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Review

Internet of Things for smart energy systems: A review on its applications, challenges and future trends

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Abstract: Internet of Things (IoT) is a terminology used for a mixed connection of heterogeneous objects to the internet and to each other with the employment of recent technological and communication infrastructures. Its incorporation into engineering systems have gradually become very popular in recent times as it promises to transform and ease the life of end users. The use of IoT in smart energy systems (SES) facilitates an ample offer of variety of applications that transverses through a wide range of areas in energy systems. With the numerous benefits that includes unmatched fast communication between subsystems, the maximization of energy use, the decrease in environmental impacts and a boost in the dividends of renewable energies, IoT has grown into an emerging innovative technology to be integrated into smart energy systems. In this work, we have provided an overview of the link between SES, IoT and Internet of Energy (IoE). The main applications of IoT in smart energy systems consisting of smart industries, smart homes and buildings, and smart cities are explored and analyzed. The paper also explores the challenges limiting the employment of IoT technologies in SES and the possible remedies to these challenges. In addition, the future trends of this technology, its research direction and reasons why industry should adopt it are also addressed. The aim of this work is to furnish researchers in this field, decision and energy policy makers, energy economist and energy administrators with a possible literature outline on the roles and impacts of IoT technology in smart energy systems.

Keywords: internet of energy; energy subsystems; smart energy; energy systems; smart energy systems; energy trends

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1. Introduction

Recently, the demand for energy has been steadily increasing around the world. Globally, energy demand has increased by 2.3% between 2017 and 2018 and by 3.1% between 2018 and 2019. This is undoubtedly a clear evidence that the current energy demand is likely to skyrocket in the nearest future [1,2]. As a consequence, CO2 levels emitted from the energy sector has also reached a new high in 2019, which has a strong impact on global warming. Numerous environmental problems such as depletion of fossil energy resources, air pollution, global warming and insufficient water resources for thermal energy production have led to an urgent need for more resource-efficient use of the available non-renewable energy resources and the economical use of renewable energy resources. The constant demands on our depleting fossil fuels have made them very costly and the ageing distribution infrastructure seriously threatens the security of supply. Renewable energy, however, is considered as a promising paradigm to lessen the problems of dwindling energy resources and become the preferred source of energy for the future, both locally and internationally. In the near future, they will be predicted to rapidly grow in the world energy markets since they do not cause any severe environmental problem that alters the ecosystem. The vast development in the field of information and communication technologies (ICT) has also led to a considerable transformation in the world of technology and automation processes in the industry [3,4]. The merging of these technological advancement with energy systems has created the way for the progression of an innovative idea called the Internet of Energy (IoE) which enables an energy system to be smart. IoE is considered as a single entity and a subcategory of the Internet of Things (IoT) digital space and envelopes the entire energy sector, including thermal and electrical power energies. The idea of the IoT is essentially to connect heterogeneous objects and subsystems together such as devices people, processes and data via the internet and advanced communication and technology infrastructures [5]. The word "internet" in this context does not necessarily represent the World Wide Web, but any form of server-based or peer-to-peer networks. The communications embedded in these networks possesses the ability to send instructions or raw data, analyse commands, receive, control and create an ideal connection between nodes in the network. Therefore, IoT can help make various operations more computable and predictable by collecting and processing massive amounts of data [6]. The incorporation of IoT into power and energy systems affirms a promising future in the mitigation of environmental and operational issues relating to energy systems. Although this comes with drawbacks due to high investment costs, there is hope that the advancement of existing technologies and the development of new ones will be economically sustainable, cost-effective and that the persuasive power of this modern technology will increase.

In literature, there are a couple of review and research findings that have been carried out that relates to incorporating IoT into SES. For example, Chinese researchers in [7] explored power IoT architecture for SG demand while focusing on the characteristics and application scenarios. An overview of IoE in an energy management system is also presented in [8] while the researchers in [9], discussed a kind of ubiquitous power IoT system for strong smart power grid. The work in [10] investigated the IoT based on free space optical communications for SGs and the applications of this technology in power transmission lines statues monitoring and information collection are also explored. The design and implementation of IoT system based on customer electricity behavioral analysis is also presented in [11] with a bid to minimizing the energy waste and reduce the cost of electricity for users in a SES.

2. Motivation for research and contribution

The motivation for this review arises from the rapid growth in the world of IoT technologies as it relates to smart energy. IoT technologies offers the required structure and protocols for Smart Energy Systems (SES) to operate in its full capacity thereby enabling functions like actuating, sensing and swift communications.

This paper is geared at assisting energy and ICT stakeholders, decision and policy makers and potential researchers in this sector to comprehend the overview, functions as well as the challenges of IoT-enabled smart energy systems.

The major contributions of the work are as follows

- In the work, we presented an overview of IoE and SES where an architecture for smart energy systems comprising of thermal, electrical and communicational infrastructures are also presented. The key factors and elements that must be taken into account for the cooperation and incorporation of IoT technologies in SES are also discussed.
- We also analyzed the applications of IoT technologies in SES and provided an IoT communication architecture for IoE.
- The challenges brought about by incorporating IoT technologies in SES are discussed and the optimal solutions to these challenges available in literature are also presented.
- We also explored the future trends of this technology and presented insightful reasons why companies need to fully exploit the advantages of IoT.

The organization of the paper is structured as thus: Section 3 surveys SES and its management; section 4 presents an outline of IoT as it connects to energy while section 5 examines the applications of IoT in energy systems. Section 6 presents the existing challenges these IoT applications poses and the future directions of this technology are investigated in section 7. Reasons why energy companies need to take full advantage of IoT is detailed in section 8 while section 9 concludes the paper. The pictorial organization of the paper is depicted in Figure 1.

