Applications of Internet of Things (IoT) in Green Computing

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1 Introduction

IoT is the combination of two essential terms "Internet" and "Things." The world has now become smart with the development and improvement of science and technology. With the development of various technologies, the users of IoT networks are collaborating themselves using various IoT-enabled devices. The use of various sensors, controllers, actuators, and other miscellaneous objects enables people to link with the digital world for sharing information through the Internet of Things (IoT). The sharing of information in this way provides intellectual perceptions into human beings [1–5]. All the IoT devices such as RFID tags and their inbuilt sensors consume more energy to process the information they exchange over the network [6, 7]. Big data and cloud computing are interlinked with the IoT to investigate the behavior of IoT enables devices. Nowadays organizations are trying to adapt to the environment in which the demands of IoT users are increasing exponentially. According to the available literature, by 2025, the IoT nodes can be inbuilt in everything such as washing machines, food packages, documents, etc. For the establishment and betterment of the greener and smart world, IoT devices should be easily acceptable, eco-friendly, easily disposable, energy-efficient, and economically viable [8, 10, 11]. IoT devices are making strong utilization of diverse cloud platforms. These devices store and transmit the information of sensed data to cloud providers like Thingspeak.com to facilitate the users for real-time monitoring of devices [12]. The concept of green computing explores various prominent areas such as designing and manufacturing of products, disposing of electronic devices, and suggests the possible ways to minimize the hazardous impact on the environment.

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The methods of green computing promote the utilization of waste materials (recycling) and develop energy-efficient hardware and software systems. Green computing provides a sense of social responsibility to the people in the public sector to minimize the financial requirements of the nation. The concept of "Green Computing" originated by the US Environmental Protection Agency (EPA) in 1992 with the launch of a voluntary labeling program, i.e. Energy Star, to promote energy efficiency in computer hardware.

Nowadays, various agencies are promoting green computing by providing certification like Energy Start Label to computer systems. Similarly, the TCO certification program that is launch by the Swedish organization TCP development promotes the consumption of low emission components. Researchers have been explored various areas of research in the field of IoT-based green computing such as the design and development of IoT enables devices, managing operations, and their maintenance. This field of research fascinates the researchers to explore the challenges and issues related to change of climate, the crisis of required energy, and other environmental issues [9]. Nayyar et al. [13] provide in-depth view of Internet of Nano Things (IoNT), its architecture, application areas, and various challenges to make researchers aware of IoNT standards. IoT ecosystem is used to connect heterogeneous IoT devices, controllers, servers, gateways, and platforms efficiently into a single system. Various communication protocols and interfaces such as low-power Wi-Fi, Near Field Communication (NFC), Zigbee, etc., are used to connect these components to exchange the information. The block diagram in Fig. 1 presents the IoT ecosystem.

Information and Communication Technologies (ICT) have now been automated to make various routine tasks easier. Computers and the Internet play a significant role to improve various processes of the ICT sector in the real world. Billions of users are getting a response to their queries using the "Client-Server" model. A huge amount of information can be distributed worldwide that store on the servers of social websites and networks. In addition to this, with the development of a machine to machine communication various systems over the network are used to provide information and services to other machines. Till date, more than 50 billion IoT devices have been connected to the IoT networks. Researchers have been predicted that in the next coming years, this number can be increased up to 3 trillion. Green ICT is required to maintain green IT to create a healthy environment with the optional use of the Internet and other IT resources. All IoT-enabled devices are required ample amounts of energy for their operations and put a large encumbrance on the electrical grid and greenhouse gases. The regular change in the pattern of climate and the accumulation of greenhouse gases may be the cause of drought and flood in some areas. The exponential growth in the temperature of the earth may be responsible for the severe environmental glitches. From various studies carried out by researchers present that the number of weather-related disasters is increasing every year. To overcome this situation we need to focus on the growth of global emission of greenhouse gases and their preservation. Unnecessary consumption of energy emitted from natural resources such as coal and oil must be suppressed which can be highly responsible for the drastic change in the environment. The deduction in

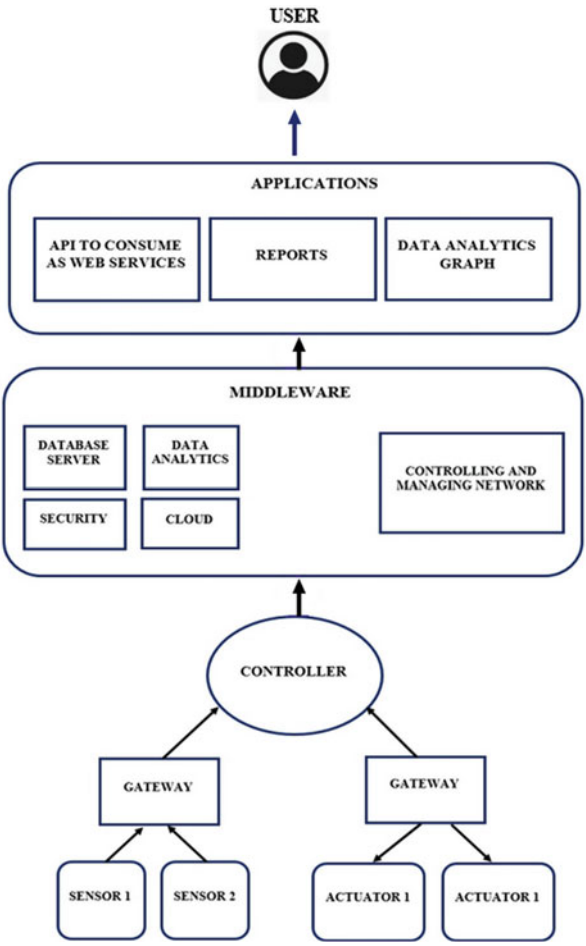

Fig. 1 Block diagram of IoT ecosystem

unnecessary electric power consumption can lay hold the acute impact of global warming. To minimize the impact of CO2 in the environment a concrete road map must be designed in which existing technologies of IoT can be utilized. The manufactures should adopt the advanced design for manufacturing products that require less energy and other natural resources. The exponential growth of the population and the integration of IoT devices over the network are a never-ending process. To change the utilization and buying behavior of the users, some green policies should be formulated. These policies and regulations motivate users to use only green products. Besides this, the traditional methods should be exterminated and new trends must be incorporated to build a green environment.

The major contributions of the chapter can be summarized as follows:

- The chapter gives an introduction to the IoT ecosystem, explains the concept of green computing and information and communication technologies (ICT).

- The chapter emphasis on many focused areas of green computing such as efficient utilization of resources, the establishment of data centers, proper recycling of hazardous materials, and minimizing the effect of the greenhouse, etc.
- The chapter focuses on various factors that are useful for crucial planning and decisions making to incorporate significant improvements in the development of IoT green computing devices.
- The chapter explores how different IoTGC technologies that are based on virtualization can reduce the demand for hardware resources and power consumption to perform various operations.
- The chapter reviewed various aspects related to awareness to improve the efficiency of IoT green computing.
- Finally, the chapter explores various challenges that are needed to be focused to recycle the products to attain successful environmental-friendly IoT green computing.

In this chapter, Sect. 1 provides a brief introduction to the Internet of Things (IoT), IoT-based green computing, and green ICT. Section 2 explains various common elements and applications of IoT. Section 3 presents an overview of green computing and green IoT. In addition to this, it provides knowledge to the readers about various principles of green IoT. Section 4 explains various applications of IoT green computing based on five different categories such as hardware, recycling, awareness, software, and policy. The various subsections of this section provide the details about how real-time software and hardware, awareness of the users, and various initiatives taken by the government and private agencies can be useful for the development of IoT green Computing environment. Finally, based on some observations in the field of IoTGC, Section 5 presents discussion and conclusions.

2 Internet of Things (IoT)

IoT is widely used to connect billions of physical devices through sensors and other wireless technologies to the Internet. It provides facilities for the use of IoT systems to exchange massive information for effective decision making. It enables security, data management, resource management, and other useful operations to provide better service to the IoT users. According to the available literature it has been suggested that by 2025, billions of IoT-enabled devices may be connected to the IoT networks. Various key segments of IoT such as hardware, middleware, Internet, and presentation are used for gathering data to provide the best services to the users.

Figure 2 presents various common elements of IoT.

