Energy Reports 11 (2024) 5504–5531

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Review Article

A comprehensive review of advancements in green IoT for smart grids: Paving the path to sustainability

P. Pandiyan [a], S. Saravanan [b], R. Kannadasan [c,*], S. Krishnaveni [d], Mohammed H. Alsharif [e], Mun-Kyeom Kim [f,*]

[a] Department of EEE, KPR Institute of Engineering and Technology, Coimbatore, Tamilnadu, India
[b] Department of Electrical and Electronics Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India
[c] Department of Electrical and Electronics Engineering, Sri Venkateswara College of Engineering, Sriperumbudur 602117, India
[d] Department of Electrical and Electronics Engineering, Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam 603110, India
[e] Department of Electrical Engineering, College of Electronics and Information Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 05006, the Republic of Korea
[f] School of Energy System Engineering, Chung-Ang University, 84 Heukseok-ro, Dongjak-gu, Seoul 06974, the Republic of Korea

ARTICLE INFO

Keywords:
Smart Grid
Internet of Things
Fog Computing
Energy Management System
Edge Computing
Artificial Intelligent

ABSTRACT

Electricity consumption is increasing rapidly, and the limited availability of natural resources necessitates efficient energy usage. Predicting and managing electricity costs is challenging, leading to delays in pricing. Smart appliances and Internet of Things (IoT) networks offer a solution by enabling monitoring and control from the broadcaster side. Green IoT, also known as the Green Internet of Things, emerges as a sustainable approach for efficient communication, data management, and device utilization. It leverages technologies such as Wireless Sensor Networks (WSN), Cloud Computing (CC), Machine-to-Machine (M2M) Communication, Data Centres (DC), and advanced metering infrastructure to reduce energy consumption and promote environmentally friendly practices in design, manufacturing, and usage. Green IoT optimizes data processing through enhanced signal bandwidth, enabling faster and more efficient communication. This comprehensive review explores advancements in Green IoT for smart grids, paving the path to sustainability. It covers energy-efficient communication protocols, intelligent energy management, renewable energy integration, demand response, predictive analytics, and real-time monitoring. The importance of edge computing and fog computing in allowing distributed intelligence is emphasized. The review addresses challenges, and opportunities and presents successful case studies. Finally, the review concludes by outlining future research avenues and providing policy recommendations to foster the advancement of Green IoT.

1. Introduction

In the earlier fifties, the use of non-renewable energy is more frequent. As the days pass, the conventional energy resources that are frequently used in daily routine life get depleted. Within a few years, there is the possibility of complete extinction of energy resources like coal, nuclear energy, natural gas, and oil which are said to be non-renewable resources. In search for alternate sources of energy for utilization purposes, paved the way for energy sources called renewable energy sources which employ solar as the main source of energy for the generation purpose. The other sources of renewable energy sources (Green energy) are hydro energy, bio-mass energy, wind energy, and geo-thermal energy (Alsharif et al., 2024a) which are transformed into electrical energy as follows:

- Hydro energy- Generating electricity from the flow of water which runs through the turbine to produce energy accordingly.
- Wind energy- Blowing of air that strikes the blades of the windmill, thus converting the mechanical energy into electrical energy.
- Solar energy- Energy generation by converting photons of light energy into electrical energy through photovoltaic cells.
- Biomass energy- Energy is harvested by heating the biomass materials such as energy crops, crop residues, algae, and municipal waste.

* Corresponding authors.
E-mail addresses: kannadasanr@svce.ac.in (R. Kannadasan), mkim@cau.ac.kr (M.-K. Kim).

https://doi.org/10.1016/j.egyr.2024.05.021
Received 20 January 2024; Received in revised form 30 April 2024; Accepted 11 May 2024
Available online 22 May 2024

Nomenclature

ACO	Ant Colony Optimization
ACTLBO	Adaptive and Comprehensive Teaching-Learning-Based Optimization
AMC	Adaptive Modulation and Coding
AMI	Advanced Metering Infrastructure
AMM	Advanced Metering Management
ANN	Artificial Neural Network
BDA	Big Data Analytics
BFO	Bacterial Foraging Optimization
BPSO	Binary Particle Swarm Optimization
BSS	Battery Storage Systems
CC	Cloud Computing
CHP	Controlled Heat and Production
COA	Coati Optimization Algorithm
CSP	Cloud Service Provider
DC	Data Centres
DFR	Digital Frequency Records
DL	Deep Learning
DAE	Distributed Analytical Engine
DMS	Distribution Management System
DRL	Deep Reinforcement Learning
DRP	Demand Response programs
DSM	Demand-side Management
DER	Distributed Energy Resource
EADP	Edge-node-aware Adaptive Data Processing
EC	Edge Computing
EEM	Elastic Energy Management
EMM	Energy Management Module
EPG	External Power Grid
EV	Electric Vehicle
EVB	Electric Vehicle Batteries
FAN	Field Area Network
FCRBM	Factored Conditional Restricted Boltzmann Machine
GA	Genetic Algorithm
GCC	Green Cloud Computing
GDC	Green Data Center
GEQCC-FLP	Green Energy-Aware Cluster Communication and Future Load Prediction
G-IoT	GreenIoT
GOA	Grasshopper Optimization Algorithm
GPS	Global Positioning System
GWSN	Green Wireless Sensor Networks
HAN	Home Area Network
HEMS	Home Energy Management Systems
HESS	Hybrid Energy Storage System
HGACO	Hybrid Genetic Ant Colony Optimization
ICT	Information and Communications Technology
IoT	Internet of Things
IRS	Intelligent Reflecting Surface
LAN	Local Area Network
LSTM	Long Short-Term Memory
LPWANs	Low-Power Wide-Area Networks
M2M	Machine-to-Machine
MDMS	Edge Metre Data Management System
MEC	Mobile Edge Computing
ML	Machine Learning
MLP-ELM	Multi-layer perceptron-Extreme Learning Machine
OPLC	Optical Power Line Communications
OLFS	Optimum Load Forecasting Strategy
PAR	Peak-to-Average Ratio
PGS	Power Grid Systems
PLC	Power Line Communications
PMU	Phasor Measurements Units
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PSO	Particle Swarm Optimization
PV	Photovoltaic
PRO	Promoted Remora Optimization
QoS	quality of service
ReLU	Rectified Linear Unit
RES	Renewable Energy Sources
RFID	Radio Frequency Identification
RL	Reinforcement Learning
ROC	Receiver Operating Characteristic
SBC	Single Board Computer
SCADA	Supervisory Control and Data Acquisition
SDN	Software-Defined Networking
SE	Solar Energy
SEMA	Smart Energy Management Algorithm
SG	Smart Grid
STLF	Short-Term Load Forecasting
TCP/IP	Transmission Control Protocol/ Internet Protocol
TLBO	Teaching Learning-Based Optimization
TSCH	Time-Slotted Channel Hopping
UAV	Unmanned Aerial Vehicles
WAMS	Wide Area Management System
WAN	Wide Area Network
WBFA	Wind-Driven Bacterial Foraging Algorithm
WDO	Wind-Driven Optimization
WE	Wind Energy
WSN	Wireless Sensor Networks

- Geothermal energy- The hot ground water from the inside core of the earth is concentrated into steam and passed over to the turbine for electricity production.