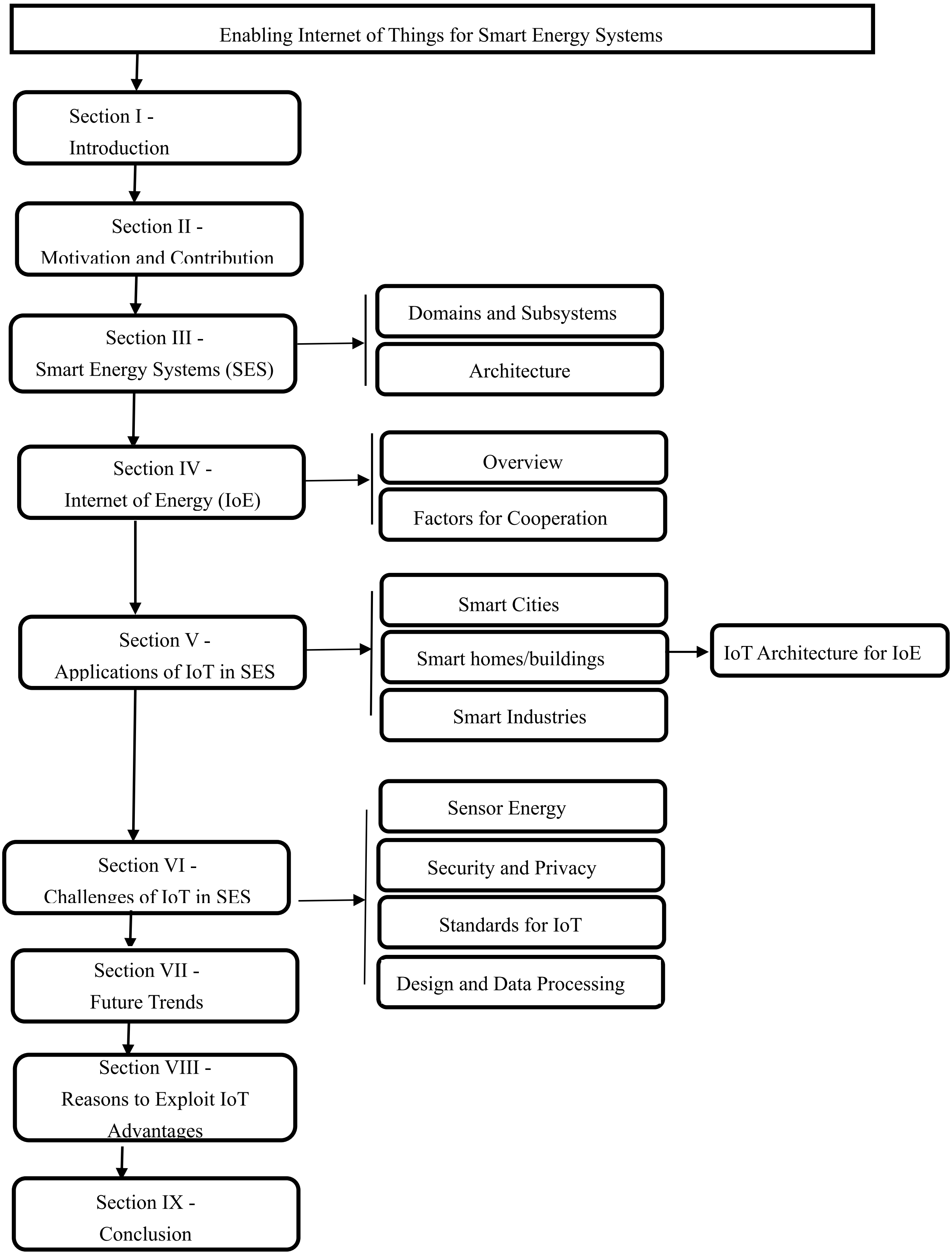

Figure 1. Organization of review paper.

3. Smart energy systems

In recent years, several definitions and terminologies have been used to describe recent approaches associated with the design of future sustainable energy systems, including smart grids [12], cyber-physical energy systems [13] power-to-gas [14,15], energy buildings [16], and a lot more. These sub-concepts and terms are usually limited to sub-sections and sub-infrastructures that refer to a single area that may not be fully analyzed or understood unless placed in the point of view of the whole energy system. The phrase "Smart Energy Systems" (SES) is often used as a totality of energy systems to establish a conceptual shift from a sole-domain system to a unified and better coherent comprehension of how to model and identify the most achievable and ideal methods for implementing an intelligible and unified future sustainable energy systems. SESs can be pictured as a sustainable, economic and secure energy system that integrates and harmonizes renewable energy technologies, infrastructure technologies through digital technologies, active users and energy services [17]. That is to say, SES consists of novel and innovative technologies and infrastructures that introduce a new kind of flexibility to the energy system, as shown in Figure 2. It includes distribution, operations, transmission, generation, market service providers, customers, and operations. However, this can be achieved by moving from the traditional straight linear technique energy systems (i.e., from conversion of fuel to end use) to a more interconnecting and evolving approach. Quite simply, the idea is to combine heat, power and transport in such a way that the versatility and flexibility of these areas can compensate for the lack of versatility of the other energy sources.

In a typical SES such as smart grid, there exist some communicational infrastructures for the efficient working of the system. These communicational infrastructures are Advanced Metering Infrastructure (AMI) [19], Customer Energy Management Systems (CEMS) [20] and Supervisory Control and Data Acquisition (SCADA) [21]. The AMI is a key component that ensures the implementation of control signals, monitoring systems, integrating software and hardware components and managing data as well as smart meters. In other words, it facilitates communication between energy consumers and the utility. The Consumer Energy Management System is an application service that communicates with devices in the home of an end user and a tool for enhancing grid stability and efficiency. It executes centralized monitoring, controlling of electrical loads so as to cut down energy cost and usage and also advanced energy forecasting. In other words, CEMS is responsible for reducing energy cost by limiting electricity usage during peak periods and automatically rescheduling loads to off-peak periods. SCADA is an important and highly distributed infrastructure employed for controlling geographically dispersed assets spanning thousands of kilometres where centralized data acquisition and control are crucial to a system’s operation. For example, SCADA provides an intelligent monitoring system for a communication infrastructure across an electrical grid from 11 kV to 32 kV. It comprises of both software and hardware elements used to monitor, gather and process real-time data. It directly interacts with devices in the system through a human-machine interface. SCADA is very vital in smart energy systems as it helps to maintain efficiency, process data for smart decisions and communicate system issues in order to assist in reducing downtime.

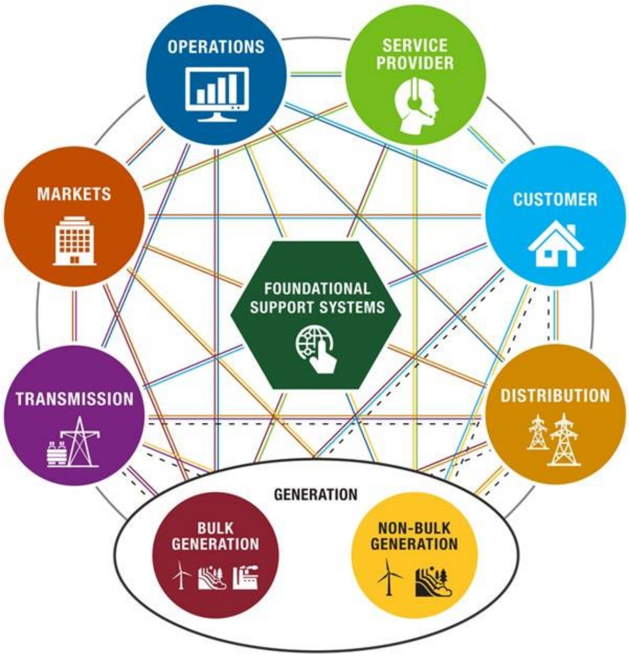

Figure 2. Smart energy systems domain and subsystems [17].