- *Identification:* Through this key element a unique identification is provided to the different IoT devices such as Ubiquitous Code (Ucode), object identifier (OID), Radio-Frequency Identifier (RFID), Universal Unique Identifier (UUID),

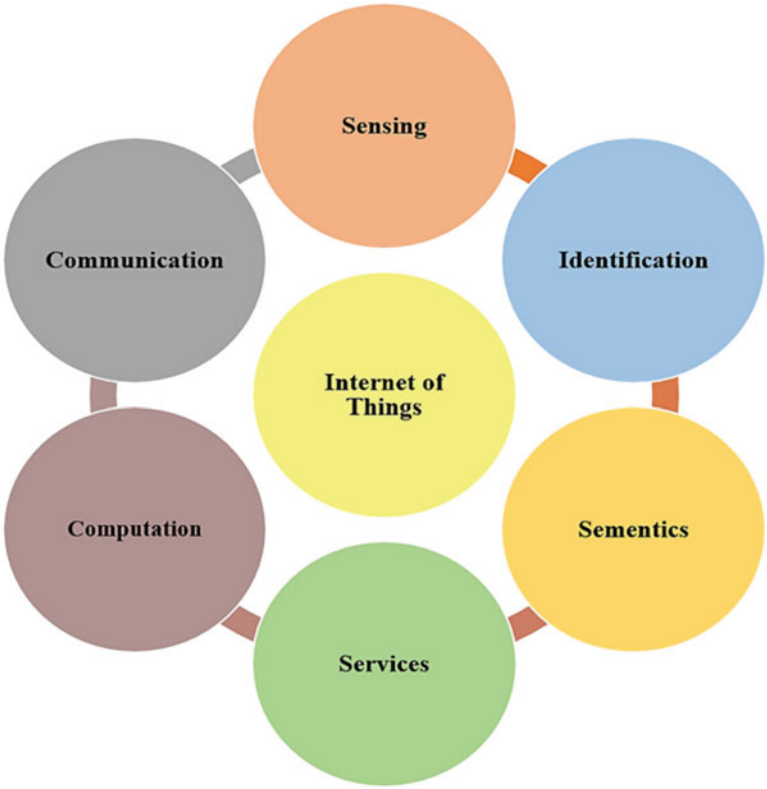

Fig. 2 Various common elements of IoT

Automatic Identification and Data Capture (AIDC), and International Mobile Equipment Identity (IMEI), etc.

- *Sensing:* To make the system smarter the sensors gather and distribute the data among various connected devices of the network. These sensors are used to sense useful information such as temperature, acceleration, pressure, chemical reactions, etc.
- *Communication:* In wireless communication, many communication protocols are widely used such as Internet Protocol Version 6 (IPv6), Bluetooth, Wi-Fi, over Low-power Wireless Personal Area Networks (6LoWPAN), Z-Wave, and ultra-wide bandwidth (UWB), etc.
- *Computation:* Various common hardware platforms such as Raspberry Pi, Arduino (Genuino), ESP 8266, Intel Edison, Intel Galileo, etc. and software platforms such as Axeda, Nimbits, SensorCloud, etc., are used to carry out various computational tasks.
- *Services:* A large number of IoT applications require a particular IoT service. These services can be of four types such as information aggregation services, identity-related services, collaborative-aware services, and ubiquitous services.

Table 1 Segmentation of various IoT application domains into different categories [16–19]

S. no.	Application domain	Description
1	Application Development	Development and deployment of the IoT-enabled products by the companies
2	Network Management	Establishing and maintaining communication among various IoT entities on the IoT networks
3	Data Analytics	Data produced by various IoT devices can be analyzed based on various classification and clustering techniques
4	Visualization	Presenting analyzed data in an understandable form
5	Data Management	Handling and managing data efficiently using various existing technologies
6	Research	Use of IoT in different fields of research such as green IoT for a sustainable environment [14, 15]

- *Semantics:* Various common semantics are widely used to extract the information into a meaningful form by adopting the steps such as identification and proper utilization of resources, data modeling, and analysis. The most widely used semantic technologies are Efficient XML Interchange (EXI), Resource Description Framework (RDF), Web Ontology Language (WOL), etc.

The architecture of IoT can be subdivided into various layers such as perception (Layer-1), network (Layer-2), and application (Layer-3). The architecture of IoT is further extended by adding middleware and business layer. The middleware layer is also known as processing layer that processes and analyzes the massive collection of data supplied by the network layer. Establishing connection and managing various services are the major responsibilities of this layer. The business layer deals with the well-constructed business models for decision making. This layer plays a major role in various business strategies, user privacy, and other applications. Different application domains of IoT and their description are shown in Table 1.

Nowadays the concept of IoT is widely used in various significant areas such as the development of smart cities, smart transportation system, smart health care systems, home automation systems, smart agriculture systems, etc. [20–22]. Gathered and analyzed data related to various applications of IoT can be used in various commercial applications. Various IoT devices are widely used to gather useful data for the establishment of IoT-based smart cities. The smart cities use the data to provide better services to the users and also improve the infrastructure of the smart cities.

IoT-enabled smart health care systems provide better health care to the patients by maintaining and analyzing their regular health records. These systems are used to check the availability of medical resources and error-free communication between physicians and patients. The existence of all these facilities in the IoT-based health care system provides the trust and reliability of IoT systems among the users [23–25]. Figure 3 presents various IoT applications.

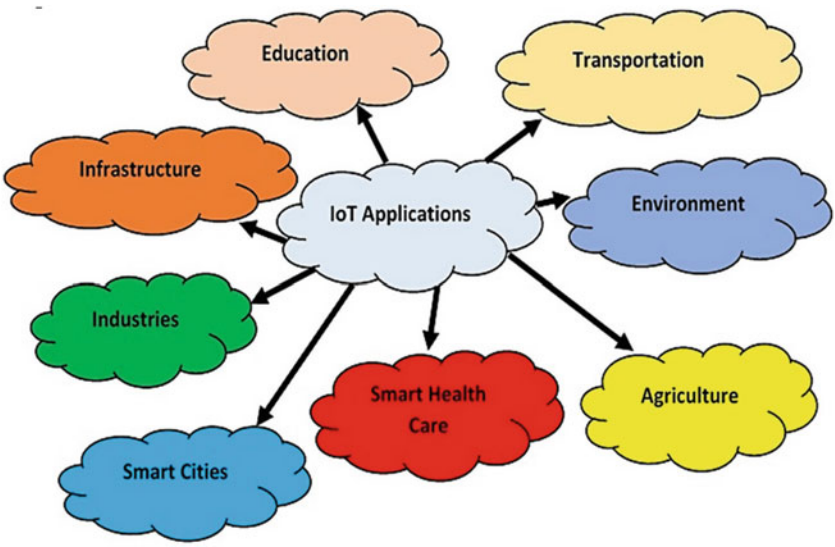

Fig. 3 Various applications of IoT

For IoT-based transport systems various efficient framework has been suggested by the researches. These frameworks exploit the collected data by different IoT sensors to process the information among the IoT-enabled devices. These frameworks provide the facilities of better communication, coordination, safety, and control in the transportation system. IoT-based smart vehicle monitoring system can be used to detect the accidents at a very early stage so that any miss happening can be stopped. IoT-enabled devices can be used for the construction of the smart home and other infrastructure systems. IoT-based technologies are best suited for various service-oriented industries, IoT-based agriculture, environment and energy management, security and monitoring systems, and various other similar kinds of areas.