Renewable energy sources are more environment friendly in nature but the problems arise with their cost of implementation and production and the availability of resources as these resources are not always available at any period of time. Due to the less availability with respect to weather conditions the determination of exact generation of energy is unpredictable (Alsharif et al., 2021). Considering the above challenge, the smart grid plays a crucial role in determining the exact numbers with the help of communication technology in determining the generation that will be connected with the grid-tied system, as these grids are located close to the generation plant.

Once electrical energies are generated from a variety of renewable energy-based power plants, taking into consideration suitable site factors, these power plants become part of a grid-tied interaction system. In this context, the role of a smart grid is to optimize the productive efficiency of these plants through monitoring facilitated by an advanced metering infrastructure with end-to-end communication. Intelligent elements are added to the power system by switching from a conventional power grid to a smart grid (Li Na et al., 2010). The IoT technology concept is interfaced with the smart grid to enable seamless integration. This enables the gathering, processing, visualization, and analysis of data pertinent to power system operations.

IoT is known for connecting the equipment/sensors over to the internet. The equipment is connected through the sensor network as it collects the various parameterized values and processes them over to further actions. To establish the sequential communication between the devices, the system is embedded with the various fields. They are,

- Visualization field- The field consists of sensor networks, data readers, etc. And they are responsible for the data feeding.
- Network field- Telecommunication network comes under this field like mobile communication networks, optical networks, WIFI, etc. This section is responsible for transmitting data (Akyildiz et al., 2002).
- Application field- The Core area of IoT is to analyze and process the data for the appropriate action to take place and make the devices run as per the reception of data.

As the communication between the devices concerned it takes place through the WSN to convey the information faster with minimal consumption of power, as the communication happens through the nodes that are interlinked across the networks. In-order to make the actuation of the above system in a steady state, the communication network should be as much secure and reliable (Alsharif et al., 2022). Usually, the communication network of the power system which includes generation, transmission, and distribution is categorized into 3 sections. There are WAN, FAN, and HAN.

The communication occurs between the operator, service provider, and users. HAN wraps up the smart home appliances and various applications of Home Energy Management Systems. FAN links the user end devices with the grid. The data are collected from the smart meter and passed over to the supervisory control management. The collected information is under the maintenance of the power system operators to regulate the operating criteria for WAN which regulate the demand response and Distribution Management System DMS. WAN includes the connection of the grid to the substation transmission unit and the generation unit (Al-Rubaye and Cosmas, 2018).

As the population and technological aspects are concerned, there have the drastic changes over the years with the phenomenal reach of height. With the cause of the aforementioned statement, energy demand also increases day by day both domestically and commercially (Etxegarai et al., 2018; Alsharif et al., 2014; Wang et al., 2017). There is no complete halt situation when it comes to the point of energy consumption scenario. As the demand increases, there is a necessity for increasing the production with the available resources, but generation alone is not the complete solution to meet the problem, besides that energy conservation is one of the possible solutions to optimize the demand. When conservation concerns one can contribute by switching off the loads when not in use but more precisely to notice the behavior of the loads upon certain peak situations.

Through the vision of IoT the multidisciplinary features of the smart grid are speculated in the above points. The reason to transform the power grid into an intellectual power grid is to ensure the equilibrium between the energy generation and the power consumption (NIST, 2014). In IoT evolution, smart grid infrastructure is the longest connectivity from the point of generation unit to the consumer end unit which includes house hold, industries, e-vehicles, public consumption, smart appliances i.e., the entire unit of power system.

IoT integrated with a smart grid enables the connection of over 50 billion smart objects with standard communication networks over to TCP/IP-based solutions for easy end-to-end communication (Evans, 2011). Due to the complexity of integration, this may lead to malicious activity such as cyberbullying in an unauthorized way that results in bringing damage to the electrical equipment influences financial losses, increasing the demand response situation by making unusual interactions with the data. In summary, this review paper presents an innovative perspective and offers valuable insights, positioning it as an essential reference for researchers, industry experts, and policymakers aiming for a sustainable future fueled by green IoT technology in smart grids. Additionally, it differs from previous works, as outlined in Table 1.

Based on the above literature Table, additional information such as challenges, research gaps, and providing solutions are crucial steps in advancing the field of green IoT systems for smart grids. The following is the concise overview encompassing these aspects:

Challenges: The integration of green IoT technologies into smart grids faces several challenges. Firstly, interoperability and standardization issues persist among diverse communication protocols and IoT devices, hindering seamless integration and data exchange. Additionally, scalability and reliability concerns arise as the scale of IoT deployments increases, leading to potential network congestion and performance degradation. Moreover, ensuring the security and privacy of IoT data presents a significant challenge, with vulnerabilities in devices and communication channels susceptible to cyberattacks and data breaches. Furthermore, the energy consumption of IoT devices and communication networks poses an environmental challenge, as the proliferation of devices contributes to increased energy consumption and carbon emissions.

Research Gaps: Despite the progress in green IoT systems for smart grids, several research gaps remain. Firstly, there is a need for standardized frameworks and methodologies for assessing the environmental impact of IoT deployments within smart grids comprehensively. Additionally, research on optimized energy-efficient algorithms and protocols tailored specifically for green IoT applications is lacking, with existing solutions often not sufficiently addressing the dynamic and heterogeneous nature of smart grid environments. Moreover, there is a paucity of studies examining the socio-economic implications of green IoT adoption, including issues related to equity, access, and affordability, particularly in underserved communities. Furthermore, the lack of real-world deployment studies and empirical evaluations hampers the validation and scalability of proposed green IoT solutions.

Solutions: To address these challenges and research gaps, collaborative efforts from academia, industry, and policymakers are essential. Firstly, the development of interoperability standards and protocols, coupled with robust security mechanisms, can enhance the compatibility and resilience of green IoT deployments within smart grids. Additionally, investing in research and development of energy-efficient algorithms, machine learning techniques, and edge computing architectures tailored for smart grid applications can optimize energy consumption and enhance system performance. Moreover, promoting interdisciplinary research initiatives focusing on the socio-economic aspects of green IoT adoption can facilitate the development of inclusive and equitable solutions. Furthermore, fostering partnerships for large-scale pilot projects and field trials can provide valuable insights into the real-world performance and scalability of green IoT systems, thereby bridging the gap between theory and practice.

Further, this review paper on green IoT in Smart Grids adds a distinctive perspective to the body of literature by providing an original and novel point of view. It gives a thorough overview of the most recent developments while highlighting their importance for smart energy management in smart grids. To give a path for forthcoming research and development, the study examines several research topics and cutting-edge methods, such as Green IoT technologies, cloud computing, AI, optimization, distributed energy resources, and data analytics.

Key contributions of the article include:

- Illuminating the novel intersection of green IoT technology with smart grid infrastructure, offering a comprehensive analysis of their integration for sustainable energy solutions.
- Providing a nuanced exploration of smart energy management within grids, underscoring the unique challenges faced by urban areas in regulating energy consumption and highlighting the imperative for technological advancements to address these complexities.
- Introducing a pioneering categorization of recent technological advancements in the field, coupled with in-depth discussions on their distinct advantages and potential applications, thereby contributing to a deeper understanding of their impact on smart grid development.
- Offering invaluable insights through case studies showcasing successful implementations of smart grid projects, elucidating the

Table 1
Comparative study relating to green IoT system.

