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Review Article

Empowering Energy Efficiency: Exploring Applications, Overcoming Challenges, Charting the Future Trends of the IoT in Smart Energy Systems

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ABSTRACT

The term "Internet of Things" refers to a combination of technological and communication infrastructures that connect many heterogeneous things to the internet and to one another. \Its integration into engineering systems has increasingly gained popularity in recent years due to its promise to improve and revolutionise end users' lives.IoT integration in smart energy systems enables a wide range of applications that span a number of different energy system domains. IoT has developed into a cutting-edge emerging technology to be integrated into smart energy systems thanks to its many advantages, which include unmatched fast communication between subsystems, the maximisation of energy use, the decrease in environmental impacts, a boost in the dividends of renewable energies. We have given an outline of the relationship between SES, IoT, the Internet of Energy (IoE) in this study. The primary IoT applications in smart energy systems—which include smart cities, smart buildings and homes—are investigated and analysed. The article also examines the obstacles preventing the use of IoT technologies in SES as well as potential solutions to these obstacles. In addition, the path of this technology's research and the justifications for industry adoption are discussed. The purpose of this work is to provide scholars working in this area, decision-makers in the field of energy policy, energy economists, energy administrators with a potential literature overview on the functions and effects of IoT technology in smart energy systems.

Keywords: Internet of Energy, Energy Subsystems, Smart Energy, Energy Systems, Smart Energy Systems, Energy Trends

Introduction

Globally, the demand for energy has been rising significantly in recent years. Between 2017 and 2018, the world's energy demand rose by 2.3%, between 2018 and 2019, it rose by 3.1%. It is undeniably abundantly evident from this that the current energy demand will almost certainly soar in the near future.[1,2] As a result, CO2 emissions from the energy industry have also increased in 2019, which has a significant impact on global warming. There is an urgent need for more resource-efficient use of the available non-renewable energy resources and the economical use of renewable energy resources due to a number of environmental issues, including the depletion of fossil fuel energy resources, air pollution, global warming, a lack of water resources for thermal energy production. The continual demand on our finite fossil resources has driven up their price, the deteriorating distribution network poses a severe danger to supply security. However, renewable energy is viewed as a paradigm that has a good chance of reducing the issues associated with diminishing energy resources and becoming the preferred source of energy for the future, both locally and globally. They are anticipated to see a high growth in the global energy markets in the near future because they do not significantly harm the ecosystem or cause other serious environmental issues. The rapid advancement of Information and Communication Technologies (ICT) has significantly changed both the technological landscape and industrial automation processes.[3,4] The Internet of Energy (IoE), a cutting-edge concept that enables an energy system to be smart, has advanced as a result of the fusion of these technology advancements with energy systems. IoE, which encompasses the entire energy sector, including thermal and electrical power energies, is seen as a single entity and a subclass of the Internet of Things (IoT) digital world. The core concept of the IoT is to link disparate items and systems together, including devices, people, processes, data, using the internet and sophisticated communication and technological infrastructures.[5] The use of IoT in power and energy systems signals a bright future for reducing operational and environmental problems with energy systems. There is hope that the creation of new technologies and the progress of existing ones will be economically sustainable, cost-effective, that the persuasive power of this modern technology will increase. However, this has negatives due to large investment costs.[6] The IoT's integration into power and energy systems signals a bright future for reducing environmental and operational problems with energy systems. Even though this has limitations owing to high investment costs, there is hope that present technology innovation and the creation of new ones will be financially viable, cost-effective, that the persuasive power of this contemporary technology will grow.

There are a few reviews and research findings related to integrating IoT with SES that have been published in the literature. Chinese researchers, for instance, examined power IoT architecture for SG demand in[7] with an emphasis on the features and application situations. In addition,[8] provides an overview of IoE in an energy management system,[9] presents a discussion of a type of ubiquitous power IoT system for a robust smart power grid. The work in[10] investigated the Internet of Things (IoT) based on free space optical communications for SGs, it also looked at how this technology may be used for monitoring and information gathering on power transmission lines. In an effort to minimise energy waste and lower the cost of electricity for users in a SES, the design and implementation of an IoT system based on consumer electricity behavioural analysis is also discussed in.[11]

Motivation for Research and Contribution

The swift development of IoT technology in relation to smart energy is what inspired this review. IoT technologies provide the framework and protocols necessary for Smart Energy Systems (SES) to run at maximum efficiency, hence making it possible to do tasks like actuating, sensing, quick communications.

The goal of this article is to better understand the overview, features, problems of IoT-enabled smart energy systems for energy and ICT stakeholders, decision- and policy-makers, potential researchers in this field.

The following are the work's main contributions:

- In the study, we provided an overview of IoE and SES, as well as a presentation of the architecture for smart energy systems, which includes infrastructures for the thermal, electrical, communication systems. Also covered are the crucial features and criteria that must be considered for the cooperation and integration of IoT technologies in SES
- In addition, we examined IoT applications in SES and offered an IoT communication architecture for IoE
- The difficulties posed by integrating IoT technology into SES are examined, the best available literature-based solutions are also provided
- We also looked at how this technology can develop in the future and provided perceptive justifications for why businesses should make the most of IoT's benefits