3 Green Computing and Green IoT

The demand for energy to operate various IoT-enabled devices is increasing day by day. Different manufacturing companies are trying to develop efficient technologies to reduce the requirement of energy. Researchers have been suggested that by 2030 the number of IoT devices can be reached up to 100 billion. In the same proportion, the level of carbon dioxide is exponentially increasing due to the heavy use of IoT devices. The study carried out by the researchers reveals the fact that by 2020 approximately 344 tons of carbon dioxide could be generated from cell phones. The exponential growth of CO_2 in the environment can be harmful to the health of the human being. Therefore, to maintain a sustainable environment globally it is

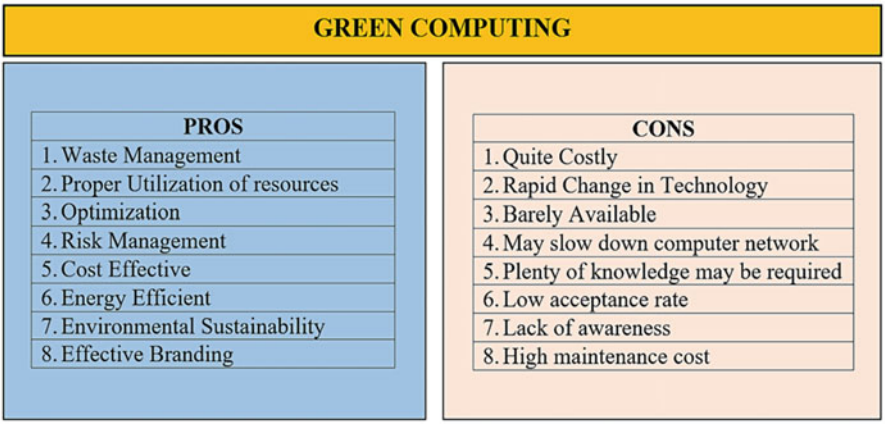

Fig. 4 Pros and cons of Green Computing

required to take some major steps towards the inclusion of green computing in IoT systems. There are many focused areas of green computing such as efficient utilization of resources, the establishment of the data centers, proper recycling of hazardous materials, minimizing the effect of the greenhouse, etc. [14, 15]. Various efficient technologies of green computing can be incorporated to minimize the adverse effect of greenhouse gases and their impact on the global environment. According to the literature and case studies, the hazardous impacts of greenhouse gases have been reduced after adopting the technologies of green computing [18, 20, 26–28]. Nowadays the demand for energy utilization is exponentially increasing to operate various IoT devices. To fulfill the energy consumption requirements companies and their subscribers are adopting green IoT. Manufactures and other service providers are using various recent technologies to save energy in smart homes and buildings. An ample amount of energy can be conserved technologies related to air-conditioning and ventilation and are implemented efficiently.

Various techniques have been suggested by the researchers to save energy in Wireless Sensor Network [29]. Perera et al. [30] suggested an orchestration agent (OA) which is used for the evaluation of resource consumption of the servers and also ensures reliability. Figure 4 shows the pros and cons of green computing in the current scenario.

Murugesan et al. [31] have been proposed an efficient C-MOSDEN model to reduce the requirement of power consumption. The suggested scheduling algorithms in the proposed model are used to accumulate the energy in IoT sensors. In smart health care systems, IoT devices are widely used to store the real-time data of the patient [32]. Kim et al. [33] have been suggested an efficient algorithm that manages the consumption of energy in cloud storage as well as in the exchange of the data.

3.1 Principles of Green IoT

In today's scenario, it can be observed that conventional energy resources are obsoleting day by day. Various IoT-enabled devices are widely used among IoT users that require significant energy consumption. With the exponential growth in power consumption through IoT devices, the concept of green IoT plays a major role in ICT research. Researchers have been suggested the below-mentioned principles of green IoT to gain the benefits from it.

- In the IoT system different nodes are required to be placed diligently and to conserve energy-efficient routing techniques can be adopted.
- IoT-enabled devices are required to gather the most essential data and wipe out the irrelevant data which require a high amount of energy consumption.
- Deployment of passive and active sensors on the network can significantly reduce the amount of energy consumption.
- Effective decisions and policies are required to be developed to reduce the exponential growth of energy utilization by the smart transport system, smart health care system, etc.
- Cost-effective trade-offs are required to be selected based on cost, communication, and processing.

4 IoT in Green Computing

The communication process of IoT to exchange the information must be energy efficient. In exchange of the data over network different IoT devices, sensors must consume less energy to perform various operations. Various applications of the IoT green computing can be used in various areas such as the development of smartphones [16], efficient utilization of data storage [18], development of IoT-based ecosystem [19], development of an energy-efficient system to exchange the data [20], smart health management and agriculture system [9], and in the establishment of Green Campus [21]. Various application areas of IoT in green computing can be divided into different subcategories as depicted in Fig. 5.

Fig. 5 Applications of IoT Green Computing

4.1 Applications of IoT Green Computing Based on Policies

Based on real-time data the crucial planning and decisions can be taken at different levels for the development of IoT green computing devices. The effective decision-making process can supply various inputs to give an impact on the environment. Proper management of data, better planning for energy consumption, and an industrial automation system can be helpful for the establishment of effective IoT green computing. In a home automation system, proper data gathering and its processing can minimize the significant amount of energy depletion [22–25]. Figure 6 presents various applications of policy-based IoT green computing.

4.1.1 IoT-Based Green Campus

With the exponential growth of population, the limited number of resources are depleting rapidly. For example, in 1995, the atmospheric CO_2 concentration was less than 320 ppm. After the industrial revolution, it has been significantly increased by up to 25% [18]. It is an indicator of a deteriorated situation that presents a contaminated and unhealthy environment around us. The other problems such as a sudden difference in temperature, soil degradation, and acid rain cannot be ignored completely. Government and other organizations have to take some initiatives to minimize the carbon emissions in the environment. For a better civilization government have to develop some energy proficient systems. Proper promotion of policies and awareness of the green world among the human being can play a crucial role in

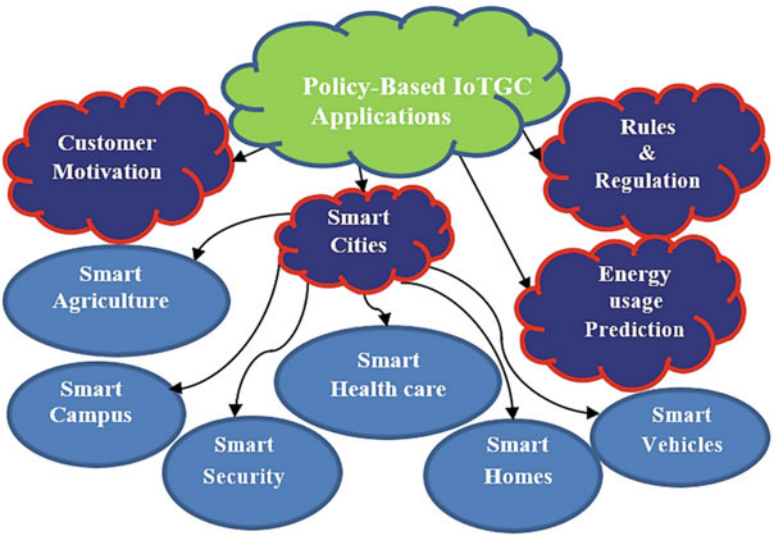

Fig. 6 Applications of policy-based IoT Green Computing

the development of the green campus or residence. These smart campuses must be equipped with an automated monitoring and control mechanism to manage several facilities economically. The purpose of a smart campus is to provide the facilities that require a minimum amount of energy [20]. The advanced technologies in the smart campuses effectively control different facilities such as air conditioners, computer laboratories, etc., and establish a planned IoTGC system that can save electricity.

4.1.2 Green Agriculture and Green Health Care

In conventional health care and agriculture systems, IoT green computing can play a major role. IoT green computing-based health care systems have some applications such as smart health monitoring systems, handling a massive amount of data using data mining and artificial intelligence techniques. Similarly, a smart agriculture system enables farmers to increase crop yields, and also aware farmers about the efficient technology of irrigation. Efficient farming with modern IoT-enabled equipment can reduce the cost of farming [20, 21]. The integrated IoTGC model with these systems can improve versatility, intelligence, and interoperability. The administration cost in both types of smart system can be minimized due to the use of IoT-enabled device. Such tools share information over the Internet through different modules of the network, thus greatly simplify and reduce the tasks of administration. For example, in case of an emergency, the automatic alarming system can provide information about the nearest reachable hospital. Similarly, IoTGC based smart farming system can improve the crop yield using several IoT-enabled devices such as moisture sensors, temperature sensors, etc. [9].

4.1.3 Intelligent Automobiles

In IoTGC based smart transportation system various efficient techniques have been investigated by the researchers. Through IoTGC based smart vehicle systems, time and cost can be significantly saved. In these automated systems various IoT- based sensors are used to detect the possibility of an accident in advance. These systems also provide e-notification about traffic and weather conditions via remote servers. Through IoT sensors, the speed of the vehicles can be controlled in heavy traffic and bad weather condition.

The automatic alarming system can estimate the response time and travel time of the drive to generate information about the miss happening to his family. Likewise, the use of GPRS tracing scheme, GSM dial-up connection, and infrared proximity sensors are some of the few examples that can be helpful in the smart vehicle management system [23]. The smart vehicle management mechanism reduces the pollution due to unnecessary blockage of traffic and also save the oil from the excessive acceleration and braking of vehicles [24]. The equipped vehicle monitoring sensors can identify the state of the vehicle, its owner, and can provide the

appropriate support by alerting the agencies in uncontrollable conditions on the road [34, 35].