Innovational technologies are also incorporated into SES to guarantee the merger of diverse subsectors and sub infrastructures to promote system's flexibility and also guarantee efficient machine-to-machine (M2M) communication. By the introduction of IoT into SES, components are interconnected with the aid of the Internet [22]. IoT provides advanced interconnectivity to several heterogeneous components for a single SES. Figure 3 displays the architectural model of a SES that includes thermal, electrical, and communication infrastructures. When compared to the conventional energy system, it can be seen that SES are organized in a two-way-communication arrangement and an entire network sensor array possessing the ability to self-monitor and self-recover, thereby providing decentralized energy storage and generation. However, the SES architecture evolves into a bigger architecture with the introduction of more microgrids (MGs) into the system. Microgrids are the integration of a number of distributed energy generation and consumer loads that are capable of operating in a stand-alone or grid-connected mode [23]. The integration of the IoT into all subsystems is very important, as IoT provides a platform for communication between smart devices and objects regardless of their category or type. The next section will focus on IoT in the context of energy.

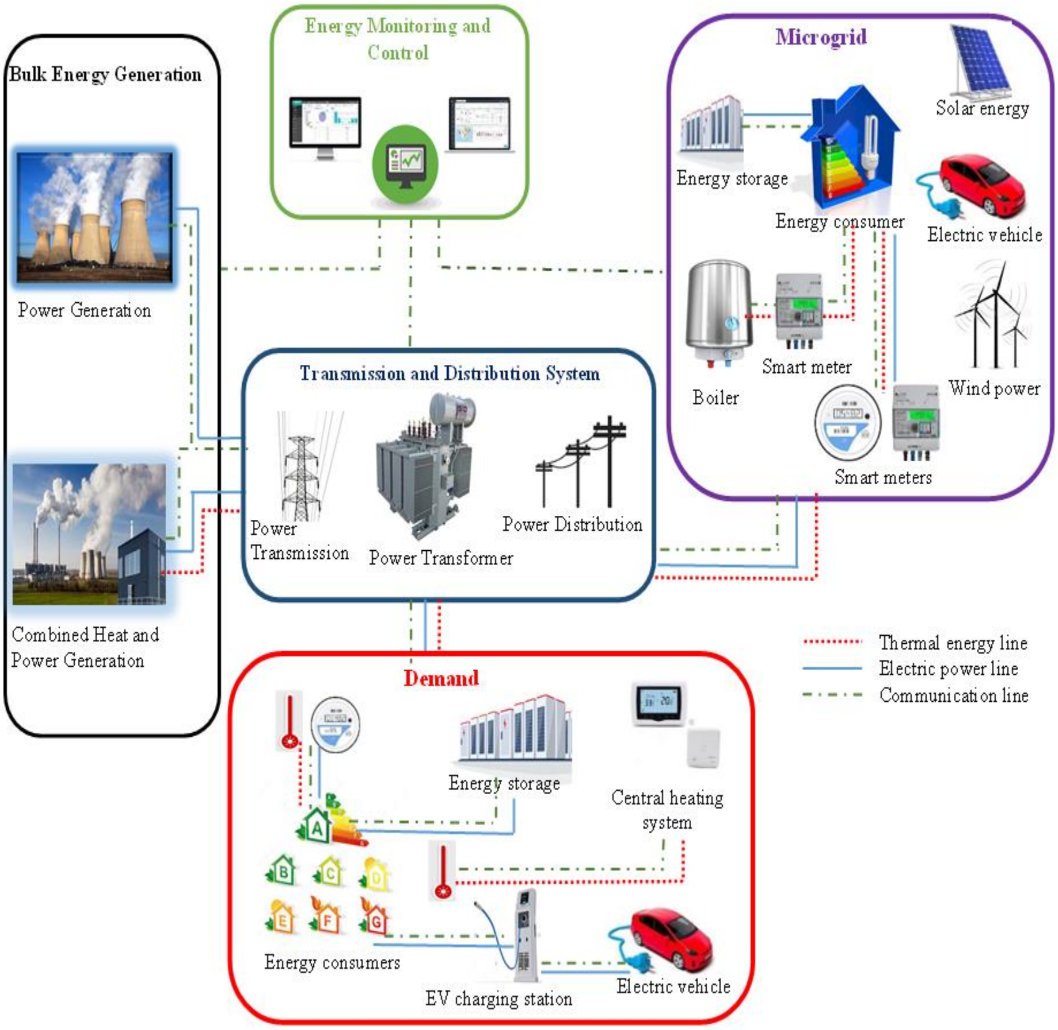

Figure 3. Smart energy system architecture.

4. IoT for energy – Key factors for an Internet of Energy (IoE)

IoT is an innovative and revolutionary technological advancement that uses the internet to provide swift connectivity and relationships between devices, objects, or "things" [24]. These devices include a range of appliances and everyday objects, that includes smart security systems, computers, industrial and commercial machines, smart home appliances and more. Through the use of appropriate sensors and communication network infrastructures, a connection is established between these objects and other internet-enabled systems and devices to deliver valued data and several other services to the consumer. IoT offers an exclusive range of applications spanning from construction to industrial manufacturing [25]. IoT is also used in medical systems and health care, building energy management, drone-based services and environmental monitoring [26]. With the latest development in power supply and renewable energy, recent technological advances in telecommunication and information communication technology systems, storage technologies, control systems and cybersecurity, combined with the merging of IoT, have initiated a new conceptual idea called the "Internet of Energy" [27]. IoE can be described as a new model for the incorporation and operation of most or some of the components in an energy system, e.g. renewable energy resources, energy storage technologies, hydrogen-based generation resources, electric vehicles and distributed generation resources for numerous application purposes that can be operated and managed via the internet [28]. In simple terms, IoE is considered as the union of information and communication technological systems and SES [29]. The term "Internet of Energy" was first coined in a book called The Third Industrial Revolution written by Jeremy Rifkin, an American economic theorist in 2011. In the book, which he explored the impact of science and technology in growing economies with a focus on energy. The use of the internet in SES certainly increases the visibility, observability, controllability, and smartness of an energy system. However, unifying a wide variety of components, taking into account their logical and technical aspects, should be a vital priority to ensure the wide acceptance and adaptability of the system. Therefore, there are some key factors and elements that need to be considered for the cooperation and integration of these components in an intelligent way. Stochastic behaviour of energy sources, controllability, and emission awareness are some key factors that need to be considered.

4.1. Stochastic behaviour of energy sources

Due to some stochastic behaviour of a number of energy sources for instance, wind and solar power and the fixed nature of some energy sources like thermal power, power production level becomes random and uncertain. It then becomes imperative to develop a mathematical programming model to determine an optimal production schedule [30]. As a result of global warming, delivering green energy is of great benefit to the environment as this is the only solution dedicated to eradicating future global emissions.