	Smart Grid	Communication Protocols	Green IoT Technologies	Energy Management System	Machine Learning	Edge Computing	Fog Computing	Salient points discussed
Proposed Work	√	√	√	√	√	√	√	• Discussion regarding the progress of green IoT technology within smart grid systems. • An overview of smart energy management within grids, focusing on the challenges cities face in controlling energy consumption and the need for technological advancements. • Classification of recent technological advancements, along with discussions on their advantages. • Illustration of case studies showcasing successful implementations of smart grid projects, including challenges faced and solutions implemented. • Investigation into emerging research areas and innovative methodologies, such as green IoT cloud computing, artificial intelligence, and smart grid technologies.
(Benhamaid et al., 2022)				√		√	√	• This paper provides a comprehensive and current survey of energy management techniques in IoT networks. • Outlined the challenges associated with energy consumption in IoT networks. • Introduced both novel and established energy management approaches for IoT, with a particular emphasis on the latest solutions proposed within each approach.
(Varjovi and Babaie, 2020)			√					• This article discusses Green IoT (IoT) technology, highlighting its distinctive features such as enhanced energy efficiency, eco-friendliness, and widespread adoption across various applications. • The challenges associated with GIoT are also examined to elucidate the issues faced by researchers in the field. • Furthermore, the environmental requirements of GIoT are taken into account across various network layers, encompassing hardware, software, communication, and architecture.
(Tabaa et al., 2020)		√	√		√			• A smart grid framework integrating renewable energy sources for optimization and efficiency purposes enables the IoT to adopt a sustainable and industrial role, referred to as the Green Industrial Internet of Things
(Albreem et al., 2021)			√		√	√	√	• This study discusses several effective behavioral change models and strategies aimed at raising awareness about energy conservation among users and service providers of IoT devices. • Fog/Edge computing provides a platform that extends cloud services to the network's edge, thereby reducing latency, mitigating power consumption, and offering improved mobility, bandwidth, data privacy, and security.
(Malik and Kushwah, 2022)			√					• This paper conducts a thorough examination of various prevalent and

(continued on next page)

Table 1 (*continued*)

	Smart Grid	Communication Protocols	Green IoT Technologies	Energy Management System	Machine Learning	Edge Computing	Fog Computing	Salient points discussed
								innovative IoT solutions within the context of Green IoT. • Specifically, the evaluation and comparison of these Green IoT solutions are conducted based on their characteristics, technology utilization, outcomes, usability, and limitations. • This survey is intended to serve as a guideline and conceptual framework for the development and research of Green IoT.
(Alsharif et al., 2023)			√					• This article contributes to promoting the adoption of eco-friendly IoT solutions by providing a comprehensive examination of energy-efficient practices and strategies for IoT. It aims to facilitate the advancement of sustainable and energy-efficient IoT technologies in the future.

obstacles encountered and innovative strategies employed to surmount them, thereby offering actionable lessons for future initiatives.
- Pushing the boundaries of research by delving into emerging areas of study and cutting-edge methodologies, including the fusion of green IoT with cloud computing, artificial intelligence, and smart grid technologies, thus charting a course for future exploration and innovation in the field.

These contributions collectively enhance the understanding and advancement of green IoT in Smart Grids and provide insightful information for researchers, electrical engineers, and policymakers.

The paper follows a structured organization to widely address the topic of green IoT and smart grids. The introduction sets the stage by providing an overview and highlighting the significance of these technologies. Section 2 outlines the plan for the literature review, detailing the scope and methodology adopted for the study. In Section 3, the basic requirements of green IoT and smart grids are presented, forming a crucial foundation for the subsequent discussions. Building upon this foundation, Section 4 delves into the technological advancements in green IoT for smart grids, exploring innovative solutions and approaches in this domain. To provide real-world insights, Sections 5 and 6 showcase case studies of smart grid implementations. These case studies examine the current applications, challenges faced, and future developments in the field, offering valuable lessons from practical experiences. Finally, Section 7 culminates the paper by summarizing the review work. It presents the important findings and conclusions drawn from the literature and case studies, giving a comprehensive understanding of the state of green IoT and smart grids. Section 8 illustrates the Future Directions and Research Trends that trigger the future transitions globally. Section 9 concludes the work based on the holistic discussions.

2. Literature survey strategy

Digital databases used for conducting the proposed comprehensive review are discussed in this section. A systematic searching methodology is needed to use the numerous digital resources effectively and find the research articles that meet the hunt parameters. The review process that is being proposed combines manual as well as automated searches, following the PRISMA strategy, to obtain the most appropriate research publications.

The review technique commences with an algorithmic exploration of digital archives to identify relevant research publications as its initial step. In the second stage, our team of specialists in categorization reviews the results to ensure their applicability. The survey only incorporates articles published between 2018 and 2023. Every single research article listed has undergone a thorough search, employing both manual and automated methods.

The keywords used for the proposed survey include "Smart Grid" AND "Green IoT" AND "Energy Management System for Smart Grid" AND "Predictive Analytics and Artificial Intelligence for Energy Forecasting and Optimization" AND "Edge Computing for Distributed Intelligence and Real-time Decision Making" AND "Fog Computing for Data Processing and Analytics at the Network Edge". The subsequent steps are employed to determine the search keywords:

- The keywords are formulated based on the difficulties being investigated.
- Identify alternative synonyms, alternate spellings, or significant phrases for each main keyword
- Extract keywords from learned journals and textbooks that are pertinent to the research problems.
- Used the Boolean function operator "OR" to consider different spellings, synonyms, or significant phrases.
- The search string/essential phrases are formed by combining the essential keywords using the Boolean function operator "AND." Subsequently, these keywords are analyzed to extract relevant data from electronic databases.

Each digital repository analyzes the mentioned search terms and keywords and customizes their pattern based on the results. The set of keywords, all of which are relevant to the proposed survey, are connected to the four research queries created using the PICO framework.

Problem:	How can the adoption of Green IoT solutions address environmental concerns and promote sustainability in smart grid infrastructures?
Intervention:	How do Green IoT technologies enable efficient energy management and demand response in smart grids?
Comparison:	What are the differences in performance, reliability, and scalability between Green IoT and conventional IoT solutions in smart grid infrastructures?
Outcome:	How can the findings from this comprehensive review guide future research and policy-making decisions in the pursuit of sustainable smart grid development?

Following the PRISMA approach, the papers initially extracted undergo inclusion/exclusion studies. The selection criteria for publications that were included and excluded are summarised in Table 2. The article selection process involves three straightforward steps. Firstly, redundant research articles are removed. In the second phase, the relevance of the article title, abstract, and keywords is meticulously assessed. After a comprehensive examination, the remaining research publications are then included.