4.1.4 Intelligent Houses

The IoTGC can be used to design the map of intelligent houses that can provide comfort to the end-users. Smart homes provide various facilities to the users so that they can be capable to manage their daily scheduled and plans. Usually, smart houses are equipped with advanced software, sensors, smart monitoring systems, smart alarming systems, etc. [36]. All IoT-enabled devices are interconnected with each other through a gateway to provide the necessary information to the end-user on time. IoTGC emerges with a revolution that the devices and humans must be connected in every space and time to make life easier. Significant innovations in the field of IoTGC transform human life and force manufactures to developed eco-friendly devices. These eco-friendly devices can be helpful to create a clean and healthy climate around the human being. The reduction of energy consumption through IoT-enabled devices can manage the utilization of the limited resource of the world such as water, oil, and other sources of energy.

4.1.5 Intelligent Protection/Security

Due to significant improvements in the World Wide Web the human being and hardware devices are now linked together at every place and time. The smart security system based on IoT can provide a way to disseminate sensitive information among various private and government agencies. The use of IoT-based gateways can prevent the leakage of sensitive information over the network. Various password protection mechanisms, encryption, and decryption techniques, and efficient routing algorithms can be used to secure the information. The smart protection system avoids unnecessary threats that can theft information related to the public and government sectors of the nation [37]. Furthermore, various factors such as integrity, confidentiality, and reliability of the information should be maintained over perception and its sub-layers. The smart access control mechanism should be implemented over the IoT network so that unauthorized access can be restricted. The efficient fault tolerance technique should be adopted to manage the various operations and communication among the devices.

4.2 IoTGC Applications Based on Software

In Fig. 7 various applications based on the IoTGC are presented. Various applications of IoTGC based on software are explained in the subsequent sections.

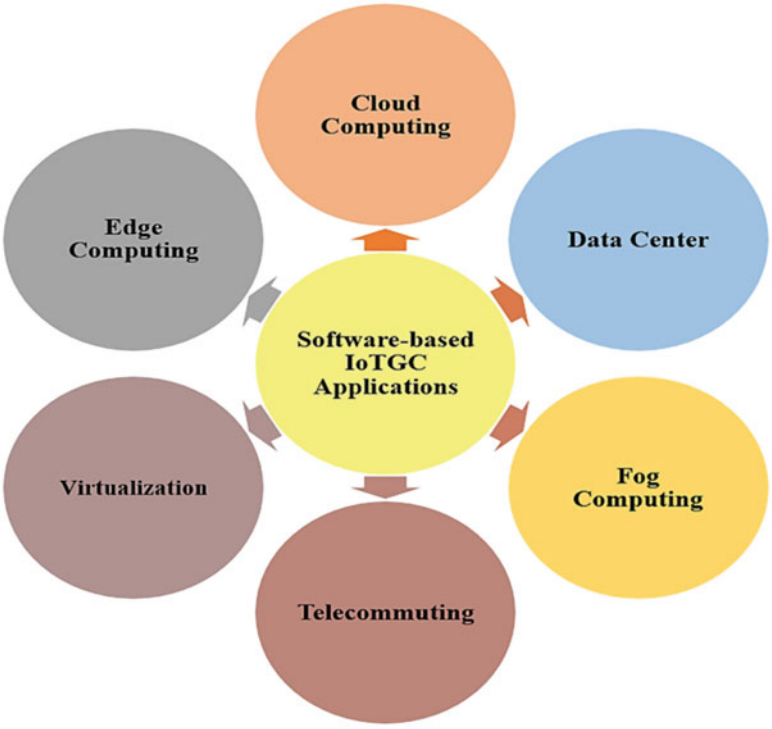

Fig. 7 IoTGC Applications based on software

4.2.1 Cloud Computing

Cloud computing provides services to the user to access servers, databases, and various other application services over the Internet. The five main characteristics of cloud computing are (1) measured services, (2) quick provision of the resources, (3) resource pooling, (4) broad network access, (5) on demand self-service. In distributed and parallel networks various applications and hardware can be utilized as essential services.

Nowadays industries and users are trying to shift their attention toward managing various business activities through virtualization. Through this cloud computing method, a virtual version of storage, hardware, and software can be created. Virtualization of various resources can save the time of many organizations. In a cloud computing environment, various virtualized systems are intertwined together [17, 18].

Virtualization of various resources in cloud computing reduces the emission of carbon in the environment and also minimizes the consumption of energy to a great extent. Online shopping system over commercial websites is a good example of virtualization. The user can purchase various products and demand for the services without being present physically at the supermarket. Through online shopping traffic

on the roads can be reduced that results saving of unnecessary consumption of vehicle oil and emission of gas from the vehicles.

4.2.2 Edge Computing

Nowadays the applications of Internet of Things (IoT) are rapidly growing. The conventional cloud computing-based technologies encounter several challenges like high latency, low spectral efficiency, etc. These challenges motivate researchers to develop new technology. Through these technologies various functions of conventional cloud computing can be shifted to the edge devices of the network. Various technologies that are based on edge computing can resolve various challenges that are being faced in cloud computing. In edge computing, edge devices are the smart devices that are mainly used for processing and computation. It provides server resources, data analysis, artificial intelligence to data collection sources, and cyber-physical sources. These cyber-physical resources can be smart sensors and actuators [38, 39]. The developers can create various applications by managing and harnessing the energy that is available in remote locations such as hotels, warehouses, retail stores, etc. The applications based on edge computing can minimize latency, improve privacy, minimize the demand of the network bandwidth, and provide better services even when the network is disrupted. Edge computing brings data processing to the edge of the network, where speed and reliability are critical to a successful customer experience. The key components of edge computing are discussed below and presented in Fig. 8.

Cloud: The clouds are the server over the Internet. These servers contain various applications and databases that are being accessed by users and companies. The concept of cloud facilitates the users to manage their data without managing their physical servers. Without using their systems, users can directly execute their applications on the clouds.

Edges: An edge is a network edge where the devices are used to communicate with the Internet. At the network edge, various edge nodes such as servers, gateways, and other edge devices are used to perform various computations. These edge devices are used to perform various tasks related to the assembly machines in a factory, an intelligent camera inside the house, and automobile companies. Generally, edge devices like edge servers can have multiple cores of computing capacity and 12–16 GB of memory. These servers are used to execute software of industries to exchange services to the clients. Similarly, an edge gateway performs various functions over the network like network termination, firewall protection, etc. The edges in edge computing are generally considered in between the path of data sources and cloud data centers.

Sensors, controllers, and actuators: Sensors in the Internet of Things (IoT) play a major role to collect various information such as information about temperature, moisture, etc. The important data that is being collected by the sensors is first tuned according to the need of the customer or user and transmitted over the network. The tuned data can be used by the user to perform their useful tasks. For an effective

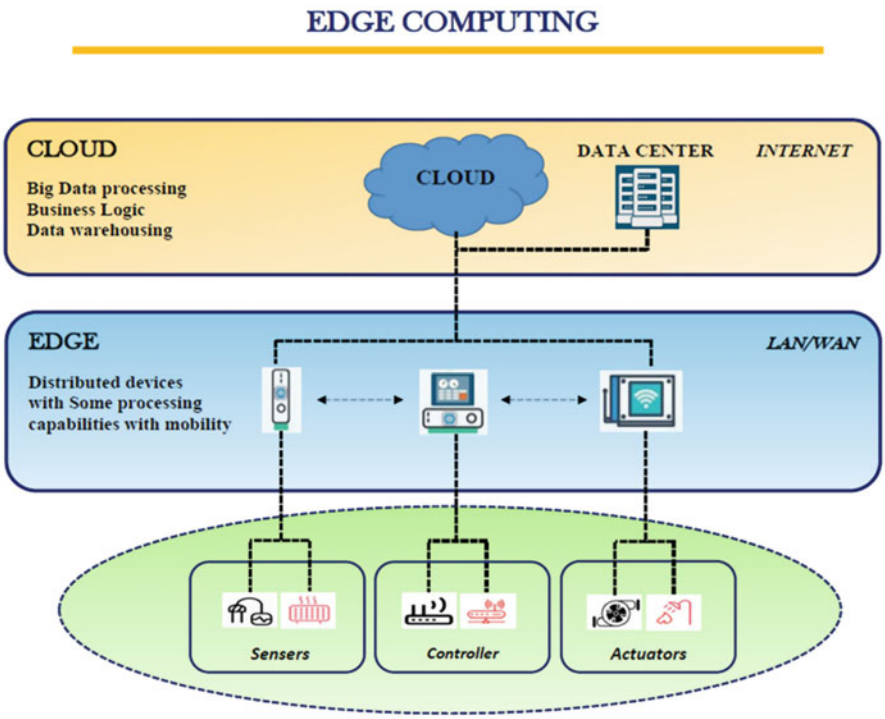

Fig. 8 Key components of edge computing

decision-making process, the controllers figure out how data can be utilized that is being collected by the sensors. The actuator works in opposite direction of a sensor. It receives input in the form of electrical signals and performs the physical action accordingly. An electric motor and hydraulic system can be good examples of actuators.