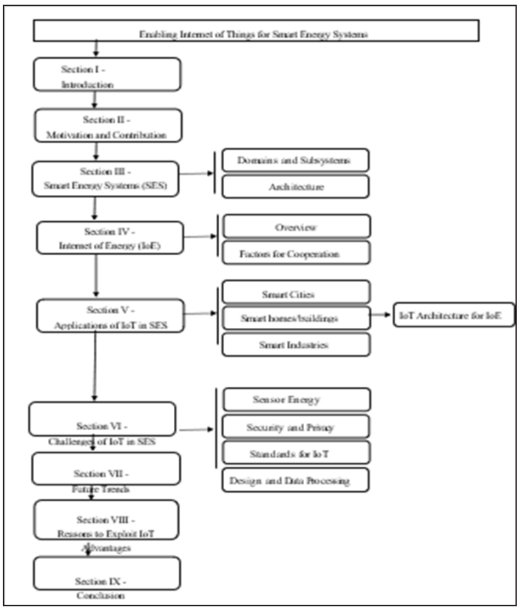

Figure 1.Organization of Review Paper

The paper is structured in the following way: Section 4 provides an overview of IoT as it relates to energy, while Section 5 looks at the uses of IoT in energy systems. Section 3 explores SES and its management. The current difficulties that these IoT applications offer are discussed in Section 6, Section 7 explores the potential prospects for this technology. Section 8 explains the reasons why energy firms must fully utilise IoT, section 9 wraps up the report. Figure 1, shows how the paper is organised pictorially.

Smart Energy Systems

Recent developments in the design of future sustainable energy systems have been described by a number of definitions and terminologies, including smart grids[12] cyber-physical energy systems,[13] power-to-gas,[14,15] energy buildings,[16] many others. These words and subconcepts are typically restricted to sub-sections and sub-infrastructures that pertain to a specific area that may not be properly analysed or understood unless seen from the perspective of the entire energy system. The term "Smart Energy Systems" (SES) is frequently used to refer to the entirety of energy systems in order to establish a conceptual shift from a single-domain system to a better coherent understanding of how to model and identify the most practical and ideal approaches for putting into practise an understandable and unified future sustainable energy systems. SESs can be thought of as a secure, affordable, environmentally friendly energy system that combines and harmonises active users, digital infrastructure technologies, renewable energy technology.[17] As depicted in Figure 2, SES is composed of fresh and cutting-edge infrastructures and technologies that give the energy system a new level of flexibility. It covers customers, market service providers, operations, transmission, generation, distribution. However, by switching from the conventional straight-linear energy systems (i.e., from the conversion of fuel to the final usage) to a more interconnected and developing approach, this can be accomplished. Simply said, the goal is to combine heat, electricity, transportation so that their flexibility and adaptability may make up for the other energy sources' lack of adaptability. There are some communicational infrastructures for the system's effective operation in a typical SES, like a smart grid. Advanced Metering Infrastructure (AMI),[19] Customer Energy Management Systems (CEMS),[20] Supervisory Control and Data Acquisition (SCADA)[21] are some examples of these communication networks. The AMI is a crucial element that makes sure that control signals are implemented, monitoring systems are monitored, software and hardware components are integrated, data is managed, smart metres are used. In other words, it makes it easier for customers to communicate with the utility. The Consumer Energy Management System is a technology for improving grid efficiency and stability that interacts with gadgets in the end user's house. It carries out centralised monitoring, the regulation of electrical loads to lower energy costs and consumption, as well as sophisticated energy forecasts. In other words, CEMS is in charge of lowering energy costs by restricting the use of electricity during peak hours and automatically moving loads to off-peak hours. SCADA is a significant and widely dispersed infrastructure used to manage assets that are geographically dispersed across thousands of kilometres and where centralised data collecting and control are essential to the proper operation of a system. As an illustration, SCADA offers a smart monitoring solution for a communication infrastructure over an electrical grid with voltages ranging from 11 kV to 32 kV. It is made up of both hardware and software components that are used to track, collect, interpret real-time data. Through a human-machine interface, it communicates with the system's components directly. In order to maintain efficiency, process data for informed decisions, communicate system faults in order to help reduce downtime, SCADA is essential in smart energy systems.

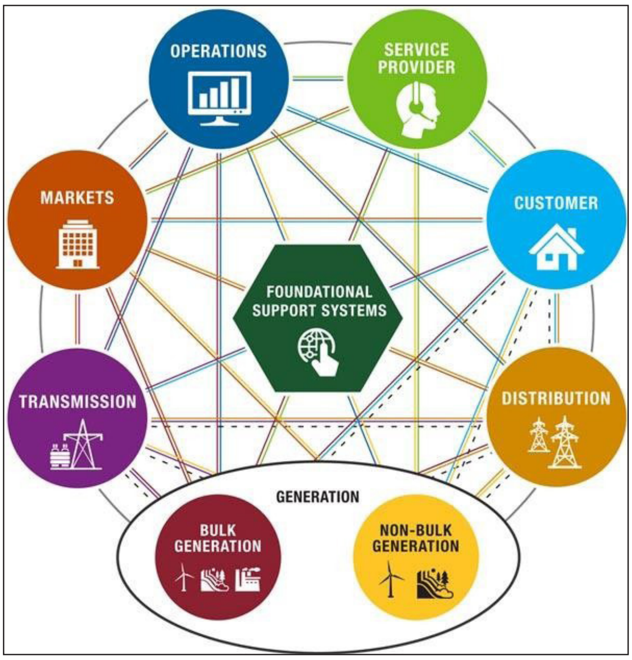

Figure 2.Smart Energy Systems Domain and Sub Systems[17]

In order to ensure effective machine-to-machine (M2M) communication and to ensure the fusion of various subsectors and sub-infrastructures, innovative technologies are also implemented into SES. Components are connected via the Internet thanks to the advent of IoT into SES.[22] For a single SES, IoT offers sophisticated interconnection to a number of heterogeneous components. The architectural model of a SES, which consists of thermal, electrical, communication infrastructures, is shown in Figure 3. In contrast to the traditional energy system, the SES is set up with two-way communication and a network sensor array that is capable of self-monitoring and self-recovery, allowing for decentralised energy generation and storage.