The article selection procedure resulted in a collection of 971 research articles to conduct a literature review based on the proposed review work objective. The screening process began with manual screening of the paper titles, resulting in 512 selected papers out of the initial 971. These 512 articles were further screened based on their abstracts and conclusions, resulting in 437 papers. In the second stage, 384 papers were filtered based on methodology and results, leaving 216 articles. After a thorough examination of the contents, 102 papers were deemed suitable for the proposed review work based on criteria such as methodology, comprehensive results, journal impact factor, and citations.

The quality assessment was conducted after completing the paper scrutiny process, evaluating the parameters for each research article in relation to the research questions. The authors themselves read and examined each selected article. Fig. 1 illustrates the publication channels used for article searching and the stepwise selection procedure.

3. Fundamentals of green IoT and smart grids

The Grid is a connection of multiple power lines to form the network, with the implementation of information and communication tools to act intellectually with the computational methods known as smart grid. Grid operation involves generation, transmission, and distribution.

Generation of energy from the non-conventional energy sectors such as solar energy, wind energy, hydro energy, etc. This Harvested energy from the resource gets tied up with the nearby grid. To initiate the linkage between the energy sectors and the grid, there the challenges of operating the process from the operator, identifying the stable generation, and controlling the generation plant as per the command provided by the control. The production house should contain monitoring equipment such as DFR, PMU, and GPS to measure the parameters such as regulated voltage, and frequency of transmission. These parameters get transmitted through the IEC 61850 standard protocol for enabling safety and secured transmission. With the inferred value, the command corresponds to the generation provided to the generating plant. Thus, the grid begins to initiate bidirectional communication.

WAMS involves interlinking multiple micro grids to one single point with the defined security protocols as per the topology of the network (Hassaine et al., 2014). The System manages the steady generation and distribution of distributed resources and is involved in regulating the steady demand response according to the situation of electric markets that are scheduling the electric tariff to the consumption. It also deploys the automatic circuit breakers to close and release the contacts in case of a fault emergency (Massoud Amin, 2011).

Fig. 2, illustrates the overview of the entire SG structure with

Table 2
Summary of inclusion and exclusion criteria for research articles.

Demand for inclusion in a research study	Demand for exclusion from a research study
For this proposed study, only cutting-edge content from the years 2018–2023 is considered.	Duplicate research publications are not included.
Only English-language research publications are included.	Non-English-published research papers are not considered.
Research outputs that directly relate to the study's main subject of inquiry are taken into consideration.	Research articles that do not adequately clarify the core topic of the intended analysis are excluded.
Only significant research manuscripts with clear outcomes and supporting evidence are included.	Articles lacking precise results and comparisons are disregarded.

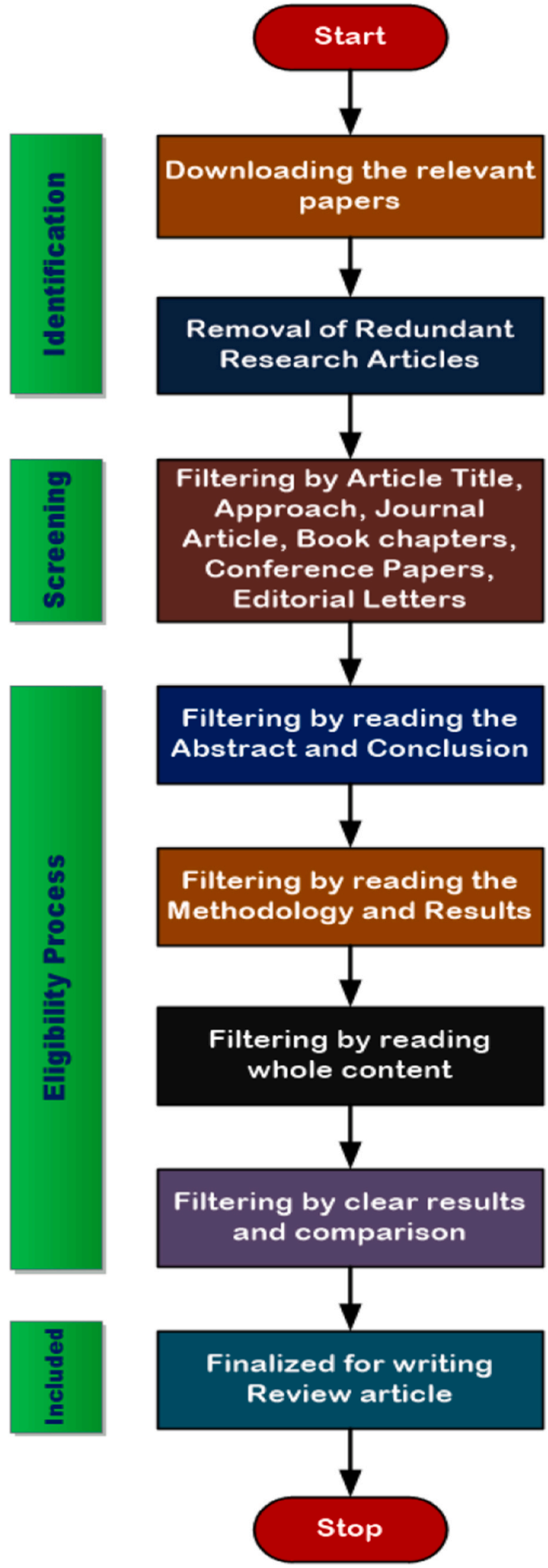

Fig. 1. Flowchart for literature survey strategy.