4.2.3 Fog Computing

The concept of Fog computing improves performance and significantly reduces the amount of information, its processing, and storage requirements. It is a decentralized computing infrastructure in which data, its storage, applications are usually located in between the source of data and clouds. Fog computing integrates various sensors that are utilized at the edge of the network and provides the services to the cloud's core computing structure [40]. Through fog computing quality of service, security in real-time systems and stability of the real-time system can be achieved in a better way as compared to Cloud Computing. In fog computing, useful data can be processed on a data hub, routers, and gateway devices [41, 42].

The concept of fog computing supports the IoTGC when the different sensors produce an excess amount of information and find itself incompetent in its transmission through the cloud. The transmission of the data among various sensors on the cloud requires a high bandwidth of the communication channel. In future the fog computing can replace the concept of Cloud Computing due to its efficient processing of data, better services, smart transportation, and agriculture system, etc.

4.2.4 Telecommuting

Various teleconferencing software is widely used in the field of IoT Green Computing (IoTGC). The development of these applications significantly improves productivity and reduces the inefficient utilization of time. To organize and attend the conference people usually travel by flights that result in the emission of gas in the air. The cost of space, the requirement of light, and other useful resources can be avoided after the utilization of teleconferencing software [23]. It has been reported that using these software 70% of the total energy that was utilized in a US office building has been saved. The main cause of energy consumption was the heavy utilization of air conditioners, heaters in winters, and other lighting resources [43]. Telecommuting software can be used in other work lines such as telecommuting-integrated hoteling, consulting, and distribution of various services to the end-user.

4.2.5 Based on Data Center

Data centers are generally responsible for the consumption of energy. The data centers need to be optimized to save the wastage of energy. Various efficient power scheduling algorithms can be used to minimize unnecessary power consumption by passive sensors. The algorithms supply power only to the active sensors to minimize the requirement of the energy over the network [29]. To manage the data centers efficiently following challenges can be faced.

- Estimation and optimal allocation of the workload judiciously to the various servers.
- Recognition of future ideal servers, and workload reallocation.
- Use of renewable generators.
- An effective utilization of available energy and resources.

4.2.6 Virtualization Based

The IoTGC technology based on virtualization significantly reduces the demand for hardware resources to perform various operations. The usage of Mixed Integer Linear Programming (MILP) in the virtualization process of four-layer architecture

results in energy preservation up to 35% [8]. The advantages of virtualization-based IoTGC are given below.

- Management of data centers in an efficient way.
- Risk management in various business operations.
- Processing of requests and services in a faster way.
- Improving performance, profitability, responsiveness, and agility.
- Reduction in operational cost and smooth IT operations.
- Redistribution of workload and automation of various operations.

4.3 Hardware-based IoTGC Applications

In the IoTGC system, efficient hardware design plays a crucial role to make the system eco-friendly and efficient in terms of power consumption. Few of the IoTGC hardware modules have been presented in Fig. 9 and discussed in the subsequent sections.

4.3.1 RFID Based

The detection of the radio frequency (RFID) remains crucial in IoT green computing. These are the wireless microchips that identify dissimilar substances automatically. These chips are used to collect data in a cost-effective manner related to various business activities of an organization that are expended in various continents. In the IoTGC network, various functions of the network objects can be easily identified and managed to obtain real-time data. The real-time data stored in the database can be further used in various research and business-related activities [44]. The utilization

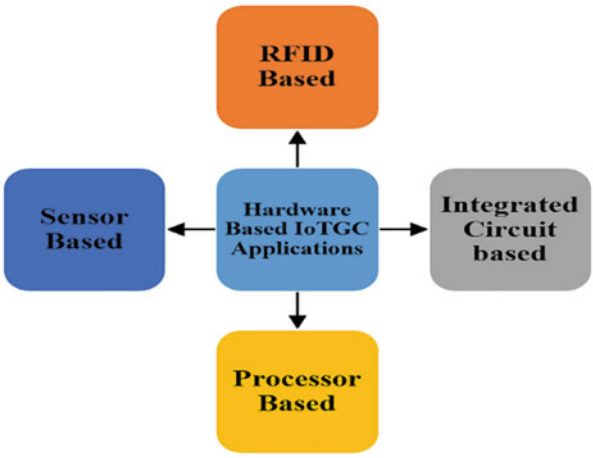

Fig. 9 Hardware-based IoTGC Applications

of RFID in the field of IoT green computing can provide significant improvements in various areas such as industry, health care, online payment system, military projects, and operations, etc. [45]. Anuj et al. suggested elliptic curve signcryption based security protocol for RFID and mutual authentication protocol for smart card [46, 47]. The challenges related to the use of RFID technology in various applications of IoTGC are given below.

- *Collision issues:* Electromagnetic interference among multiple broadcasts can cause problems. Various efficient protocols such as the binary tree, question tree, etc. can be used to resolve the problem of collision. The efficiency of these protocols is however below 50%, hence advanced techniques and protocols are needed to be designed.
- *Privacy and security concerns:* The use of RFID also plays a major role to resolve the traffic analysis problem. In an efficient security mechanism of RFID tags results in DoS attacks, eavesdropping of targets, and can create problems in traffic analysis. Researchers are trying to implement more secure algorithms and protocols that can efficiently manage the RFID system. Efficient protocols can preserve the applicability of RFID systems in the field of IoTGC.

4.3.2 Based on Integrated Circuit

The improper design of integrated circuits that are used in the IoTGC network can create various issues related to power consumption. Integration of multiple sensors in a single chip can significantly minimize the carbon footprint and consumption of energy. Balanced IC technologies based on logic platforms such as IPs, Fin Field-Effect Transistor (FinFET), Complementary Metal Oxide Semiconductor (CMOS), and Silicon on Insulator (SOI) with specific qualities such as Micro-Electro-Mechanical Systems (MEMS), Power Management, CMOS Image Sensor (CIS), Non-Volatile Memory (NVM), and Radio Frequency (RF) are some of the future requirements in the field of IoTGC.

4.3.3 Based on Processor

The CoreLH is a competent processor that is specially designed for various applications of IoTGC. The Core L and Core H of this processor are basically designed for various computation tasks that require less and high energy, respectively [18]. To minimize the utilization of the resources efficient scheduling methods are used. These scheduling methods allocate various tasks to each core of the processor. The manufactures of mobile phones face difficulty to add advanced features to smartphones due to the use of deep learning (DL) processor [48]. For example, in iPhone X a more precise face locking system can be implemented by integrating a neural engine with an A11 Bionic chip. Similarly, the advancement in neuromorphic processors can approximate the mechanism of human neurons [49]. The processor

widely uses Spiking Neural Network (SNN) to make the system efficient in both the spatial and temporal domain. These processors consume less energy as compare to the deep learning (DL) processors and also resolve the problems associated with the online machine learning.

4.3.4 Based on Sensor

In IoTGC applications the use of sensors plays a vital role to detect the status of patient health and manage the security of smart homes. Sensors are also used as an integral part of various units of the industries. Proper utilization of sensors in various manufacturing units, sales units, and other sub-divisions significantly controls the production process and other important activities [11]. In the production department of the industries, these sensors are used to measure the pressure, temperature, and humidity. Different sensors like pressure sensors, motion sensors, thermometers, etc. are used to produce the electrical signals. These signals are further consumed by the computer for various important activities. Various classes [5, 20, 22, 45] of these sensors are given below.

