: PRELIMINARY RESULTS

This section presents the results that were formulated from the comparative analysis shown in **Table 3**. A total of four scholarly articles relating to the scope of Green IT were critically analyzed to highlight various approaches of attaining energy-efficiency in IoT. The results in **Table 3** were evaluated which outlined some key principles and practices that can be implemented to achieve energy-efficiency in IoT. The analyses of the articles were focused on the criteria devised in the methodology; this included Green Designs and Production, Green Power Sources, and Green Use. The main purpose of selecting the aforementioned criteria is due to the enormous importance these factors encompass. Green Designs and Production, Green Power Sources, and Green Use are the top three factors that cover all areas of principles and practices to enable energy-efficiency approaches in IoT.

To conclude the above results, all articles are significantly beneficial in their own way as each provide information on a unique IoT scenario, the issues arising from those scenarios, and a possible solution to decrease or eliminate those issues. One of the most common solutions identified in each article were based on the "Green Use" criteria which asserts the need of human capacity to help reduce the effect of high energy consumption. All sources have stressed the technique of 'sleep scheduling' of electronic and smart devices to increase productivity, device lifespan, as well as conserve energy. The second most significant aspect considered was the alterations in the designs and manufacturing of the devices. The authors have proposed alternative solutions where non-toxic and biodegradable materials can be used to create devices and their components; for example, paper-based RFID tags. Additionally, the articles stressed the utilization of natural energy derived from the sun, weather, and temperature that can reduce carbon emissions and excessive heat production in Data Centers.

Although all the articles are advantageous for their approaches in energy-efficiency, the article '*Green Internet of Things for Smart World*' has focused on the notion of Green solutions in a constructive manner. Compared to the other articles, *Green Internet of Things for Smart World* has been classified with a higher value of significance due to the valuable information provided on more than one IoT device, as well as a solution that had focused on each device. Unlike other articles, where the solutions have been generalized in one main paragraph, the authors have individually outlined the issues of Radio-Frequency Identification (RFID) and Wireless Sensor Networks (WSNs) along with their solutions. As demonstrated in **Table 3**, *Green Internet of Things for Smart World* exemplifies the details of the solutions which allow a clearer articulation of the scope.

CHAPTER VII: CONCLUSION

IoT in its own ground is a highly beneficial technology, however, Green IoT is an environmental imperative against the issues caused by IoT. According to the state-of-art literatures, Green IT remains a hot topic of discussion, and research analysts continue to assess the global and economic possibilities offered by Green IT. The objectives of this report were to examine the key challenges inherent in IoT, as well as assess the soluble contributions of Green IoT to those challenges. Through a critical evaluation of various scholarly papers, many literature reviews were provided that adhered to the research questions. The research questions focused on analyzing the challenges in IoT, the characteristics of Green Computing, the design principles of Green IT, and finally, how these sustainable designs help improve the performance of IoT. Following an in-depth literature review of the sources, a methodology was conducted which explained the procedure of the comparative analysis to be presented. A comparative analysis was highly valuable to conclude the report as it focused on the scope of attaining the best approach of energy-efficiency in Green IT. A table has been presented which highlights four scholarly sources and their contributions of adhering to a green energy-efficient solution. The criteria of Green Designs and Production, Green Power Sources, and Green Use were considered to evaluate the energy-efficient techniques. Finally, a value had been added against each source which measured the best solution for energy-efficiency.

The challenges of IoT still remain a contemporary issue since the past decade. And though there are numerous articles that assess these challenges and solutions, there have not been any significant changes on the implementation of the solutions. There remains the difficulty in implementing solutions in IoT which need to be addressed. Furthermore, Green IT has been envisioned as a significant solution to many of the challenges in IoT, however, Green IT also inherits many challenges of its own. Much research has focused on the positive aspects of implementing Green IT into the infrastructure and systems, however, there is a vital need to address potential challenges which can be expected as well.

REFERENCES

Ahmed, R., Asim, M., Khan, S. and Singh, B. (2019). *Green IOT- Issues and Challenges*.

Alsamhi, S., Ma, O., Ansari, M. and Meng, Q. (2018). *Greening Internet of Things for Smart Everythings with A Green Environment Life: A Survey and Future Prospects*. Arxiv.org.

Al-Turjman, F., Rehmani, M., Radwan, A. and Pathan, A. (2019). The Green Internet of Things (G-IoT). Hindawi.com.

Arshad, R., Zahoor, S., Shah, M., Wahid, A. and Yu, H. (2017). *Green IoT: An Investigation on Energy Saving Practices for 2020 and Beyond.*

Chen, S., Xu, H., Liu, D., Hu, B. and Wang, H. (2014). *A Vision of IoT: Applications, Challenges, and Opportunities With China Perspective*. Ieeexplore.ieee.org.

Khan, M. and Salah, K. (2017). *IoT security: Review, blockchain solutions, and open challenges*.

Lee, I. and Lee, K. (2015). *The Internet of Things (IoT): Applications, investments, and challenges for enterprises*.

Maksimovic, M. (2017). *The Role of Green Internet of Things (G-IoT) and Big Data in Making Cities Smarter, Safer and More Sustainable*.

Murugesan, S. (2008). *Harnessing Green IT: Principles and Practices*.

Nandyala, C. and Kim, H. (2016). *Green IoT Agriculture and Healthcare Application (GAHA)*. Pdfs.semanticscholar.org.

Zhu, C., Leung, V., Shu, L. and Ngai, E. (2015). *Green Internet of Things for Smart World - IEEE Journals & Magazine*. Ieeexplore.ieee.org.