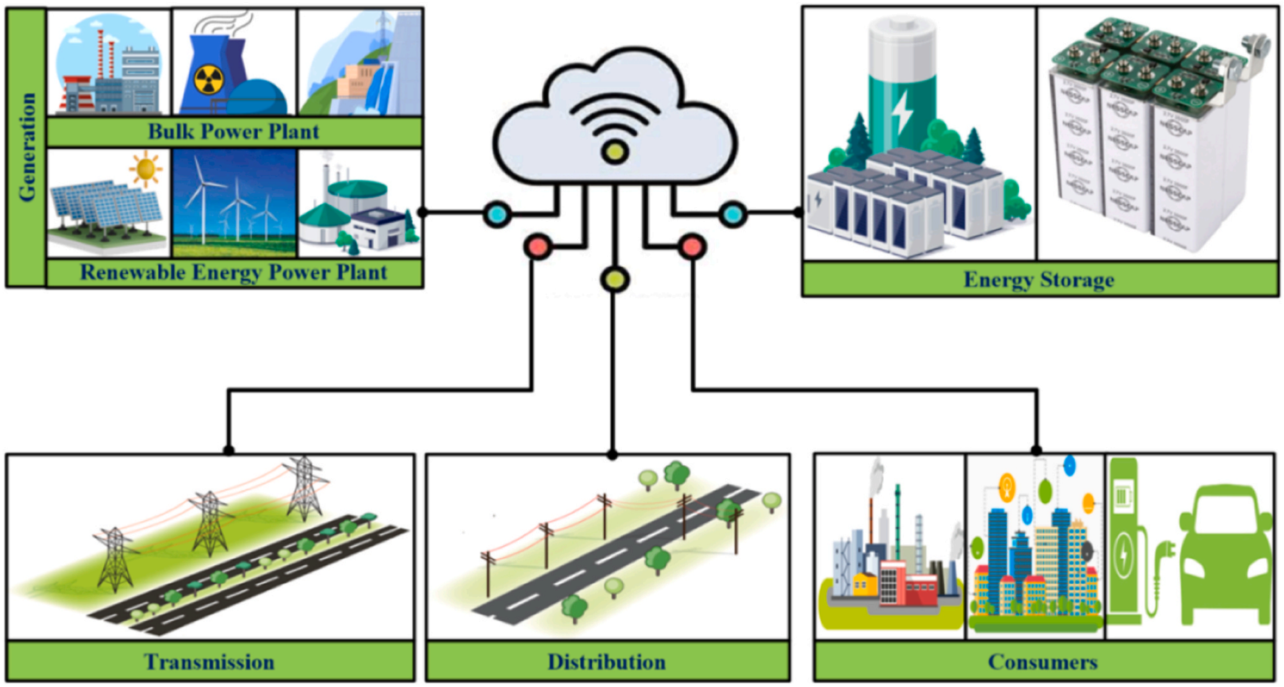

Fig. 2. Energy Integration in smart grid.

renewable energy integration concerning the solar farms, wind farms, fossil fuel generation plants such as thermal and nuclear, vehicle to grid charging are all connected to the microgrid at specific nodes that link to the substation and centralized control room utilizes the SCADA and AMI for gathering the data regarding generation. On the Other side of distribution by the schedule, a centralized network distributes the energy for domestic and commercial utilization.

The main challenges in integrating renewable energy sources into smart grids are addressed by Green IoT solutions (Gorea et al., 2023).

- **Intermittency and Variability:** Renewable energy sources like solar and wind power fluctuate due to weather conditions and time of day, posing challenges for grid stability. Green IoT enables real-time monitoring and forecasting of renewable energy generation, allowing smart grids to adjust energy distribution and storage dynamically.
- **Grid Integration and Stability:** Integrating renewables into existing grid infrastructure requires maintaining stability. Green IoT provides real-time insights into grid conditions, load balancing, and voltage regulation, ensuring stability and resilience.
- **Data Management and Analytics:** Managing the data generated by renewable sources and IoT devices is challenging. Green IoT offers advanced data management and analytics capabilities, improving decision-making and optimizing grid operations.
- **Cybersecurity and Data Privacy:** Connected devices in smart grids raise cybersecurity concerns. Green IoT implements robust security measures to protect sensitive information and critical infrastructure, building trust and accelerating renewable energy adoption.

By leveraging advanced technologies and cybersecurity measures, Green IoT helps utilities overcome challenges, facilitating a transition to a cleaner, more sustainable energy future.

3.1. Intersections between Green IoT and smart grid technologies

The various SG operations that rely on the key role of IoT are as follows,

1. Auto Meter Reading
2. Smart Home Switching Control
3. Real Time Tracking of Transmission Line
4. Electric Vehicle Charging Management System and
5. Centralized Data Server Control

3.1.1. Auto meter reading

Meter Monitoring is an essential parameter for the computation of electricity charges and to infer the power consumption of the various loads. Traditionally, tracking of power consumption is measured from an on-board meter manually. Since this method also increases time consumption and reduces the accuracy of measurement. So, this creates the path for the online remote meter monitoring system which is incorporated using WSN, PLC, and OPLC. These Components communicate with smart power devices gather the data periodically and transfer them over to the public and private communication networks and the gathered data is recorded in the database server. This method signifies collecting, analyzing, and processing the power consumption details over to the server and simultaneously gets notified to the consumer side via advanced computing technologies which are represented in Fig. 3. As this system creates dominance in real-time accuracy, enhances the reliability and stability and provides information about the distributed energy tracking of different loads. By knowing the statistical analysis about the power consumption of loads the consumer end can be well aware of the electricity charges and can operate the loads appropriately and able to conserve energy as much as they can do. Interfacing the IoT with a smart meter enables the action of collecting, processing, and real-time monitoring of data in a more efficient manner (Chen et al., 2011; Ram et al., 2023).

3.1.2. Smart home switching control

Smart home control ensures the regular tracking of the residential loads which keeps on noticing from the IoT (Sensor nodes) of the smart power devices onto the grid. This, in turn, allows the real-time interaction between the grid and the consumer side to optimize the use of power-consuming devices to regulate the demand during peak hours and enhance the standard of service both commercially and domestically

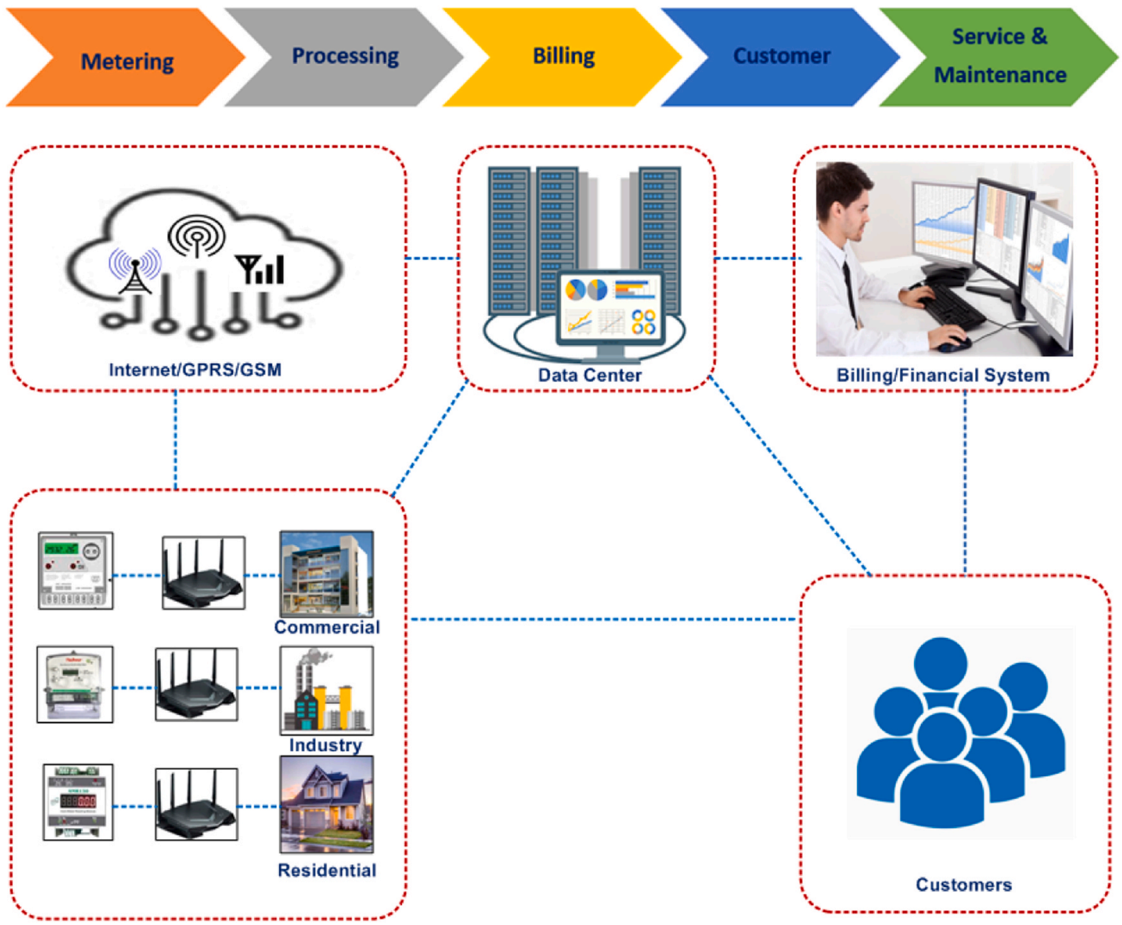

Fig. 3. Automated meter reading (AMR).