- *Active or passive:* To boost up the work over the network, active sensors are widely used. These sensors require an external power source to carry out various important activities. The example of active sensors can be GPS and radar. Whereas the passive sensors do not require any additional external power sources, hence, they generate their own electrical signals. Examples of these types of sensors are electric field sensors, thermal sensors, and metal detecting sensors.
- *Based on property:* Different types of sensors can be categorized based on their usefulness and properties. Sensors are selected based on the immediate requirements in the field of automated systems, biomechanical systems, and other related areas.
- *Digital or Analog:* The sensors that can be used to generate and transfer analog and digital information. These sensors are used to transmit the information to other devices on the network.

To get the benefits of IoTGC applications, various types of sensors are integrated. These sensors are integrated based on their sensitivity, applicability, and reliability. By adopting the sensor-on-chips the power consumption of the sensors can be minimized. Utilization of these chips can reduce the traffic overhead and energy consumption that is required in communication. Similarly, other powerful sensors can be based on the requirements over the IoT network. Development of energy-efficient, cost-effective, and echo-friendly sensors is still a challenging task in the field of IoTGC.

4.4 Applications of IoT Green Computing Based on Awareness

IoT green computing has wide applications in various areas such as smart transportation systems, smart homes, etc. Still people do not aware of where IoT can function effectively. Due to unawareness among the users, they are not getting the benefits of IoT in their routine work. The precise feedback of various IoT-based applications is essential from the user to improve the existing IoT-based technologies [18].

The government must take the initiatives to begin a few awareness programs so that audiences, manufacturers, and service providers can include wide applications of IoTGC in their workplace. The effectiveness of these awareness programs depends upon the country, its cultures, and type of audience. The usefulness of the smart metering system must be communicated among the audience, house owners, and industries so that power can be utilized efficiently. Various users of IoTGC must be aware of the usefulness of energy control mechanism so that more efficient technologies can be developed by the industries. Various prominent areas of IoTGC are needed to be focused on the awareness programs which are shown in Fig. 10.

4.4.1 Usefulness of Ambient Notification

Fixed proliferous displays are widely used to aware the end-users about the effective use of green IoT or IoTGC. According to the market survey, it has been proven that the use of these devices for awareness is more effective than the smartwatch and smartphone. To fit the images of various awareness programs in these small screen display devices various image retargeting techniques are being developed [50–52]. Various devices are placed at different locations in the societies for the advertisement of IoTGC and to promote its various useful applications.

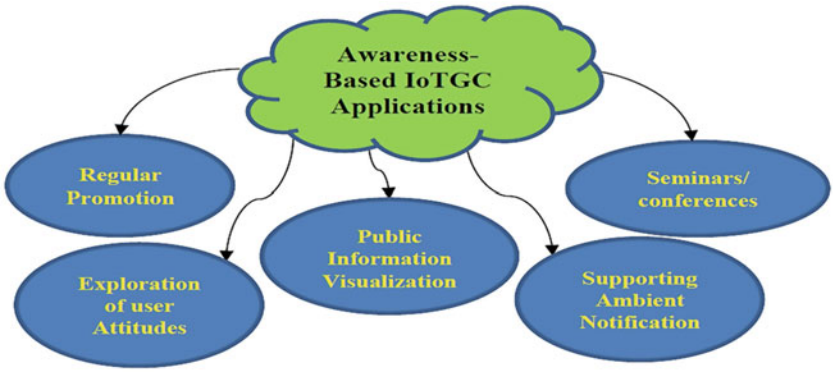

Fig. 10 Various IoTGC applications based on awareness

4.4.2 Proper Visualization of Information in Public Sectors

After adopting the techniques of information visualization the facts can be represented in a meaningful way. Representation of the facts in such a manner can increase the understanding of end-users about the IoTGC. The most common examples of information visualization can be dashboards and scatter plots. Information visualization provides useful information to the experts so that their skills can be utilized for a specific purpose. The concept of ambient visualizations can be adopted to influence various users who are interested to use IoT-enabled devices in their daily life. Various methods can be adopted to aware the public through information visualization. Representation of useful information through the decorated objects, visualization of information through air balloons, and mounting of ambient displays at various locations can significantly increase the awareness of IoTGC among the end-users [44, 45].

4.5 IoTGC Applications Based on Recycling

To attain successful environmental-friendly IoT green computing the raw materials used in the manufacturing of various products must be recycled. For example, non-biodegradable materials such as plastic, copper, or another similar kind of materials highly influence the greenhouse effect. These materials must be avoided in the development of cell phones and other electronic gadgets [18]. Similarly, instead of utilizing other power generating resources, solar energy in industries and homes can also minimize various environmental issues and challenges. Figure 11 shows various recycling-based IoTGC applications to minimize carbon footprints for better IoT green computing.

For energy-efficient IoTGC applications, the size of the network can be minimized by implementing efficient routing algorithms. Elimination of redundant data over the network can also save the energy that is required to access the nodes. The

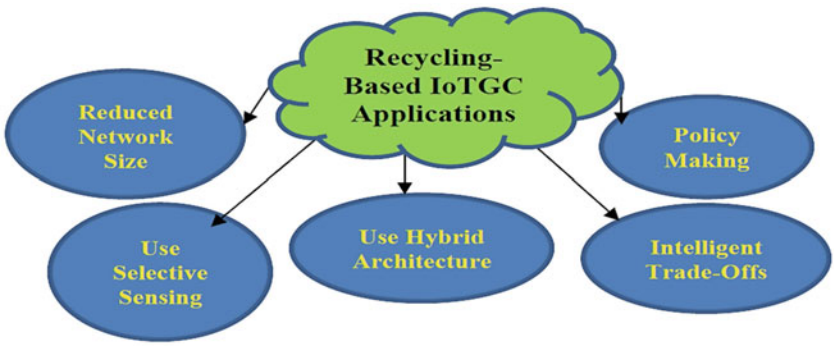

Fig. 11 Various steps used in recycle-based IoTGC

hybrid network architecture with various active and passive sensors should be used to reduce power consumption and to accomplish various IoTGC tasks. In this regard, concrete decisions, better planning, and policies can also reduce the power consumption in the manufacturing of various electronic products and construction of smart buildings [9]. Finally, various essential factors such as the cost, utilization of power, and other resources allow the smooth functioning of IoT green computing.

5 A Case Study on the Influence of Smartphones on the Environment

To implement the concept of green computing the products that are environmentally friendly must be manufactured. Green computing plays a major role to investigate the various influence of smart IoT-based devices such as mobile devices, computers, and other smart digital gadgets in the environment. With the exponential usage of these digital devices in the public domain, the problem of pollution in the environment can be faced. The heavy usage of smartphones can be the cause of the emission of CO_2 in the environment that can influence the present and future of mankind. This section presents a case study on smartphones. The main reason behind the selection of this highly used IoT component is its wide usage in the public domain. Through this case study, the impact of the smartphone on the environment and its recycling are discussed.

5.1 Minimization of the Drastic Change in the Environment

To maintain a sustainable environment manufactures are trying to incorporate various latest trends in the development of smartphones. To achieve green computing the smartphone must be assembled through energy-efficient hardware components. The government must take some major initiatives to investigate and develop new guidelines related to the hardware and software design of smartphones. The energy-efficient design of smartphones and the use of lightweight algorithms can minimize the energy consumption of smartphones. To minimize the release of CO_2 and its impact on the environment power saving batteries must be manufactured. In the available literature it has been suggested for a sustainable environment we need to select green materials. The cost incurred in the packaging and assembling of the smartphones can be minimized through the proper guidelines of the companies to their manufacturing units.

5.1.1 Hazardous Materials of Smartphone

Nowadays smartphones may contain various types of toxic materials. These materials can be nickel, mercury, lithium, etc. that are harmful to the environment. This section explains how these toxic materials are harmful to mankind. From the study, it has been revealed that the old smartphones must be recycled and should not be thrown in the garbage. The presence of Nickel in the batteries of mobile phones causes cancer. Similarly, in the batteries of older mobile phones, the presence of mercury found another type of dangerous substances. The presence of Magnesium may be responsible for the neurochemical changes. Manganese is widely used in the production of circuit boards of smartphones. The inconstancy property of lithium may cause various environmental problems. Most of the products may contain Zinc and Cadmium. The use of Cadmium at a high level may cause kidney failure. Arsenic that is a well-known poison is heavily used in the production of LEDs. Antimony compound that is poisonous and similar to arsenic can be widely used as a flame retardant. Beryllium material can be used in cooling may cause a prolonged allergic disease in the human body. Furthermore, due to the use of Copper, and other precious materials such as Iridium, Silver, and Gold companies are recycling smartphones for the production of new devices. Nowadays various mobile companies like Samsung, Motorola, Vivo, Oppo, etc. are promoting recycling programs through which people can exchange their old smartphones and can get some discount on a new device. From the available literature, it has been found that the PCBs of smartphones and heavy use of plastic material in the phone chargers may be harmful to the environment. The emission of CO_2 due to the burning of plastic material of smartphones may hamper the sustainability of the environment. It has been found that the printed circuit boards of smartphones are manufactured by 12% of polymers, 62% of metals, and 23% of ceramics [53].