Energy consumers or end users in terms of controllability and mobility of loads are also factors for consideration. Energy end users prefer the electrical form of energy as it is much easier to transmit or convert. This however increases the demand level and thereby making load shedding almost impossible. To solve this, energy consumption patterns can be modelled by studying end user energy consumption behaviours over time. This can be done by gathering information through sensors, processing and storing this information with the aid of a data processing system hence making it easier to reach logical decisions on load shedding for decision maker’s benefit and consumer’s preferences [31].

4.2. Load mobility

Mobility of loads is also a factor that attracts both benefits and challenges to a smart energy system. For instance, in Electric Vehicles (EV), optimal charging scheduling can assist in the smoothening of the system load profile but real-time communications and communication infrastructures are needed to enable the exchange of data amongst EVs and central controllers [32].

In an IoT based Smart energy system, it is understood that “things” are expected to be connected together with little or no human involvement hence, each subsystem sould possess the ability to heal and organize themselves. This cannot be achieved without a robust communication infrastructure [33] which is an important factor for IoE systems. This means a well-designed communication architecture system must be put in place to ensure that each component of the system is connected to each other. In doing this, communication societies need to come up with an agreement about the standards and protocols to be used at different levels of communication in the system [34].

4.3. Privacy and security

Privacy and security in an IoT based energy system remains a major factor to consider especially when it becomes an inseparable part of the IoT architectural system due to the effects it has on the entire system performance. As an energy system becomes larger coupled with the inclusion of IoT and communications networks (both wired and wireless), security issues become a major challenge due to the increase in the accessibility of system information [35]. In this case, a key feature necessary for implementation is trust in which users can seek for permission in advance before using a facility so as not to violate user privacy and to ensure a more secured system. Also, due to the availability of big data in energy systems, data confidentiality becomes a vital factor for consideration since information can be shared with third parties like private, public and health care companies. For instance, an EV owner might not be willing to share his specific location due to privacy. To resolve this, it is imperative that consumers share their information for a specific purpose and service providers can assure users that information will not be shared to other third parties [36]. In doing this, end users can be more confident when accessibility of their information is requested.

4.4. Energy management in IoE systems

The management of energy in an IoE system is one major factor of concern as it helps in managing energy in an optimal way since the energy retailer is trying to maximize profit while the energy consumer is equally trying to minimize cost. In settling this, energy consumers may also produce and inject energy (prosumers) into the system hence making it a distributed system. This means prosumers can exchange energy and data with the system with the aid of a bi-directional flow of energy and information [37,38]. Also, two different energy management schemes (interactive and passive) can be applied in an IoE system. In the interactive energy management system, global and local information is exchanged amongst nodes in the system so as to help determine the operational point of each consumption unit. With the help of the integrated communications technologies in creating an intelligent system, the computational burden on each component or node in the system and other relative constraints can be determined. The communicational layout that can be used for this scheme can either be decentralized, centralized or hybrid. In the passive energy management scheme, self-autonomy of operations for a localized controller is used. This is usually in operation where sharing of information between nodes is not possible or seem expensive. The control objective of each node in the system is clearly defined and local optimization is always needed. This management scheme is mostly employed for very low harvested power levels [39].

There are various main applications of IoT in energy systems. These applications assist in increasing the efficiency of these systems while it aims at providing systemic approaches for consuming and managing energy in a more efficient manner. These key applications are mentioned in the next section.

5. Applications of IoT in smart energy systems

A system of software and hardware elements like data acquisition systems, industrial automation systems and supervisory control systems in the energy sector have been introduced to minimize the risk of lost production and mitigate power outages. The aging power plants not only suffer from environmental pollution, energy efficiency, reliability and maintenance issues, but also face outdated equipment that leads to system unreliability and substantial energy losses. By means of deploying IoT in existing energy systems, these problems and challenges can now be addressed and overcome [40,41]. Internet-connected devices couple with IoT sensors can be deployed in a power or energy system to detect operational faults or unusual reduction in energy efficiency that require system overhaul or maintenance. This can reduce maintenance costs and increase system reliability. In a study conducted by Immelt in [42], it was found that a newly established power plant equipped with IoT technologies can save up to $230 million, while an existing power plant of the same magnitude and size equipped with IoT technologies can still save up to $50 million. The applications of IoT technologies in SES can also assist in achieving efficient energy use and an optimal balance of power between thermal energy plants and other self-generation systems through machine learning (ML) and artificial intelligence (AI) algorithms [43]. Also, several analysts have tried to establish electrical energy in the basis of renewable energy sources employing different sensor technologies. ML and various AI models are used to exploit power generation in an IoT based energy system as seen in [44].

5.1. Applications of IoT in smart cities

In an effort to reduce energy costs and enhance the quality of life, smart cities have been a key research area recently due to the increasing overpopulation and several pollution and environmental problems, most especially in urban areas. For this reason, providing cities with affordable, clean and efficient energy resources is a huge task. With the current developments and recent trends in digital technology, the use of IoT-based technologies is becoming a viable solution to the problems related to smart cities [45]. In a typical smart city scenario, smart factories, renewable energy sources, power plants, smart homes and farms are all interconnected, and their energy consumption data are collected and shared so as to reduce energy consumption. The application of IoT in smart cities mainly focuses on the control and monitoring of industrial plants, houses, shopping malls, offices, etc., by using various IoT technologies such as information management systems (IMS), geographic information systems (GIS), global positioning system (GPS) and environmental information systems (EIS) [22]. IoT application technologies can also help create an energy-efficient smart city by managing every "thing" in a city with the connection of various components of utilities, buildings, transportation, infrastructure, and energy networks with sensors. For example, automobiles in a city can be monitored by automating street lighting and controlling it to make the optimal use of energy for automobiles on the road. In practice, IoT technologies have already been deployed in various cities around the world. In Amsterdam in the Netherlands, IoT technologies have been installed to control and monitor lighting, mobility and public applications. Currently, Cisco and Phillips are developing innovative ideas related to network-enabled LED lighting for application in smart cities to enhance the quality of life in the city [46]. Table 1 provides a list of major cities around the world with smart city initiatives and technologies. By implementing several IoT applications, smart cities can help reduce waste, reduce emissions and also save up to 80 liters of water per person per day, resulting in a much greener environment [47].

Table 1. Major cities around the world with smart city initiatives and technologies.