concerning the market situation. Switching operations are recommended during the peak hours, as this control is based on daily power consumption monitoring, it is possible to reach out device that consumes more energy so having reference to the data measured, the respective switching off the load function takes place from the grid connection and the users gets notified through the web server and they can monitor the actions regularly with the help of the web server. The alert messages are also prompted when a security break takes on. A smart grid equipped with IoT under the LAN protocol ensures the above functioning of the devices like appliance control, renewable energy storage, and utilization, Meter Reading by tracking with the help of Wireless Sensor Nodes connected to each device and centralized to the router and the server from power line communication cables (Chen et al., 2011).

Smart Home Switching Control helps in diverting the operation of heavy loads in residential buildings during the high peak hours which reduces the demand and therefore increases the efficiency of transmission and usage of these heavy loads in residents is encouraged during relaxed hours other than peak hours. During those peak hours, these powers get shifted to commercial exploitation.

3.1.3. Real-time monitoring of transmission line

Generation, Transmission, and Distribution are the principal roles of the power system. To supply the power over to the entire area these three actions should take place without any interruption. If anyone of role fails from these three then it brings huge trouble to the society. So, to monitor, detect, and diagnose those faults that occur in the power system, highly effective progress of artificial intelligence and machine learning techniques should be incorporated in terms of decision-making and action execution within a shorter period.

The transmission line network in the power system is necessary to inspect the site of the high-voltage transmission line. By making the system autonomous, tasks in a smart grid equipped with artificial intelligence and ICT tools can monitor the transmission line regularly to detect and eliminate the faults and then diagnose and execute the respective operations is shown in Fig. 4. For example: during the time of blackouts the failure grid can communicate with the nearby grid to perform the distribution operation since these grids are interconnected.

For the aforementioned discussions, the integration of the visualization method is an effective solution for various problems that occur in transmission lines. The visualization technique involves a comprehensive view of faults like swinging, icing, bird hazards, and any man-caused disasters as real-time information. Visualization is a method of transforming numerical data into visual representation. More than data, visual representation is easier to understand. As IoT discussed above from the sensing field, the system gathers the numerical data and imports them into the cloud server and represents the data as images, animations, or videos and analyses the collected data and the reaction occurs very quickly (Alsharif et al., 2024b).

Visualization of data occurs in the following flow: Pre-processing of gathered data to transformation of visual symbols and finally to visualization of objects through visual mapping (Sanchez-Hidalgo and Cano, 2018). Visualization is divided into three sections namely traditional visualization, Visualization of multivariable data, and Geographical visualization

Traditional Visualization and Visualization of multivariable data are done on the generation side and distribution side as they represent the data of the equipment positioning, power supply reliability, environment of the equipment, maintenance, and operation guide. Geographical visualization incorporates the entire image of the object as facilitated by satellite communication technology which can able to

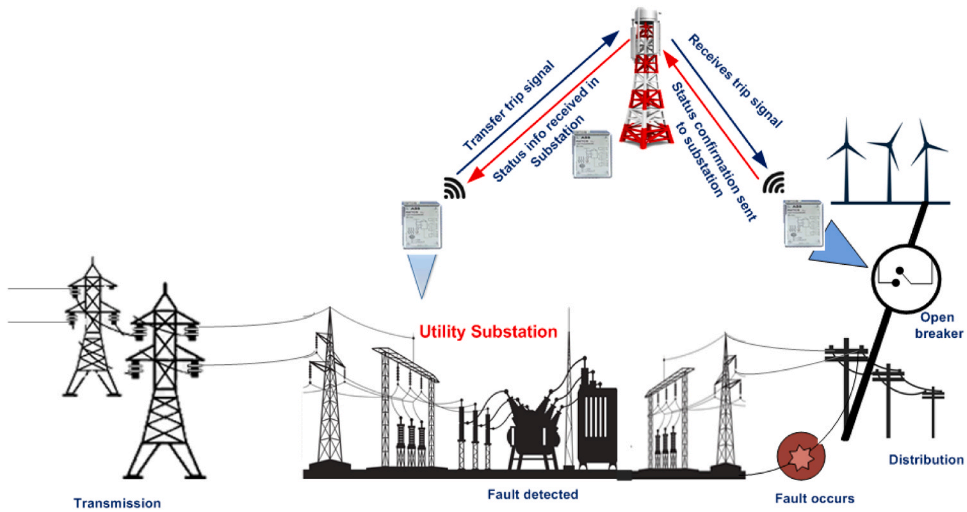

Fig. 4. Real-time tracking of the Transmission line.

monitor the running condition of the transmission lines. The network consists of a ground fiber optic network for quicker transmission of data to the server and establishes in making visualization of the object. Visualization effect was proved in 1000 kV Yellow river span and Hang River span projects

3.1.4. Electric vehicle charging management system

In succeeding generations, the role of electric vehicles is huge. Due to the depletion of resources and to reduce CO_2 emissions (Tingjie, 2010), EVs have come into the market. The challenges faced by the electric vehicle are battery management and the charging station. The research work is on the progress in the area of battery management of electric vehicles. When it comes to the scenario of charging stations it is integrated in both private and public. State Grid is planning for the construction of a large number of electric vehicle charging stations to facilitate IoT, GPS, interlinking of renewable resources, and wireless communication technology like WIFI, Zigbee, etc. for interaction between the monitor center and electric vehicle.

The EV energy management system contains of EV charging station and data center. With the help of communication technology, there exists a conversation between the EV and nearby charging stations. In need to charge the battery of the vehicle, the dashboard of the EV is equipped with GPS which navigates the most nearby charging station. Once the vehicle is plugged in for charging, the data center manages the charge duration, bill generation, and management of car batteries as they record this information with the unified ID given to the respective electric vehicle which carries information of the manufacturer, owner details, personal address, and charge scheduling. IoT integrated with the grid enables the additional feature of charging stations for electric vehicles.

Green IoT technologies facilitate the integration of EVs into smart grids without overwhelming grid capacity. Through strategies like demand response management, grid monitoring, vehicle-to-grid integration, dynamic pricing, and predictive analytics, Green IoT ensures seamless EV integration while maintaining grid stability. These approaches enable efficient management of EV charging schedules, optimization of energy distribution, and proactive grid management to prevent capacity overload.