5.1.2 Recycling

It is a process to apply new technologies to faulty materials to convert them into useful materials [54]. From the study [55] it has been found that in the market of China recycling of smartphones is very low. Most of the smartphones are sold after refurbishing. This kind of reuse of cellphones does not affect the sustainability of the environment. Most of the smartphone manufacturing companies are developing new guidelines for the refurbishment of the cellphones to develop a strong market. The results obtained from the study suggested that the first cell phone recycling act was developed in the state of California. Various policies under this act are mainly focused on the significance and positive impact of recycling on the environment. It has been noticed that approximately 17% of smartphones are available in the market for recycling and refurbishment that is a very less percentage. Government and other private agencies must initiate some awareness programs that can promote recycling and encourage the customers to understand the urgent need of smartphones waste

management. China is promoting green card recycling activity and the green box environmental program [56]. Various activities in green IT can manage E-waste that can provide better solutions for the development of a sustainable environment.

5.1.3 Selection of Right Design of Repair and Disassembly

Most of the components of the smartphones are completely molded into the plastic case. These types of molding prevent the replacement of original components from the duplicate components available in the market. Designing and manufacturing of such smartphones may hamper the process of recycling. The smartphones can be broken for their refurbishment using electronic components that are inbuilt on their PCB. Such types of smartphones are not cost-effective as the extraction of reusable components is not possible by the customer.

5.1.4 Development of Smartphones using Green Materials

For the manufacturing of smartphones polylactic acid plastic (PLA) can be used. These materials are made up of corn starch or glucose that is renewable and biodegradable. Recycling of plastic materials and other green materials like bamboos can be used for the manufacturing of smartphones.

5.1.5 Energy-Saving Smartphone Batteries

The manufacturing companies must promote the wide use of natural and organic radical battery (ORB) for the production of smartphones. These batteries do not use heavy metals and can be charged within 30–40 seconds. The energy-saving capability of such types of batteries can reduce power consumption over the IoT network.

5.1.6 Reduce Packaging and Accessories Requirements

Mobile phone manufacturing companies must jointly take some initiatives to reduce the packaging cost of smartphones. In the packaging of the smartphones, various plastic materials and other useful substances are used. The manufacturing companies can manufacture common phone charger that can be used for all the brands of the smartphone. HTC, Nokia, and Sony now promote some units with simply USB lead alternatively of needless chargers.

5.2 *Assessment of Smartphones using Life Cycle Assessment (LCA)*

An environmental LCA (life cycle assessment) is a technique to assess the potential environmental aspects associated with the product and other services. This assessment can be applied for the analysis of the life cycle of smartphones. Through the analysis, the process of traditional manufacturing can be improved to minimize the hazardous impact of smartphones on the environment. Every 3 years LCA is used to analyze the impact of materials used in the smartphone on the environment. Figure 12 shows the life cycle of the LCA. Through the analysis of the results obtained from the LCA, it can be predicted that the requirements of power consumption and the exponential growth of the CO_2 emission can be significantly reduced up to 22–59% and 20–72%. LCA can also be used to analyze the results of the recycling process and material selection of the device in the environment.

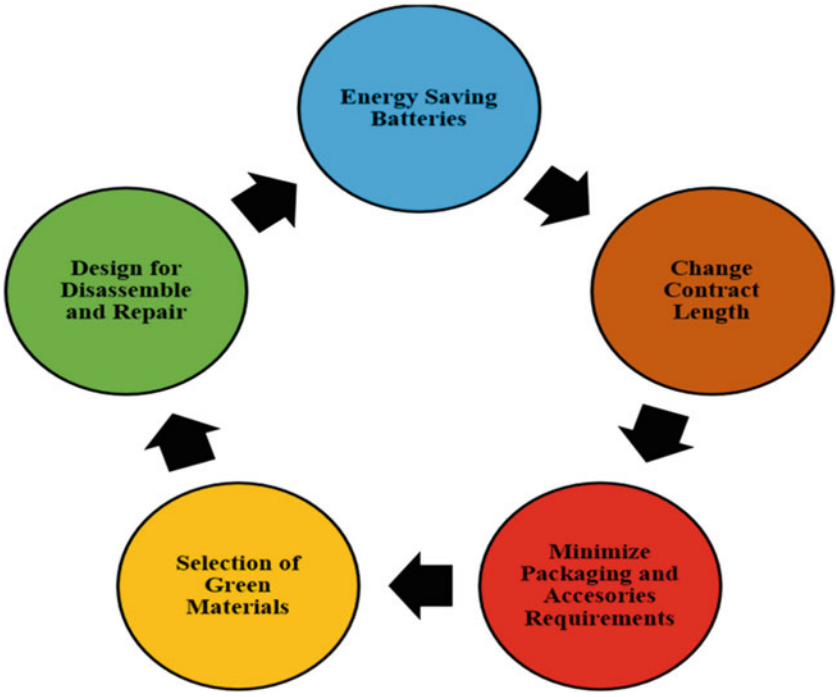

Fig. 12 Life Cycle assessment of Smartphones

5.3 Selling and Emission Rate of the Smartphone

With the exponential growth of the modern IT requirements, the manufacturing companies are expanding the structure of their manufacturing units. Due to this expansion smartphone companies are facing various challenges and issues related to green IT [57]. Figure 13 shows the emission of CO_2 in the environment due to heavy usage of toxic materials in smartphones. Table 2 shows various factors based on which LCA can be carried out that represent the impact of smartphones on the environment. After taking some important factors Table 3 shows the sales of some popular smartphones in the market and their impact on the environment in terms of CO_2 emission. The year-wise selling growth rate of the popular mobile phones is shown in Table 3. From Table 3, it can be observed that the selling growth rate of mobile is increasing that is responsible for the growth of the CO_2 in the environment. To forecast the accurate results the data of selling growth of the smartphones are collected from the year 2014 to 2020.

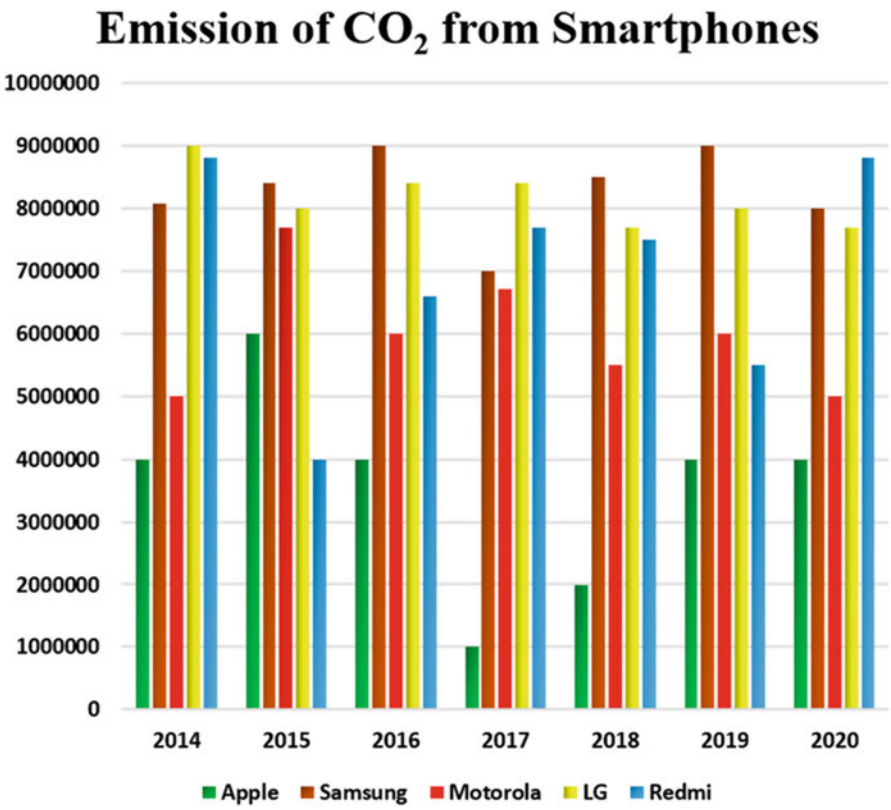

Fig. 13 Emission of CO_2 from Smartphones

Table 2 Computation of CO_2 percentage using LCA

S. No.	Technique	Influenced Medium	Important Factors	% of CO_2 Emission (%)	Ref. No.
1	To measure the performance of the Smartphones Life Cycle Assessment (LCA) is used.	AIR	Influence of smartphone chargers in life cycle	3	
2			Reduction in energy consumption	34	[58]
3			CO_2 emission in a complete life cycle of mobile phones	65–77	[59]
4			Percentage of CO_2 emission in 4 years through Sony XperiaTM smartphone	44	[60]
5			Due to use of Copper substances on the PCB of the smartphones.	33.6	[53]
6			Due to use of heat resistance components in the smartphones	49	[61]
7			Reduction of CO_2 emission before 2020.	19.5	[62]
8			Reduction of CO_2 emission in 2020	38.6	[63]