City	Name of project	Type of service	Description
City of New York, United States of America	LinkNYC	Smart services and Internet rollout	The LinkNYC project was created to deliver free internet access across the city through gigabyte-speed WiFi access delivering mobile connectivity for smart devices. This is enabled through an installed touchscreen kiosk which has replaced payphones across the city and assist visitors with advice, maps and emergency services.
City of New York, United States of America	ShotSpotter by SST	Safety and security	New York Police Department in collaboration with SST has introduced ShotSpotter into the city which assist in detecting gun fires with the aid of sensors. These sensors installed across the city uses a 360-degree coverage and geolocation algorithm to detect when weapons are fired. This service assist in crime hotspots in the city.
London, United Kingdom	Digital Catapult: Things connected	General connectivity	The UK government created the “Things connected” initiative to support UK businesses with the aid of low powered wide area network (LPWAN) technologies to develop new products and services and assist high calibre start-ups. 50 LPWAN has been rolled out already and more planned in the coming years.
City of Barcelona, Spain	Smart Barcelona	Smart services	The Smart Barcelona initiative started in 2012 with deployment of IoT technologies that assist various systems including parking, pollution control, street lighting, public transit and management of waste. It has also installed over 700 Wi-Fi hotspots across the city.
Singapore, Singapore	Smart Nation Vision	Smart services	Sensors linked to aggregate boxes are installed across the city to collect data ranging from pedestrian activities and traffic volume. These data are sent to the relevant agencies so as to ensure smooth delivery of services.
City of Dubai, United Arab Emirates	DubaiNow	Various	The city has ensured the digitalization of all government agencies including a monitoring system for bus drivers using artificial intelligence. Autonomous police stations have also been created where residents can pay fines and report crime without talking to a human.
City of Fujisawa, Japan.	Japan’s Fujisawa Sustainable Smart Town	General	This smart town is built around alternative energy by employing IoT sensors, networking and monitoring to assist the town in terms of healthcare, mobility and security. The partners of the project include the Local Government of Fujisawa city, Tokyo gas, Panasonic and Accenture.
City of Boston, United States of America	BOS:311	Smart services	BOS:311 is a mobile application that enables real time collaboration with residents deputizing and assisting the city in recording and reporting city infrastructural issues such as failed street lights and blocked drains.

City of Moscow Russia	Telesna :Parkenet	Smart parking	Parknet is a parking solution that offers the city of Moscow parking monitoring system. Magnetic sensors roads are installed in the road surface to automatically monitor cars via a low power radio system. The information assist administrators with information on city parking while the city residents can also have access to this information via a web interface.
City of Charlotte, United States of America	Envision Charlotte	Environmental Management	Interactive monitors in a kiosk are installed around the city of Charlotte to assist in gathering and analyzing information as it relates to energy usage so as to aid the reduction on greenhouse gasses and increase energy efficiency.
The City of Kansas, United States of America	The SMART City Corridor	Smart services	This project partners with Cisco, ThinkBig and Sprint and it encompasses a streetcar and 25 interactive kiosks that offers access to Kansas City services, city businesses information and entertainment.
City of Tirana, Albania		Smart services	As a way of digitalizing the city, an app has been introduced in the city that assist residents to report real-time and non-real-time issues and infrastructural problems to the municipality.
City of San Diego, Unites States of America	San Diego Smart City Solutions	General	The city has introduced a wide range of IoT based technologies that includes intelligent LED streetlighting, IoT based Port of San Diego and solar-to-electric vehicles charging technology and PETCO Park baseball stadium.
City of Tel Aviv, Israel		Smart services	The city has eliminated barriers between municipal staffs and residents by equipping residents with smart technological apps to monitor the city's infrastructures.

5.2. Applications of IoT in smart homes/buildings

The phrase smart home refers to modern houses that consist of various appliances and devices that can be conveniently controlled and managed remotely by the user. Energy consumed in smart cities can be divided into two sectors: the residential sector and the commercial sector, which encompasses offices, schools, shopping centers, and transportation. The domestic and residential sector can be considered as a smart home that includes a considerable number of smart appliances and smart "things" and has the ability to communicate with one another or with a central system (gateway). Energy consumption in the domestic sector mainly consists of heating, ventilation, and air conditioning (HVAC), smart appliances and devices, hot water, cooling, cooking, and lighting as shown in Figure 4. In [48], it was analyzed that HVAC systems consume more than 50% of the total energy consumed in smart homes. Optimal energy management in HVAC systems can be achieved by applying IoT technologies. For example, wireless sensors can be employed to detect occupied and unoccupied areas of a smart building, and an action can be triggered for the unoccupied areas to minimize the system's energy consumption. The same can be done for energy management related to lighting in smart homes, whereby end users can be alerted when the energy consumed is above the default level or a certain level. In this way, loads can be automatically switched from periods of high consumption to periods of low consumption based on real-time data analyzed by the system [49].

The communication architecture of a smart home or building is managed through a layered area network as depicted in Figure 5. A collection of smart homes makes up a Neigbourhood Area Network (NAN) and smart devices including smart meters, energy storage equipment, distributed energy resources and other loads from a Home Area Network (HAN) make up the NAN structure.

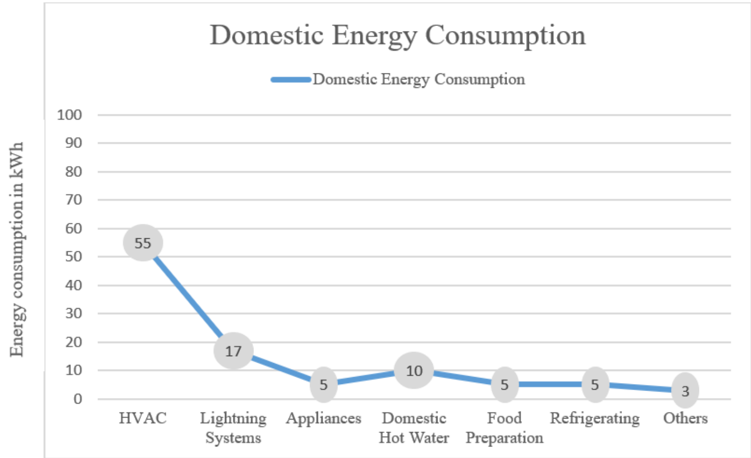

Figure 4. A Typical residential/domestic energy consumption [48].