However, as more microgrids (MGs) are added to the system, the SES architecture develops into a larger architecture. Microgrids are the combination of various dispersed energy producing and consumer loads that can function independently or in conjunction with the grid.[23] The Internet of Things (IoT) offers a platform for communication between smart things of any category or type, making its integration into all subsystems crucial. IoT in relation to energy will be the main topic of the following section.

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

IoT is a cutting-edge technical innovation that uses the internet to quickly link and establish interactions between objects, devices, "things".[24] These include a variety of home and office equipment, as well as commonplace items like laptops, smart security systems, other industrial, commercial, household machines. These items are connected to other internet-enabled systems and devices via the employment of suitable sensors and communication network infrastructures, enabling the delivery of valuable data and a number of additional services to the consumer.

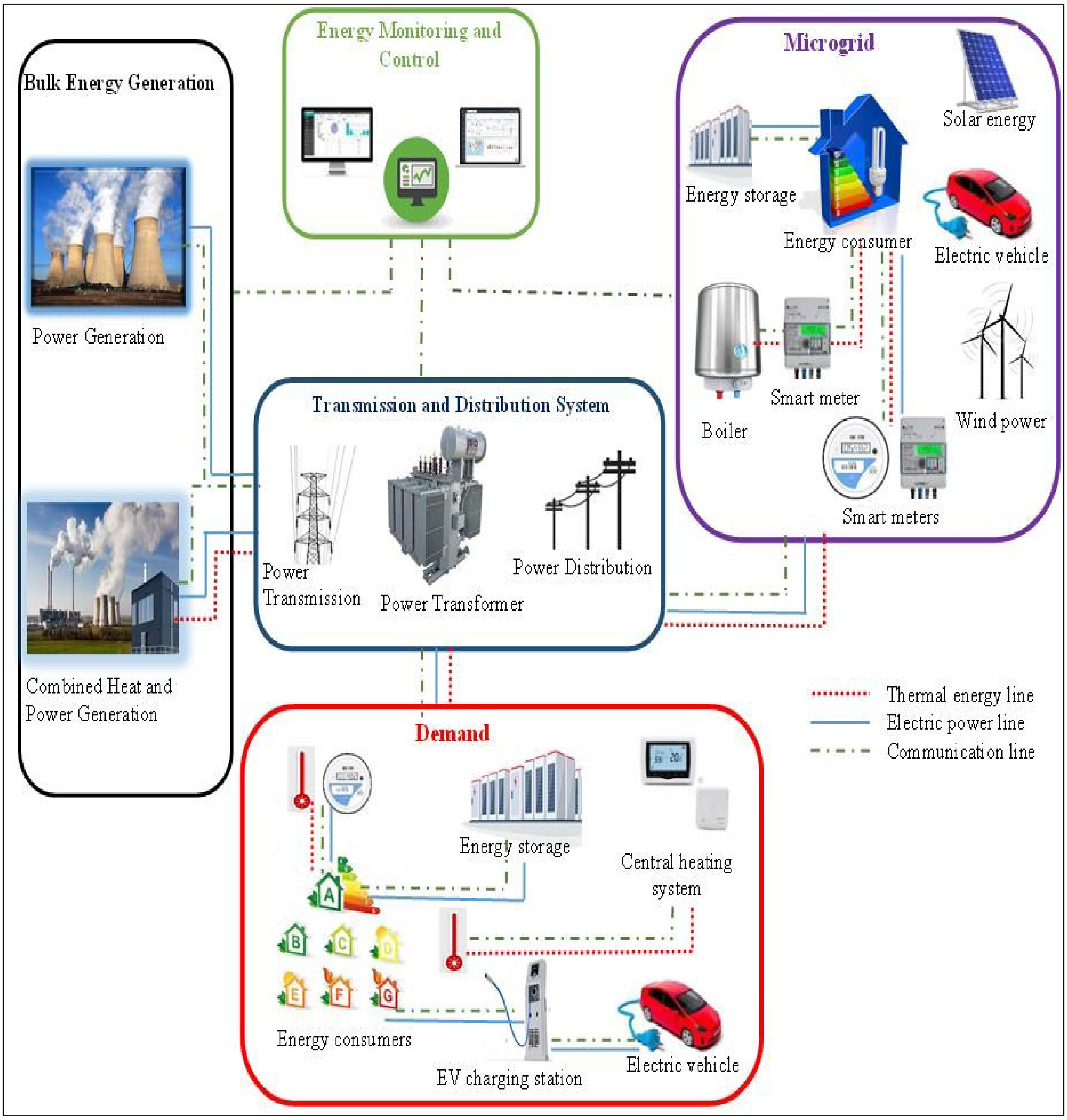

Figure 3.Smart Energy System Architecture

Construction to industrial production are just a few of the possibilities that the Internet of Things (IoT) has to offer.[25] IoT is also employed in drone-based services, environmental monitoring, building energy management, medical systems and health care.[26] A new theoretical concept known as the "Internet of Energy" has been introduced as a result of the most recent developments in power supply and renewable energy, as well as recent technological advancements in telecommunication and information communication technology systems, storage technologies, control systems, cybersecurity, combined with the fusion of IoT.[27] The Internet of Energy (IoE) can be defined as a new model for the incorporation and operation of most or some of the components in an energy system, such as distributed generation resources, hydrogen-based energy resources, electric vehicles, renewable energy resources for a variety of application purposes.[28] IoE is generally seen as the union of SES and information and communication technology systems.[29] An American economist named Jeremy Rifkin initially used the term "Internet of Energy" in his 2011 book The Third Industrial Revolution. In the book, he focused on energy as a way to examine the role that science and technology play in developing economies. The visibility, observability, controllability, intelligence of an energy system are unquestionably improved by the use of the internet in SES. To ensure the widespread acceptance and flexibility of the system, however, it should be a top priority to unite a wide range of components while taking into account their logical and technological features. As a result, there are a few crucial features and factors that must be taken into account for the intelligent cooperation and integration of various components. The unpredictable behaviour of energy sources, controllability, awareness of emissions are some important considerations.