6 Discussion on Case Study

From the case study, it has been proved that the concept of IoT green computing comprised various techniques through which in a smart world a sustainable environment can be created. The exponential growth of IoT devices has changed the overall economy of the world. Due to exponential growth in the usages of smartphones researchers have been predicted that in 2025 out of 35 billion IoT devices can be connected to the Internet. The study carried out by Cisco Internet Business Group has been predicted that almost 8–9 IoT-enabled devices of a person are being connected to the Internet in 2020. From the literature, it has been predicted that the reduction of power consumption and emission of carbon footprints can be achieved through the development of new technologies. From the report obtained from the IEEE green ICT Initiatives, it has been predicted that ICT industries are responsible for the 4% of total CO_2 emissions. Figure 14 shows the year-wise exponential growth of IoT devices over the IoT network and their impact on the environment in terms of CO_2 emission.

Many manufacturing companies are trying to adopt new technologies to provide concrete solutions and strategies related to the problems. Through the case study, we

Table 3 Selling growth rate of smartphones

Smart Phone	2014 Units	2015 Units	2016 Units	2017 Units	2018 Units	2019 Units	2020 Units
Apple	1,914,258	2,258,506	2,602,756	2,947,002	329,125	3,635,498	3,979,746
Samsung	3,075,969	3,202,197	6,096,797	8,991,397	11,885,997	14,780,597	17,675,197
Motorola	185,660	204,460	223,314	242,168	261,022	279,876	298,730
LG	165,660	194,460	203,300	352,168	301,022	259,806	328,750
Redmi	175,656	177,560	182,375	212,100	12,900,240	16,822,600	11,565,730

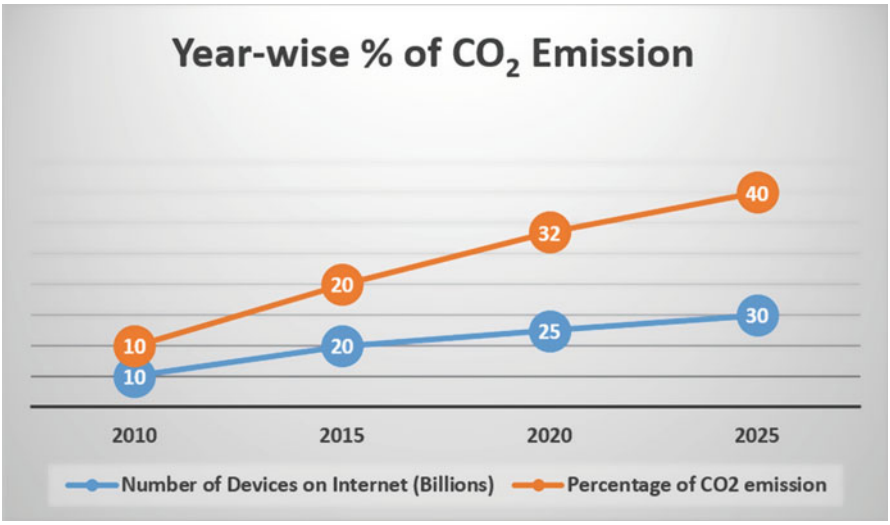

Fig. 14 Year-wise exponential growth of IoT devices and their impact on environment

provided a few observations and suggestions to the readers and researchers to find out new solutions for the growth of a sustainable environment.

Finally, through the above case study that has been carried out in Sect. 5 the following major points must keep in the mind in the production of smartphones.

- New strategies and solutions are required to find out for the development of the common hardware and software architectures in the production of smartphones.
- New recyclable materials are needed to be explored for the manufacturing of smartphones.
- Few policies and awareness programs must be initiated in the public sector through which IoT solutions can be deployed efficiently.

From the case study, we have investigated various possible solutions that can be deployed into real life to achieve environment friendly and energy efficiency green IoT. The study carried out in the case study reveals various alarming situations that are needed to take care of. The ignorance towards possible challenges can hamper the growth of a sustainable environment.

7 Conclusion

Nowadays industries are adopting the environment in which the demand of IoT devices is increasing exponentially. The purpose of implementing green IoT is to minimize the challenges and issues that can hamper the environment sustainability. For the establishment of a greener and smart world, IoT devices should be easily

acceptable, eco-friendly, easily disposable, energy-efficient, and economically viable. All the IoT-enabled devices needed ample amounts of energy for their operations and put the load on the electrical grid and greenhouse gases. Change in the pattern of climate and accumulation of greenhouse gases may be responsible for drought and flood in some areas. To overcome this situation we need to focus on the growth of global emission of greenhouse gases and their preservation. The exponential growth in the temperature of the earth may be responsible for the severe environmental glitches. Based on real-time data the crucial planning and decisions can be taken at different levels for the development of IoT green computing devices. The effective decision-making process can supply various inputs to give an impact on the environment. Proper promotion of policies and awareness of the green world among the human being can play a crucial role in the development of green campuses or residence. These smart campuses must be equipped an automated monitoring and control mechanism to manage the several facilities economically. In conventional health care and agriculture systems, IoT green computing can play a major role. IoT green computing-based health care systems have some applications such as smart health monitoring systems, handling the massive amount of data using data mining and artificial intelligence techniques. Similarly, a smart agriculture system enables farmers to increase crop yields, and also aware farmers about the efficient technology of irrigation. Through IoTGC based smart vehicle systems, time and cost can be significantly saved. In these automated systems various IoT-based sensors are used to detect the possibility of an accident in advance and also provide e-notification about traffic and weather conditions via remote servers. The IoTGC can be used to design the map of intelligent houses that can provide comfort to the end-users. Smart homes provide various facilities to the users so that they can be capable to manage their daily scheduled and plans. Due to significant improvements in the World Wide Web the human being and hardware devices are now linked together at every place and time. The smart security system based on IoT can provide a way to disseminate sensitive information among various private and government agencies. In the IoTGC system, efficient software and hardware design play a crucial role to make the system eco-friendly and efficient in terms of power consumption. The government must take the initiative to begin a few awareness programs so that audiences, manufacturers, and service providers can include wide applications of IoTGC in their workplace. The effectiveness of these awareness programs depends upon the country, its cultures, and type of audience. To attain successful environmental-friendly IoT green computing the raw materials used in the manufacturing of various products must be recycled. For example, non-biodegradable materials such as plastic, copper, or other similar kinds of materials highly influence the greenhouse effect. Researchers are continuously providing their contribution to various applications of IoTGC based on some important factors that are essential for the establishment of the smart world. Efficient technologies, protocols, and algorithms can play a significant role in the field of smart health care monitoring systems, smart vehicle monitoring systems, smart manufacturing systems, etc. The human being can make their life luxurious by adopting various sensors, actuators, and other useful IoT-enabled devices. Based

on various highlighted issues and challenges related to different categories such as policy, hardware, software, awareness, and recycling the potential researchers can contribute their significant endeavors to improve various aspects of IoT and green computing (GC). To justify the study of this chapter a case study has been carried out on the development of smartphones. The case study suggests major points that must be kept in the mind during the development of smartphones. From the case study, we have investigated various possible solutions to achieve environment friendly and energy efficiency green IoT. The case study reveals various factors that are needed to take care of. The ignorance of these suggested challenges can hamper the growth of a sustainable environment.

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