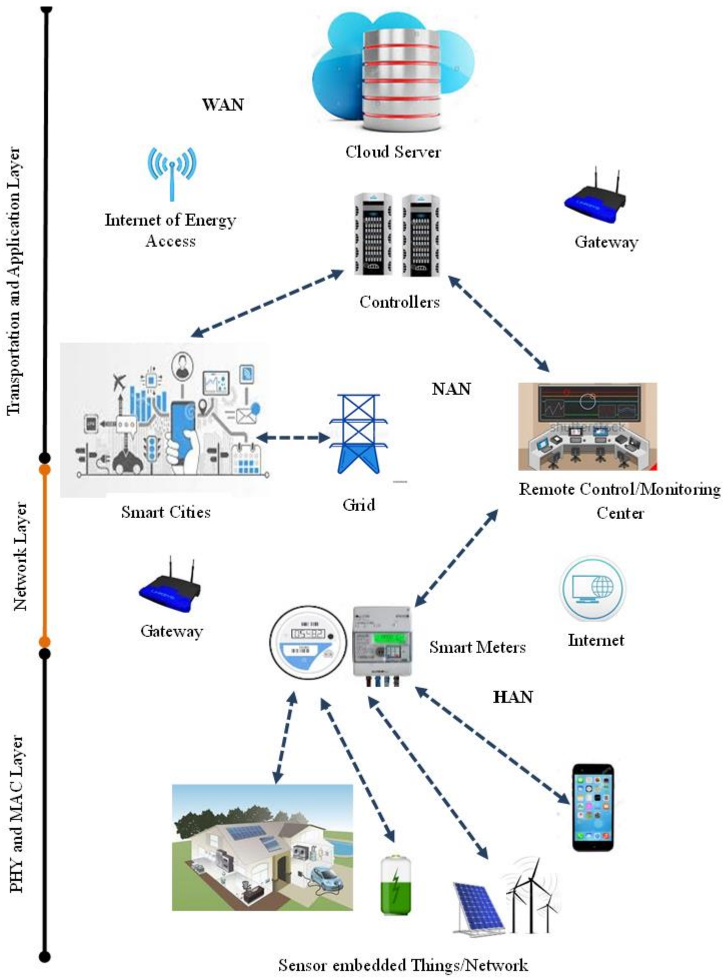

Figure 5. IOT architecture on Internet of Energy.

The PHY and MAC layers make up the device layer in which sensors, smart devices, actuators and gateways are connected. In the network layer, there are numerous wired and wireless connections linking the HANs and NANs architectures. The transportation or application layer is responsible for combining Clouds and management services and it is also responsible for guaranteeing essential services and interface to consumers.

5.3. Applications of IoT in smart industries

Given the amount of energy used in industries and factories to monitor, control, supervise and deliver the desired end products, IoT applications can be used to increase the energy efficiency of the entire line of production. In conventional factories, human resources are used for various monitoring and supervisory processes. This however, can be replaced by agile, fast, and flexible IoT-based technologies that serves the same purpose while detecting defects in products in a smart industry. In terms of product monitoring and supervisory in production lines, cloud platforms, gateway devices, IoT hub networks and web servers can be introduced, supervised and controlled by computers, smartphones or other smart mobile devices. The industry or factory equipment and the relevant IoT applications can be connected using several wired (Local Area Network (LAN)) or wireless communication means (Z-wave, Zigbee, WiFi or Bluetooth) [50]. To guarantee the efficient deployment of IoT in smart industries, sensors can be attached to each component of a huge industrial plant to sense the energy consumption of each of these components. In doing this, malfunctioning components can be easily detected and repaired while optimizing the energy consumption of each component.

The use of Cloud platform in a smart industry can enable easier processing of data and storage, which can help managers and decision makers make more efficient and accurate decisions in less time [51]. In addition, IoT technologies can enable the synergy and collaboration between manufacturers, businesses and consumers.

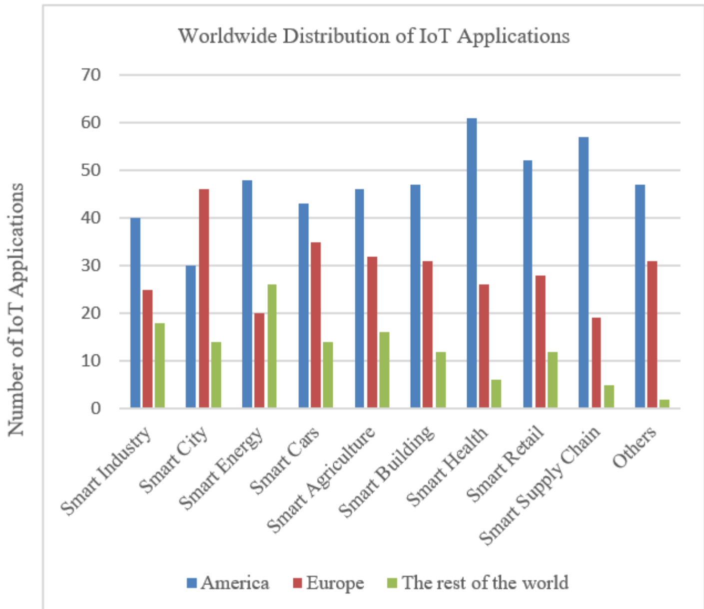

Figure 6. Worldwide distribution of IoT applications.

This will make sure that consumers are informed about every step of a production process and that products are made to suit consumer's taste. This will also help to save energy for the production of spare parts and for the operation of storehouses for these spare parts. Instead, only a specific or particular product can be manufactured and stored, which will increase production efficiency and improve energy management [52]. It is also observed that smart energy, smart retailing, smart buildings and other IoT applications are very active and in employment in most continents of the world. While the continents of America and Europe are very prominent in various applications of IoT, several parts of Asia and Africa are yet to catch up with the enormous advances and developments in this field. Meanwhile, it is also envisioned that the number of smart devices and systems on the continents of Asia and Africa will grow very rapidly once Internet connectivity reaches the innermost parts of the continents.

6. Challenges of IoT applications in smart energy systems

The use of IoT technologies in SES presents a number of challenges and problems. Since an IoT smart energy system is an integrated system that includes both internet technology applications and multiple smart energy components, there are inevitably some challenges associated with the interconnection. The most crucial of these challenges are examined below.

6.1. Sensor energy management

In an IoT based environment, sensors are employed to sense information from separate components. Of course, this means that a lot of energy is required to power and operate these sensors, which obviously poses to be an issue, especially for systems with very low power. A very big challenge that sensing technology possesses, is the capability to operate for an entire lifetime without the need for battery replacement [53]. In an attempt to solve this problem, Shi et al in [54] recommended an energy saving approach for sensors where the sensors are put into a sleep mode when they are not active and also when the battery life is critical. In [55], a technique that can harvest energy wirelessly is also presented in which energy is obtained from other alternative energy sources in order to power these sensors.

6.2. Security, privacy and confidentiality

As IoT-based smart energy systems are deployed across a wider geographic area, there is a high risk that the system will be exposed to attacks and security threats. The use of numerous IoT technologies in the system, from energy generation to the end users, makes the system vulnerable to these attacks. Therefore, encryption techniques should be applied onto the system to protect the information of the system as proposed in [56]. The privacy of energy users is also threatened in the system by unauthorized third parties, as the system continuously requests user data and personal information from users to improve and optimize decision making related to energy distribution, generation, and consumption. To minimize this, the authors in [57] proposed a trust-based privacy management scheme that can be implemented into the system in which users take control over their privacy and information and get to share it with authenticated sources and authenticated energy providers only when it is required.