Power production level becomes unpredictable and uncertain as a result of some stochastic behaviour of some energy sources, such as wind and solar power, the fixed character of some energy sources, like thermal power. The creation of an ideal production schedule must subsequently be determined using a mathematical programming model.[30] Delivering green energy as a result of global warming benefits the environment greatly because it is the only solution aimed at completely eliminating future global emissions. The controllability and mobility of loads are additional considerations for energy consumers or end users. Because it is significantly simpler to transport or convert, energy end consumers prefer the electrical form of energy. However, this raises the level of demand, making load shedding nearly difficult. This issue can be resolved by modelling energy consumption patterns using historical data on end user energy consumption behaviour. This can be accomplished by using sensors to collect data, then analysing and storing that data with the aid of a data processing system, making it simpler to arrive at logical conclusions on load shedding for the benefit of decision makers and customer preferences.[31]

Load Mobility

The mobility of loads is another element that brings advantages and difficulties to a smart energy system. In the case of Electric Vehicles (EV), for instance, effective charging schedule can help to level the system load profile, but real-time communications and communication infrastructures are required to allow data interchange between EVs and central controllers.[32] Each subsystem in an IoT-based smart energy system should be able to repair and organise itself because it is known that "things" are anticipated to be networked together with little to no human participation. Without a reliable communication infrastructure, which is crucial for IoE systems, this cannot be accomplished.[33] To make sure that all of the system's parts are interconnected, a well-designed communication architecture system must be put in place. In order to accomplish this, communication societies must agree on the standards and procedures to be followed at the various levels of system communication.[34]

Privacy and Security

In an IoT-based energy system, privacy and security are still very important to take into account, especially when they are integrated into the IoT architectural framework and have an impact on the overall system performance. Security issues become a significant challenge as an energy system gets bigger and includes IoT and communications networks (wired and wireless), due to the increased accessibility of system information.[35] In this instance, obtaining permission in advance before using a facility is a crucial element required for implementation in order to protect user privacy and ensure a more secure system. Data confidentiality also becomes a crucial consideration as a result of the accessibility of big data in energy systems because information can be shared with other parties like private, public, healthcare organisations. For instance, a private concern can prevent an EV owner from sharing his precise location. Consumers must share their information for a specified purpose in order to solve this problem, service providers must guarantee users that their information won't be disclosed to other third parties.[36] By doing this, end users will feel more secure when their information is requested to be accessible.

Energy Management in IoE Systems

As the energy retailer seeks to maximise profit while the energy user seeks to minimise expense, the management of energy in an IoE system is a crucial aspect of concern. This helps manage energy in an optimal way. In order to resolve this, energy consumers may also produce energy and inject it into the system (prosumers), turning it into a distributed system. This indicates that prosumers can interchange energy and data with the system through a two-way flow of both.[37,38] Additionally, an IoE system can use both interactive and passive energy management strategies. To help establish the operating point of each consumption unit, global and local information is transmitted across system nodes in the interactive energy management system. The computing load on each part or node of an intelligent system, as well as other relative limitations, can be calculated with the aid of integrated communications technology. This technique can be implemented with a decentralised, centralised, or mixed communication architecture. The self-autonomy of operations for a localised controller is used in the passive energy management scheme. This typically occurs in operations where information sharing between nodes is impractical or appears to be expensive. The Internet of Things has several major uses in energy systems. These apps strive to provide systematic techniques for consuming and managing energy in a more effective manner while helping to increase the efficiency of these systems. The following section discusses these crucial applications.

Applications of IoT in Smart Energy Systems

In the energy sector, a system of software and hardware components has been implemented, such as data collection systems, industrial automation systems, supervisory control systems, to reduce the risk of lost production and ameliorate power outages. The old equipment in the power plants causes system unreliability and significant energy losses in addition to environmental pollution, energy efficiency, dependability, maintenance problems. These issues and difficulties can currently be solved by implementing IoT in current energy systems.[40,41] In a power or energy system, internet-connected devices and IoT sensors can be used to identify operational issues or exceptional energy efficiency declines that call for system overhaul or repair. This can lower maintenance expenses and improve the dependability of the system. According to a study by Immelt published in,[42] a newly constructed power plant outfitted with IoT technology can save up to $230 million, while an old power plant of comparable size and scope can still save up to $50 million. Through the use of machine learning (ML) and artificial intelligence (AI) techniques, IoT applications in SES can also help to achieve efficient energy consumption and the best possible power balance between thermal energy plants and other self-generation systems.[43] Additionally, a number of analysts have attempted to base electrical energy on renewable energy sources while utilising various sensor technologies. In an IoT-based energy system, as illustrated in,[44] power generation is exploited using ML and different AI models.