3.1.5. Centralized data server control

The server is the place where there is a large amount of reception of data. One of the important units in IoT is they collect, process, and precipitate the information regarding the subsequent function to go on to the floors. Inference made about the power consumption of these servers and due to continuous functioning lead to overheating of the apparatus and may lead to the failure of the entire control system. So, to keep the computer servers from overheating, temperature sensors were interfaced to switch off the computer load to keep them in a cooler state. Centralized data servers should be protected with several security protocols. With the integration of IoT with smart grid, these servers should be maintained with as much care as they operate various functions such as video monitoring technology, accurate calculation of power consumption, interaction with the consumer end, gathering of data from the sensors of power consuming devices, linkage between the grid and the computer, decision making and execution (Kim et al., 2010).

Centralized data servers play a crucial role within the IoT ecosystem, serving as pivotal hubs. Their multifaceted functions include:

- **Data Aggregation:** Servers gather vast amounts of data from various sources, such as sensors, devices, and applications.
- **Processing and Analysis:** They handle incoming data streams, conduct computations, and extract meaningful insights.
- **Decision-Making:** Informed decisions are made by servers based on analyzed data, triggering actions, and managing system behavior.
- **Dissemination:** Processed information is distributed to relevant endpoints, including other servers, edge devices, or end-users.

Continuous operation of servers generates heat, posing several challenges. Overheating compromises server reliability, with prolonged exposure to high temperatures potentially causing hardware failures and disrupting critical services. Elevated temperatures also impact server performance, resulting in slower response times and reduced throughput. Moreover, overheated servers consume more energy due to increased cooling demands. To mitigate these risks, sensors are employed to trigger cooling mechanisms when temperatures exceed safe thresholds, with fans adjusting their speeds accordingly.

Centralized data servers must be fortified with robust security measures. Implementing strict access controls helps prevent unauthorized entry, while encrypting data transmitted to and from servers safeguards confidentiality. Continuous monitoring by Intrusion Detection Systems (IDS) detects suspicious activity in server traffic, and deploying firewalls filters incoming and outgoing network traffic. Additionally, periodic security audits assess vulnerabilities and ensure compliance (Amin, 2011).

As IoT intersects with smart grids, the importance of centralized data servers becomes increasingly pronounced:

- **Grid Monitoring:** Servers enable real-time monitoring of grid components, such as substations, transformers, and distribution lines.
- **Load Balancing:** Through the analysis of consumption patterns, servers optimize load distribution across the grid.
- **Predictive Maintenance:** Data-driven insights facilitate proactive maintenance, thereby reducing downtime.
- **Demand Response:** Servers coordinate demand response programs, adjusting energy consumption in response to grid conditions.
- **Fault Detection and Isolation:** Servers detect faults and isolate affected segments, thereby enhancing grid reliability.

4. Smart grid communication protocols

Energy-efficient communication protocols are pivotal in bolstering the sustainability of smart grids by curtailing energy consumption, slashing operational costs, and refining overall system efficiency. These protocols facilitate efficient data exchange and communication among devices, sensors, and control systems within the smart grid infrastructure, thereby enabling real-time monitoring, control, and optimization of grid operations (Tuysuz and Trestian, 2020). Several noteworthy advancements in energy-efficient communication protocols have been pinpointed in this analysis:

- LPWANs emerge as a promising communication technology for smart grids, proffering long-range connectivity with minimal power consumption. By leveraging LPWANs, smart grids can attain extensive coverage and seamless connectivity for IoT devices while conserving energy and elongating battery life, thus elevating sustainability.
- TSCH, a communication protocol, bolsters energy efficiency and reliability in wireless sensor networks by synchronizing communication schedules and hopping between different channels. TSCH curtails collisions, latency, and energy consumption, rendering it suitable for smart grid applications necessitating reliable and low-power communication.
- Zigbee Green Power, a communication standard optimized for energy-efficient operation in battery-powered IoT devices, enables ultra-low power operation, extending battery life and curbing the need for frequent battery replacements. Zigbee Green Power proves especially advantageous for smart grid applications characterized by energy harvesting and battery-powered devices.
- SDN, a networking paradigm, segregates the control plane from the data plane, facilitating centralized network management and programmable control. By dynamically tweaking network configurations and routing paths in response to traffic patterns and energy constraints, SDN heightens energy efficiency and resource utilization in smart grid communications.
- AMC techniques adapt modulation and coding schemes dynamically based on channel conditions to optimize data transmission efficiency and energy consumption. By adjusting to changing environmental conditions, AMC enhances communication reliability and throughput while curtailing energy expenditure, thereby bolstering the sustainability of smart grid operations.

The highlighted advancements in LPWANs, TSCH, Zigbee Green Power, SDN, and AMC epitomize notable progress in enhancing energy efficiency and communication reliability in smart grid applications. Emerging communication protocols address scalability challenges through several key mechanisms (Migabo et al., 2020):

- **Mesh Networking:** Protocols like Zigbee and Thread use mesh networking, letting devices communicate directly, forming a self-healing network. This approach boosts scalability by letting new devices join seamlessly without disruptions.
- **Low-Power Consumption:** Green IoT protocols prioritize low-power usage, allowing devices to run efficiently on battery power for longer periods. This minimizes energy usage, supporting the deployment of numerous IoT devices across the grid without hefty energy demands or frequent battery changes.
- **Scalable Addressing Schemes:** Emerging protocols incorporate scalable addressing schemes to assign unique identifiers to many devices within the network. This ensures efficient device management and communication, even as the number of devices grows.
- **Resource Efficiency:** Green IoT protocols optimize resource use by reducing bandwidth consumption, cutting message overhead, and prioritizing critical data transmission. This allows the network to handle more data traffic and accommodate more devices without compromising performance or reliability.
- **Interoperability:** Interoperability is crucial in these protocols, enabling devices from different manufacturers to communicate seamlessly. This fosters ecosystem growth and makes it easier to integrate diverse IoT devices into existing grid infrastructures, supporting scalability and future expansion.

5. Advancements in green IoT for smart grids

G-IoT focuses on decreasing energy consumption for IoTs to realize the vision of a smart world, preserve the intelligence of everything, and lower CO_2 emissions. G-IoT enhances the world's intelligence through the implementation of sustainable technological breakthroughs, positively impacting both the environment and human well-being. The creation of computer hardware, communication protocols, energy-efficient technologies, and network designs all fall under the category of "green IoT design" (Memić et al., 2022a; Zhu et al., 2015). Table 3 outlines the various eco-friendly IoT applications utilized in the framework of the SG. With the aid of innovative G-IoT technologies, many transportation systems have the potential to become frictionless, inclusive, cost-effective, secure, reliable, and robust. By leveraging technological advancements in IoT-enabling methods, G-IoT offers significant possibilities to enhance financial and environmental sustainability. Fig. 5 represents the G-IoT technologies used for smart grid applications.

Green RFID: Green RFID is an environmentally friendly technology that contributes to Green IoT. To transmit a signal query and receive responses from nearby RFID tags, which store information about objects, an RFID tag reader is required. Green RFID technology produces labels on reusable paper, eliminating plastic substances and hazardous compounds, and reduces RFID tag size through recycling. Energy-efficient protocols and algorithms are employed (Memić et al., 2022a). The antenna is created using a state-of-the-art laser fabrication process, with all excess aluminum being fully recycled. One of the advantages of Green RFID is its standardized, scalable, reliable, and cost-effective approach.