Confidentiality of communicated and stored data ensures accessibility only to the intended recipients and the integrity of a communication line is achieved when the received data is not modified along the communication path. Ensuing confidentiality for data transmission in IoT applications in SES is difficult due to the fact that low-end devices are resource-constrained. Methods such as encoding and ciphers can efficiently manage the confidentiality issues in transmitting IoT nodes [58]. Trappe et al in [59] proposed a secure line transmission path for microgrid applications in which a system can authenticate with the aid of a digital signature plan and assigning unique IDs to all gateways so as to maintain confidentiality and data integrity.

6.3. Standards for IoT

The integration of IoT into SES differs from a single unit device and subsystems to massive systems with embedded systems connected to different platforms. As a result of these, IoT devices that possesses different protocols and standards will have data exchange and communication between them a lot more difficult. For instance, exchanging data and information via Bluetooth between an Apple smart device and another operating device becomes a challenge because Apple devices are configured to connect another Apple devices via Bluetooth. To solve this problem, a system of mutual functioning systems can be designed and defined to allow the same access and usage between all devices. This will in due course lead to various companies and organizations coming together to adopt the standards required for IoT-based energy systems to function. For example, in the area of communication technologies, ZigBee (IEEE 802.15.4) [60] is a widely used standard for low-rate wireless communication networks where data can be transmitted at 800/900 MHz and 2.4 GHz.

6.4. Architectural design and big data processing

When several IoT technologies are integrated into a power system, these technologies are expected to provide seamless communication anytime and anywhere, no matter how complex their architectural design, distribution and mobile characteristics might be. This means that in most cases, heterogeneous reference architectures are needed so that consumers are not limited to utilizing fixed end-to-end IoT communication [61]. The larger an energy system becomes, the larger the amount of data that needs to be processed in the system. This however, becomes a key issue for IoT-based power systems, as the system should have the ability of processing, analyzing, and storing current and previous data so as to plan for the future. In this context, Stojmenovic in [62] recommended a localized data processing technique that ensures local data are processed with the state information of the main servers and the neighboring servers. A Big Data architecture technique can also be used where knowledge extraction is done on the Big Data and the data is classified into different levels based on their priority of use, as described in [63].

After extracting useful knowledge from big data, the energy system should be able to further categorize the information and provide certain services (such as sending signals to the actuators or sensor systems). For example, in SES, data collected from heat consumption and electricity can be subjected to customers' type (domestic or industrial), and each of the consumption level can be further classified into off, standby and active operation mode. Due to this fact, a big data architecture is introduced [64].

6.5. Managing bandwidth

In order to incorporate IoT into a SES like local microgrids, a large number of sensors need to be installed and a significant amount of information is communicated over 24 hours of everyday.

Connecting all objects and things to the internet is quite daunting and expensive due to high computation and increased bandwidth usage. To utilize IoT technologies in smart microgrid systems, technologies such as smart sensors and data mining technologies should be considered because of the restricted bandwidth usage features present in IoT devices hence, making IoT an inferior way to communicate all unregulated information. Information fusion technologies can also be exploited to exchange valuable information [65].

Narrowband IoT (NB-IoT) is a new form of LTE standard accredited by Third Generation Partner Project (3GPP) as one of the low-power wide area solutions to accomplish the goals of broad coverage, power consumption and cheap and complex combination. A combination of characteristics, such as synchronization series, random access preface, telecast channel and control channel are transformed to be recognized with the LTE blueprint although NB-IoT reuses most LTE principles, such as Orthogonal Frequency Division Multiplexing (OFDM) type of modulation in downlink, Single Carrier Frequency Division Multiple Access (SCFDMA) in uplink, channel coding, rate matching and interleaving [66].

6.6. Connectivity

IoT continue to grow with the connection of more devices and each of these connections presents more opportunity to collect and analyze more data, make more informed decisions, achieve greater automation and offer a plethora of new services [67]. To ensure that the systems is always well connected, a set of commands needs to be sent to the module equipped gateway. The gateway in turn sends these commands to the home appliances via ZigBee for implementation. The gateway is also equipped with an optional diagnostics and configuration mode in which it can be used as a WiFi access point. This way, users and technicians can perform local diagnostics and configuration updates by connecting the access point using their computers or smartphones [68]. Also, the Real-time Intelligence for Smart Electric Operations (RISE) center is working towards providing a cyber secured communication layer for swift wireless connectivity. The connectivity standards and technologies will be added to the layer so as to provide a secure solution to connectivity problems [69].

Packet losses will no doubt occur in transmission lines between IoT enabled devices to SES due to the fact that the structure of the distributed filter is interconnected. In the case of microgrids with Distributed Energy Resources (DER), a distributed dynamic phase estimation technique was proposed in [70] whereby the error function is rewritten employing the matrix property of the Kronecker product. The authors in [71] also proposed a state estimation and stabilization technique in which the input and output packet losses in the IoT-enabled grid communication is considered. A semidefinite programming-enabled state feedback controller for IoT-aided grid communication to regulate system states is also proposed.

7. Reasons why companies and industries need to fully exploit of the advantages of IoT

Most companies in the energy industry need to proffer ways in improving the quality of communication of their electrical units either by employing enhanced features into a wide range of digital chips, utilizing energy saving solutions and energy harvesting mechanisms or using adaptable power mechanisms. Hitherto, technological developments relating to IoT in industrial companies have not been very popular as most of these companies are still employing the traditional forms. The integration of IoT in a company's operational system is very imperative to the company's future and operations. Sensors in an IoT environment possesses a real-time control of the generation of energy and can as well assist in the realization of a centralized production.

It is a known fact that IoT applications is definitely going to change the total viewpoint of industrial companies. The exploitation of the merits of IoT technologies will also assist companies to remotely, efficiently and adequately monitor the status of their grid infrastructure, power systems equipment, solar panels, turbines and so on. From the business outlook of things, if industries and companies were to implement IoT technologies, it will contribute to the improvement in data analytics, efficient management of plant generation, improvement in predictive maintenance, improvement in safety compliance and system efficiency and most especially, efficient connectivity and availability. The business gains from implementing IoT applications are high investment returns, privacy and security, attain Federal, corporate and industry standards, enhance product interoperability, accessibility and reliability and also enable software and hardware functions [72].

With the gradual change in people's perception on IoT usage, it is projected that an addition of 2 billion devices will be IoT connected by the end of 2022 while the Worldwide IoT market is likely to be more than $1.7 billion with consumer electronics contributing to the significant share of the IoT industry. By 2024, it is also expected that IoT in the automated industry will reach $151.40 billion with a compound annual increment rate of 12.020%. In the same vein, in 2015, the World energy market for IoT exceeded $6.8 billion and it is expected to attain $26.5 billion in 2023 with a compound annual increment rate of 15.5% [73].

At present, 45% of IoT connected industry projects have already undergone operation in the United States with 7% in the energy related industry while 3% is in smart city environments [74]. In South Africa, Industries are tending towards employing IoT enabled technologies in order to achieve massive returns in investments and the South African IoT market size expected to grow by 36% in 2028 [75]. Generally, the South African government are intensifying efforts to increase the use of IoT technologies in the country. Lanseria is set to become the first South Africa smart city which will be known as "Lanseria Smart City" as this development hopes to create urban sustainability and digital solutions.