Applications of IoT in smart cities

Due to the rising overcrowding and many environmental issues, particularly in urban areas, smart cities have recently become a major research focus in an effort to lower energy costs and improve quality of life. The job of providing cities with accessible, efficient, sustainable energy sources is therefore enormous. IoT-based solutions are starting to make sense as a solution to issues with smart cities given recent advancements and trends in digital technology.[45] In a typical smart city scenario, connected smart factories, renewable energy sources, power plants, connected smart residences, connected farms all share energy consumption statistics to cut down on energy use. Utilising various IoT technologies, including information management systems (IMS), Geographic Information Systems (GIS), global positioning systems (GPS), environmental information systems (EIS), the application of IoT in smart cities is primarily focused on the control and monitoring of industrial plants, homes, shopping malls, offices, etc.[22] By connecting numerous utilities, buildings, structures, transportation, infrastructure, energy networks with sensors, IoT application technologies can also aid in the creation of an energy-efficient smart city by managing every "thing" in a city. For instance, street lighting in a city can be automated and managed to ensure that cars on the road are using the least amount of energy possible. IoT technology have already been put into use in a number of cities all around the world. IoT systems have been implemented in Amsterdam, the Netherlands, to manage lights, traffic, public applications. In order to improve the quality of life in cities, Cisco and Phillips are now creating novel network-enabled LED lighting applications.[46] A list of significant cities with smart city efforts and technologies may be seen in Table 1. Smart cities can contribute to waste reduction, emissions reduction, water savings of up to 80 litres per person per day by implementing various IoT applications, creating 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 andInternet rollout	The LinkNYC project was created to deliver free internet access across the city through gigabyte-speed WiFi accessdelivering mobile connectivity for smart devices. This is enabled through an installed touchscreen kiosk which hasreplaced payphones across the city and assist visitors withadvice, 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 moreplanned 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 systemsincluding parking, pollution control, street lighting, public transit and management of waste. It has also installed over700 Wi-Fi hotspots across the city.
Singapore, Singapore	Smart Nation Vision	Smart services	Sensors linked to aggregate boxes are installed across thecity 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 SmartTown	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.

Applications of IoT in Smart Homes/ Buildings

Modern homes that have a variety of gadgets and equipment that can be easily controlled and managed from a distance are referred to as "smart homes." The commercial sector, which includes workplaces, schools, retail malls, transportation, the residential sector can be used to categorise the energy consumed in smart cities. The domestic and residential sector can be thought of as a "smart home," complete with a sizable number of smart devices and "things" that can talk to one another or with a central system (gateway). As indicated in Figure 4, the primary energy consumers in the household sector are heating, ventilation, air conditioning (HVAC), smart appliances and gadgets, hot water, cooling, cooking, lighting. HVAC systems account for more than 50% of the total energy used in smart homes, according to an analysis in.[48] Applying IoT technologies will enable HVAC systems to control energy as efficiently as possible. For instance, wireless sensors can be used to distinguish between occupied and vacant spaces in a smart building, an action can be started in the case of the latter to save energy usage. In order to warn end users when energy consumption exceeds a predetermined threshold or the default level, the same can be done for energy management connected to lighting in smart homes. On the basis of real-time data analysis performed by the system, loads can be automatically transferred from periods of high consumption to periods of low consumption.[49] Using a layered area network, as shown in Figure 5, a smart house or building's communication architecture is controlled. A neighbourhood area network (NAN) is made up of a group of smart homes, the NAN structure is made up of smart devices like smart metres, energy storage devices, distributed energy resources, other loads from a home area network (HAN).

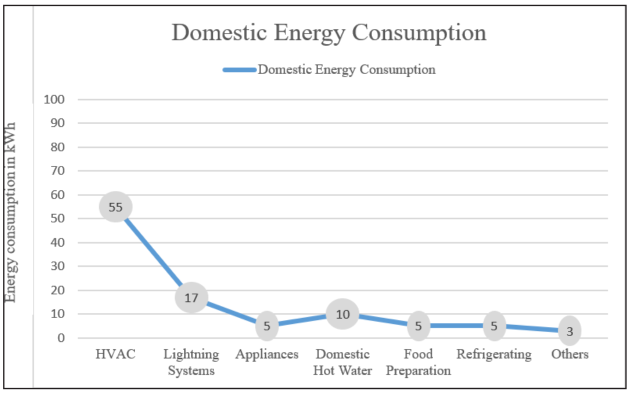

Figure 4

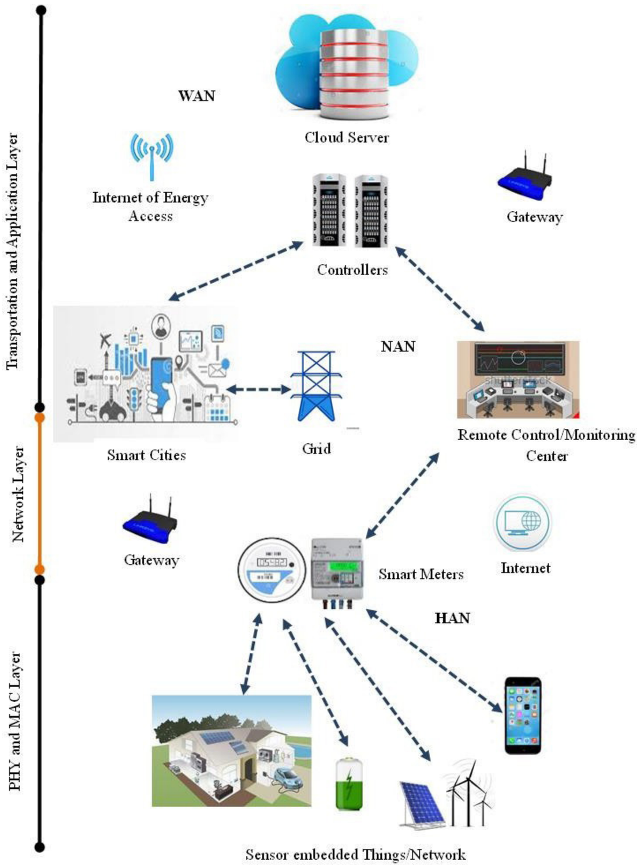

Figure 4. A Typical residential/domestic energy consumption.[48]

The device layer, in which sensors, smart devices, actuators, gateways are connected, is composed of the PHY and MAC layers. There are several cable and wireless links between the HANs and NANs architectures at the network layer. The interface and delivery of important services to customers are guaranteed by the transportation or application layer, which also integrates clouds and management services.