The global IoT industry is growing by the day and it will be very logical for companies and industries to exploit the innovations IoT technologies has to offer. According to Growths Enabler in [76], various IoT related industries will influence the world market share of IoT which are smart utilities, connected cars, smart cities and smart homes, connected health, wearables and industrial related IoT.

8. Future trends

The incorporation of IoT technologies into SES has brought an array of benefits to these systems, as described in the previous sections. As communication technologies and ICT continue to evolve, IoT systems will also continue to evolve and progress while their application into smart energy systems will see many advances and improvements. For example, currently, blockchain technologies are unable to be integrated into various energy systems due to the lack of computing resources and limited bandwidth. With recent advances in communication technology, 5G, 6G communications and Cloud technologies are already good substitutes for the current communication technologies that can help implement Blockchain. Blockchain is a chain process that guarantees each transaction record of an IoT node is stored in a block-like arrangement so that each record can be directly linked to the previous one. In this approach, data can actually be freely exchanged by users and trading of energy between users will also be possible, while ensuring efficiency and security of the entire system [77,78]. IoT technologies in smart systems were not introduced until the year 2000, when the technology took a big rise in development and massive commercialization. In the same year, LG, makers of electronics announced to launch a smart refrigerator that determines whether food needs to be refilled [79]. Today, smart IoT systems have spread throughout our businesses homes and industries thereby allowing more devices to be connected to share data, monitoring in real-time, communicate and also analyse data in real time.

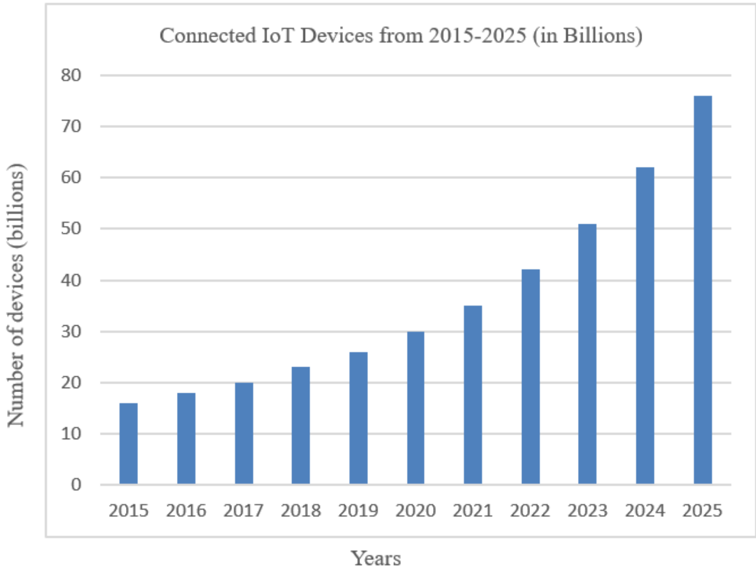

Figure 7. IoT connected devices worldwide from the year 2015–2025 [73].

Figure 7 shows the amount of devices connected to the IoT worldwide between 2015 and 2025 using data from IoT statistics in [80]. It can be seen that the number of devices connected to IoT is steadily increasing worldwide, with more than 41 million IoT devices connected in 2022. As shown in the figure, the total number of IoT connected devices is expected to attain a high of 76 million in 2025. It is also envisioned that more areas with IoT-enabled applications will be added in the coming years, which will subsequently increase the number of connected IoT devices.

As the integration of IoT into SES continues to gain traction, numerous numbers of IoT devices and appliances will be deployed and connected to the internet, especially in large energy systems. This will subsequently lead to huge consumption of energy in systems and an enormous amount of electronic waste [81]. With the adoption of Green Internet of Things (G-IoT), energy efficiency in these systems can be increased from the development stage through the production, deployment to disposal stages [82]. With the future applications of G-IoT technologies in place, the size of radio frequency identification (RFID) tags can also be reduced by simply minimizing the amount of material used in each RFID tag [83].

As IoE systems of becomes more popular among researchers, there are some aspects and areas that need further research to better fine-tune these technologies. For example, Quality of Service (QoS) issues in wireless sensor networks has not been studied much, nor has the supporting capabilities of this network. In the research field of power generation, issues related to real-time monitoring of line faults and control of power plants can also be explored. Another important area of IoT-based smart energy systems related to deep learning and machine learning techniques in Big Data analytics is also a topic that should be explored in the near future. In that way, deep learning approaches can be used to solve problems related to big data, massive stacks and large amounts of collected data in an energy system.

An important area of research that could have a considerable impact on IoT-based smart energy systems in the near future is the advancement of highly intelligent security mechanism that includes encrypting, authorizing, identifying and authenticating-based approaches. These security fields are the fundamental areas that will ensure intelligent private networking and enhanced security features in the system. It is worth noting that communication based IoT systems are gradually receiving research attention from researchers to guarantee secure communication over long distances with low power consumption. For instance, Low-Power Based Wide Area Network (LPWAN) based communication systems [84] are already receiving attention from researchers. There also exist other research interest that will emerge in the nearest future to address the issues of technologies that are currently employed in SES. These include cyber-physical systems, ensuring high QoS, connectivity and interoperability between subsystems in IoE systems.

9. Conclusions

IoE is a subcategory of IoT and a novel and developing concept in the field of energy systems that encompasses the whole energy space comprising of electrical and thermal energies in conjunction with information communication technologies. The integration of IoT technologies in SES encourages and facilitates a more resourceful usage of energy and mitigates the socio-economic and environmental impacts in energy systems. This paper examines smart energy systems and presents the contributions of IoT to SES. The adaptation of internet-based technologies into SES enhances the visibility, controllability and understandability of the system. As the integration comprises of a large number of components, the technical and logical factors that ensure an acceptable and adaptable interconnection are of vital importance. Therefore, the important factors to be considered for an efficient implementation of these technologies into SES are explored. The key adaptations of IoT in energy systems which includes smart cities, smart homes and buildings, and smart industries, are discussed and evaluated, since it is an developing technology that offers numerous benefits that can be leveraged for the improvement of smart energy technologies. Furthermore, given the abilities of a smart system to support a extensive spectrum of application and guarantee swift communication between a wide range of devices, there exist a few challenges and issues that limits the integration of IoT technologies into SES. These challenges include security and privacy, sensor energy consumption, agreed standards and architectural design. These challenges are analysed and recommendations are made to overcome them. IoT in SES guarantees a promising future with regards to efficient communications and effective energy management. Therefore, the future direction and research trends of these technologies are assessed and the reasons why industries and companies should take advantage of IoT in their systems are also evaluated.

Conflict of interest

The authors declare that there is no conflict of interest in this paper.

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