Applications of IoT in smart industries

IoT applications can be used to improve the energy efficiency of the entire production line given the amount of energy consumed in industries and factories to monitor, manage, oversee, provide the desired end goods. Human resources are used in traditional factories for a variety of monitoring and supervision tasks. Agile, quick, adaptable IoT-based solutions, on the other hand, can take its place and detect product flaws in a smart industry while serving the same goal. Cloud platforms, gateway devices, IoT hub networks, web servers can all be introduced, managed, controlled by computers, smartphones, or other intelligent mobile devices in terms of product monitoring and supervision in production lines. Several wired (Local Area Network (LAN)) or wireless communication methods (Z-wave, Zigbee, WiFi, or Bluetooth) can be used to connect the industry or manufacturing equipment with the required IoT applications.[50] Sensors can be attached to every part of a large industrial plant to measure the energy consumption of each component in order to ensure the effective deployment of IoT in smart industries. By doing this, the energy consumption of each component may be optimised while malfunctioning components can be quickly found and fixed.

In a smart industry, using a cloud platform can facilitate easier data processing and storage, which can assist managers and decision-makers in making more effective and accurate judgements in less time.[51] IoT technologies can also promote cooperation and synergy between producers, companies, customers.

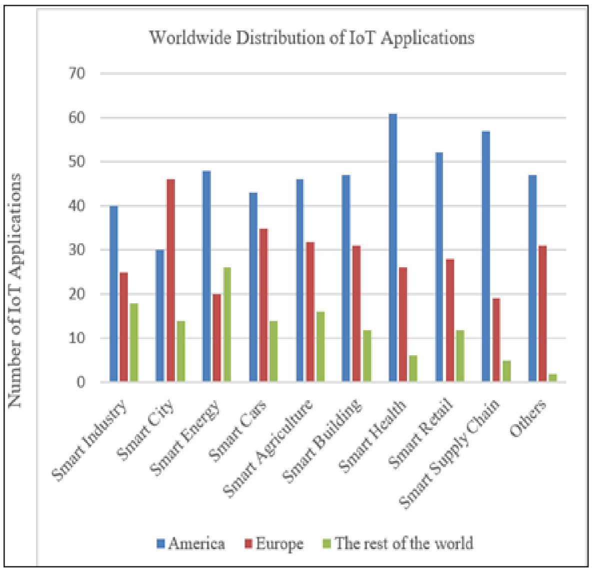

Figure 6.World wide distribution of IoT applications

This will guarantee that customers are informed about each stage of the manufacturing process and that items are created to their tastes. Additionally, this will contribute to energy savings in the manufacture of spare parts and in the running of storage facilities for these parts. Instead, only one type of product can be created and kept in stock, which will boost energy management and increase production efficiency.[52] Additionally, it has been noted that smart energy, smart retail, smart buildings, other IoT applications are quite active and in use on the majority of the planet's continents. Several regions of Asia and Africa have not yet caught up with the massive advancements and breakthroughs in this field, although the continents of America and Europe are highly prominent in various IoT applications. Meanwhile, it is anticipated that as Internet connectivity reaches the deepest regions of Asia and Africa, the number of smart systems and gadgets will increase dramatically.

Challenges of IoT Applications in Smart Energy Systems

Using IoT technologies in SES comes with a variety of difficulties and issues. There are undoubtedly certain difficulties with the connections because an IoT smart energy system is an integrated system that contains both internet technology applications and several smart energy components. Below is a discussion of the most significant of these difficulties.

Sensor Energy Management

Sensors are used in an IoT context to gather data from various components. This entails that a significant amount of energy must be used to power and run these sensors, which obviously presents a problem, particularly for systems with extremely little power. The capacity of sensing technology to operate for a lifetime without requiring a battery replacement presents a very significant barrier.[53] Shi et al. in[54] suggested an energy-saving strategy for sensors that puts the sensors into a sleep state when they are not in use and also when the battery life is crucial in an effort to address this issue.[55] also presents a method for wireless energy harvesting, where power for these sensors is supplied by other non-conventional energy sources.

Security, Privacy and Confidentiality

There is a significant risk that IoT-based smart energy systems may be vulnerable to attacks and security concerns as they are implemented across a greater geographic region. The system is susceptible to these attacks since it makes use of a variety of IoT technologies, from energy generation to end users. Therefore, as suggested in,[56] encryption mechanisms should be implemented on the system to safeguard the system's information. The system regularly demands user data and personal information from users in order to improve and optimise decision-making related to energy distribution, generation, consumption, which puts the privacy of energy consumers at risk from unauthorised third parties. To lessen this, the authors of [57] proposed a trust-based privacy management scheme that could be integrated into the system and would provide users control over their privacy and information, allowing them to share it only when necessary with authenticated sources and authenticated energy providers. The integrity of a communication line is achieved when the received data is not changed along the communication path, confidentiality of conveyed and stored data provides accessible only to the intended receivers. Because low-end devices have limited resources, it is challenging to ensure security for data transfer in IoT applications in SES. The secrecy problems in transmitting IoT nodes can be effectively handled by techniques like encoding and cyphers.[58] In order to guarantee data confidentiality and integrity, Trappe et al.[59] presented a secure line transmission channel for microgrid applications in which a system can authenticate using a digital signature plan and assign unique IDs to all gateways.

Standards for IoT

From a single unit device and subsystems to large systems with embedded systems connected to various platforms, the integration of IoT into SES varies. These will make data sharing and connectivity across IoT devices with different protocols and standards much more challenging. For instance, because Apple devices are set up to connect to other Apple devices via Bluetooth, transmitting data and information between an Apple smart device and another operating system over Bluetooth becomes difficult. 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.

No matter how complex their architectural design, distribution, or mobility features may be, numerous IoT technologies are expected to enable flawless communication anytime and anywhere when incorporated into a power system. Accordingly, diverse reference designs are typically required so that users are not constrained to using fixed end-to-end IoT connectivity.[61] The amount of data that needs to be handled in an energy system grows as it gets bigger. To prepare for the future, the system must have the capability of processing, analysing, storing both current and historical data. This presents a significant challenge for IoT-based power systems. In this situation, Stojmenovic suggested in[62] a localised data processing method that guarantees local data are processed along with the state data of the primary servers and the nearby servers. It is also possible to utilise a Big Data architecture technique, as described in,[63] where knowledge extraction is carried out on the Big Data and the data is divided into distinct tiers according to their priority of usage.

After big data has been used to extract important knowledge, the energy system should be able to further classify the data and offer specific services (such sending signals to the actuators or sensor systems). For instance, in SES, data on energy and heat consumption can be subjected to the kind of customer (domestic or industrial), each level of consumption can be further divided into off, standby, active operating mode. This leads to the introduction of a large data architecture.[64]

Managing Bandwidth

A big number of sensors must be placed, a large volume of data must be transmitted continuously throughout the day for IoT to be integrated into a SES like local microgrids. Due to the high computation and growing bandwidth demand, connecting all physical items and things to the internet is quite difficult and expensive. Because IoT devices only have a limited amount of bandwidth available to them, using IoT technologies in smart microgrid systems is preferable to using smart sensors and data mining technologies. This is because IoT is a less effective method of communicating all unregulated information. Technologies for fusing information can also be used to exchange useful data.[65] The Third Generation Partner Project (3GPP) has recognised Narrowband IoT (NB-IoT), a new LTE standard, as one of the low-power wide area options for achieving the objectives of extensive coverage, low power consumption, inexpensive and sophisticated combination. Although NB-IoT reuses most LTE principles, including channel coding, rate matching, interleaving in the uplink and single carrier frequency division multiple access (SCFDMA) in the downlink, a combination of characteristics, such as synchronisation series, random access preface, telecast channel, control channel, are transformed to be recognised with the LTE blueprint.[66]

Connectivity

As more devices are connected to the IoT, there are more opportunities to collect and analyse data, make more informed decisions, increase automation, provide a wide range of new services.[67] A series of orders must be issued to the gateway equipped with the module in order to guarantee that the systems are always linked. These instructions are then transmitted by the gateway via ZigBee to the home appliances for execution. Additionally, the gateway has a configurable diagnostics and configuration mode that enables WiFi connectivity. Users and technicians can connect to the access point in this fashion using their laptops or smartphones to perform local diagnostics and configuration upgrades.[68] A cybersecure communication layer for quick wireless connectivity is also being developed by the Real-time Intelligence for Smart Electric Operations (RISE) centre. The layer will be expanded to include connectivity standards and technology to offer a secure remedy for connectivity issues.[69] Since the distributed filter's topology is coupled, there will undoubtedly be packet losses on the transmission lines connecting IoT-enabled devices to SES. A distributed dynamic phase estimation method was put out in[70] for microgrids with distributed energy resources (DER), in which the error function is recast using the Kronecker product's matrix property. The authors of [71] also suggested a state estimate and stabilisation method that takes into account input and output packet losses in the communication of the IoT-enabled grid. In order to govern system states, a semidefinite programming-enabled state feedback controller for IoT-aided grid communication is also suggested.

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

The majority of energy-related businesses must offer strategies for enhancing electrical units' ability to communicate, whether by integrating new features into a variety of digital chips, implementing energy-saving techniques and energy-harvesting systems, or implementing adaptable power systems. Due to the fact that the majority of industrial organisations are still using traditional methods, technological advancements linked to IoT have not yet been very well received. The future and operations of a firm depend heavily on the IoT's incorporation into its operational system. In an IoT environment, sensors have real-time control over energy generation and can help make centralised production a reality. It is a well-known reality that IoT applications would unquestionably alter industrial firms' overall perspective. Utilising the benefits of IoT technologies can also help businesses monitor the condition of their grid infrastructure, power system equipment, solar panels, turbines, other assets remotely, effectively, appropriately. From a business perspective, if industries and businesses adopt IoT technologies, it will help to advance data analytics, manage plant generation more effectively, improve predictive maintenance, increase safety compliance and system efficiency,, most significantly, improve connectivity and availability. High investment returns, privacy and security, achieving corporate, industry, government standards, improving product interoperability, accessibility, dependability, enabling software and hardware functions are all benefits for businesses using IoT applications.[72] By the end of 2022, there will be an additional 2 billion devices connected to the internet, according to predictions. The global IoT market is expected to reach more than $1.7 billion, with consumer electronics accounting for a sizable portion of that market. IoT in the automated sector is anticipated to reach $151.40 billion by 2024 with a compound annual growth rate of 12.020%. The global energy market for IoT exceeded $6.8 billion in 2015, it is predicted to reach $26.5 billion in 2023, growing at a compound annual growth rate of 15.5%.[73] In the United States, 45% of IoT-connected industry initiatives are currently operational, with 7% of those projects in the energy sector and 3% in smart city environments.[74] The South African IoT market size is anticipated to increase by 36% in 2028.[75] Industries are increasingly turning to IoT enabled solutions to generate significant returns on investments. The South African government is generally stepping up efforts to expand the use of IoT technologies in the nation. As part of a plan that aims to establish urban sustainability and digital solutions, Lanseria is slated to become the first smart city in South Africa and will be known as "Lanseria Smart City."

The worldwide IoT market is expanding daily, it makes perfect sense for businesses and sectors to take advantage of the advancements IoT technologies has to offer. Growths Enabler states in[76] that a number of IoT-related industries, including connected wearables, smart utilities, connected autos, smart cities, smart homes, would have an impact on the global market share of IoT.

Future Trends

As mentioned in the preceding sections, the integration of IoT technologies into SES has provided these systems with a number of advantages. IoT systems will expand and evolve as communication technologies and ICT do, their integration into smart energy systems will witness many advancements and improvements. For instance, the current lack of computer power and bandwidth prevents the integration of blockchain technologies into a variety of energy systems. In light of recent developments in communication technology, 5G, 6G, cloud technologies are already suitable replacements for the existing communication technologies that can aid in the implementation of blockchain. Blockchain is a chain method that ensures every IoT node's transaction record is saved in a block-like configuration so that each record can be connected to the one before it. With this strategy, users can freely interchange data, trading energy will also be available, all while maintaining the effectiveness and security of the entire system.[77,78] The introduction of IoT technologies in smart systems didn't occur until 2000, when the field of technology experienced a significant uptick in growth and wide-scale commercialization. The same year, LG, a manufacturer of electronics, declared that it will introduce a smart refrigerator that could decide when food needed to be replenished.[79] Smart IoT systems have now permeated our organisations, homes, industries, enabling more devices to be connected for data sharing, real-time monitoring, communication, data analysis.

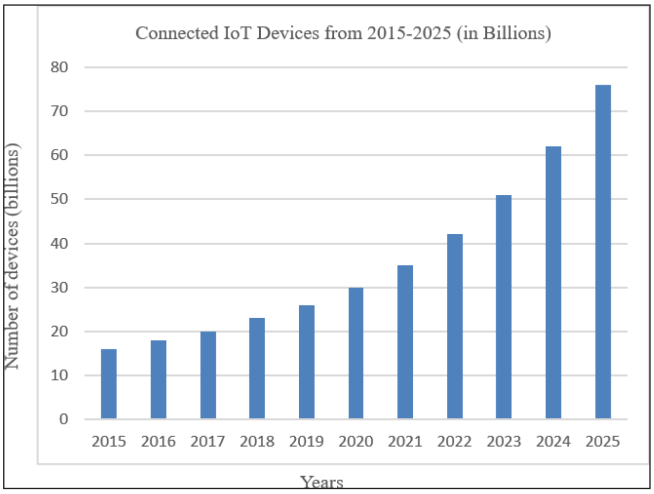

Figure 7.IoT connected devices worldwide from the year 2015-2025[73]

Data from IoT statistics in[80] is used in Figure 7 to depict the number of devices linked to the IoT globally between 2015 and 2025. With more than 41 million IoT devices connected in 2022, it is clear that the number of connected devices is rapidly rising around the globe. As depicted in the graphic, 76 million IoT-connected devices are projected to exist worldwide in 2025. The number of linked IoT devices is also expected to rise as new regions with IoT-enabled applications are introduced in the upcoming years.

Numerous IoT appliances and equipment will be installed and connected to the internet as the integration of IoT with SES continues to gain momentum, especially in major energy systems. As a result, there will be massive energy consumption in systems and a massive amount of electronic waste.[81] Energy efficiency in these systems can be improved from the development stage through the production, deployment, disposal stages[82] through the implementation of the Green Internet of Things (G-IoT). The size of radio frequency identification (RFID) tags can also be decreased with the implementation of G-IoT technologies by merely reducing the amount of material utilised in each RFID tag .[83]

There are various features and regions that require additional research as IoE systems gain popularity among researchers in order to better hone these technologies. For instance, neither the supporting capabilities of this network nor Quality of Service (QoS) problems in wireless sensor networks have received significant research attention. Real-time monitoring of line faults and power plant control are both topics that can be investigated in the realm of power generation research. Future research should focus on a crucial area of IoT-based smart energy systems connected to deep learning and machine learning methods in Big Data analytics. In this manner, big data, enormous stacks, significant amounts of collected data in an energy system can be leveraged to solve problems.

The development of highly intelligent security mechanisms that encompass encryption, authorising, identifying, authenticating-based approaches is an important field of research that could have a significant impact on IoT-based smart energy systems in the near future. These security sectors are crucial for ensuring intelligent private networking and better security capabilities in the system. It is important to note that researchers are gradually focusing on communication-based IoT systems to ensure secure connectivity over vast distances with little power consumption. For instance, researchers are already paying attention to communication systems based on Low-Power Wide Area Network (LPWAN) [84]. There are further areas of study that will take off in the near future to address problems with the technology used in SES.

Conclusions

The Internet of Energy (IoE) is a subclass of the Internet of Things (IoT) and a cutting-edge, emerging idea in the field of energy systems. It includes the entire energy sector, including electrical and thermal energies as well as information and communication technologies. IoT technology integration in SES promotes and supports more resourceful energy use while reducing the socioeconomic and environmental effects on energy systems. The contributions of IoT to SES are discussed in this research along with an analysis of smart energy systems. The use of internet-based technology into SES improves the system's visibility, controllability, comprehension. The technical and logical elements that guarantee a suitable and flexible connectivity are crucial since the integration consists of a high number of components. Therefore, it is investigated what criteria are crucial to take into account for a successful integration of these technologies into SES. Since IoT is an emerging technology with many advantages that can be used to improve smart energy technologies, the important adaptations of IoT in energy systems—including smart cities, smart homes and buildings, smart industries—are explored and appraised. Furthermore, there are a few difficulties and problems that prevent the full integration of IoT technologies into SES, despite a smart system's capacity to support a broad range of applications and ensure quick communication between a variety of devices. Security and privacy, sensor energy usage, established standards, architectural design are some of these difficulties. These difficulties are examined, suggestions for overcoming them are provided. IoT in SES ensures a bright future in terms of optimal energy management and efficient communications. As a result, the direction and research trends of these technologies are examined, along with the justifications for why businesses and industries should use IoT into their systems.

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