Green WSN: The concept of "GWSN" aims to optimize bandwidth-related properties and lifetime while diminishing the effect of carbon footprint. These networks employ highly organic energy collection methods. The objective of green IoT in WSNs is to keep the sensor in sleep mode for the majority of its life to save energy. A hierarchical network design that enables flexible and energy-efficient IoT is the first of several authors' suggested strategies to go for "green" sensor networks. With a focus on extending network longevity and improving energy efficiency, a cooperative approach is also recommended to save energy and lengthen battery life. GWSN aims to reduce energy consumption, increase network lifetime, and enhance the QoS of the network (Sajak et al., 2024). GWSN can be used in various applications, such as environmental monitoring, healthcare, and smart homes, to provide efficient and reliable services while minimizing the carbon footprint.

Green Cloud Computing: The most critical features of GCC, a resource-efficient architecture, include virtualization, environmental friendliness, and energy efficiency. The main objective of GCC is to support the adoption of recyclable and reusable products that are

Table 3
Green IoT technologies for smart grid application.

Ref, Year	Green RFID	Green WSN	Green Cloud Computing	Green Data Center	Green M2M	Observation
(Sajak et al., 2024), 2024	X	√	X	X	X	• This research aims to study how sunlight affects wireless sensor networks, which is important for creating a sustainable Green IoT. • The focus is on Malaysia's tropical climate because of its distinct weather. • NetSim simulations are used to test the network's energy efficiency and reliability, using a standard small solar panel measuring 55×70 mm.
(Tan et al., 2024), 2024	X	X	X	X	√	• This paper investigates energy-efficient UAV – IRS-assisted M2M communications for green IoT. • Specifically, it formulates an optimization problem to maximize the system's average energy efficiency by adjusting the power coefficients of all M2M transmitters, the UAV's trajectory, the base station active beamforming, and the IRS's phase shifts simultaneously.
(Alsharif et al., 2023), 2023	√	√	√	X	√	• Aims to promote eco-friendly IoT adoption. • In-depth analysis of energy-efficient practices and tactics for sustainable IoT technology. • Four framework principles were discussed: energy-efficient M2M communications, WSN, RFID, and microcontroller units/ICs.
(Aljadani and Gazdar, 2022), 2022	X	√	X	X	X	• The suggested architecture divides certification authority duty among multiple sensor nodes. • A new lightweight clustering approach selects nodes based on energy and trust criteria. • The proposed architecture provides security services: authentication, and confidentiality. • Reduces attacks like eavesdropping and Sybil.Top of Form Bottom of Form
(Memić et al., 2022a), 2022	√	√	√	√	√	• The G-IoT technologies and tactics are thoroughly examined. • Greener ICT promises efficient production and reduced energy usage for equipment. • Using enabling technologies to create a world that is intelligent and green, to support a secure and healthy atmosphere, and to improve quality of life.
(Memić et al., 2022b), 2022	√	√	√	√	√	• Focused on research into green technology, applications, and IoT infrastructure. • Does not cover IoT network specifics and connectivity perspective. • The suggested paradigm emphasizes strategies for resource conservation in green IoT systems. • Reduce the negative effects of technology on human health and the environment.
(Geetha et al., 2022), 2022	X	√	X	X	X	• New GEQCC-FLP technique proposed for IoT networks. • The purpose is to estimate incoming network load and identify effective cluster heads. • The clustering step uses Satin Bowerbird Optimizer. • The fitness function incorporates energy, distance, and delay parameters. • Hyperparameters of Deep Random Vector Functional Link Networks can be optimized with Adam optimizer for improved prediction accuracy.
(Lopez-Ardao et al., 2021), 2021	X	√	X	X	X	• Contributed to the diverse sensor network research areas to extend system/ application life. • Scenarios vary from appropriate to unprofitable, but most strategies are orthogonal and can work together.
(Priyanka et al., 2021), 2021	X	X	√	X	X	• Focused on the oil pipeline from inlet to distribution substations in Smart Grid design. • The architecture of cloud computing is fully discussed. • Applications of cloud computing for smart grids described: effectiveness, security, usability. • Examination of technical and security protocols for cloud systems. • SCADA hierarchical architecture for inspecting the oil pipeline with smart pigs and cloud computing linked to smart grid application.
(Srivastava et al., 2021), 2021	√	√	√	√	√	• Examined the most important green IoT technologies for a green and intelligent environment. • A summary of IoT and green IoT is done. • The survey includes standardized initiatives and ongoing efforts.
(Zhou et al., 2020), 2020	X	X	X	√	X	• Presented an auction mechanism for smart grids to bid for demand response. • Smart grids bid to the CSP for different amounts of demand response with varied compensation. • The proposed distributed strategy for each data center employs the proximal Jacobian alternating direction method of multipliers for parallel problem-solving. In this approach, the CSP acts as the auctioneer and resolves the champion resolve problem to maximize societal utility.
(Khan et al., 2021), 2020	√	√	√	√	√	• Addressed the major issues in IoT network energy efficiency and evaluated solutions. • Exploration of IoT system components and visualization tools for smart energy applications. • Applications include buildings, smart cities, agriculture, and health.

(continued on next page)

Table 3 (*continued*)

Ref, Year	Green RFID	Green WSN	Green Cloud Computing	Green Data Center	Green M2M	Observation
(Li et al., 2019), 2019	X	X	X	X	√	• Proposed a paradigm to improve green M2M communications with mobile edge computing. • The unique approach considers both energy usage and data computation simultaneously. • Utilizes DRL technique to train and obtain ideal stochastic policy. • Deep reinforcement learning helps handle exponential computational complexity and storage expense with numerous actions and states.
(Alsamhi et al., 2018), 2018	√	√	√	√	√	• Review and categorize important technologies for green IoT and eco-friendly society. • ICT revolution (RFID, WSN, M2M, communication networks, Internet, DC, CC) enhances greening IoT. • Things become intelligent to perform tasks autonomously based on key ICT technologies. • New green communication between people and things, and among things. • Optimized bandwidth utilization, reduced hazardous emissions, and minimized power consumption.
(Bharany et al., 2022), 2018	X	X	√	X	X	• Cloud computing offers access to diverse software platforms in one place. • Cloud addresses high resource needs and provides scalable services on demand. • Cloud service providers deal with security-related issues and offer various services. • High fault tolerance is crucial for achieving high performance in the cloud.
(Kimani et al., 2022), 2018	X	X	X	X	√	• Smart metering and dynamic power pricing as novel applications with M2M in smart grids. • Smart meters monitor consumption and relay data to the utility for flexible demand management. • Dynamic pricing regulates electricity demand in response to supply changes. • High demand requires expensive and environmentally harmful additional power sources. • Low demand results in underutilized infrastructure and wasted resources.
(Zhu et al., 2015), 2015	√	√	√	√	√	• Top of FormBottom of Form • Exploration of green IoT technologies to reduce energy usage. • Review done on IoT and green IoT. • A general outline of green ICT concepts is discussed.

*X – Not available, √ - Available

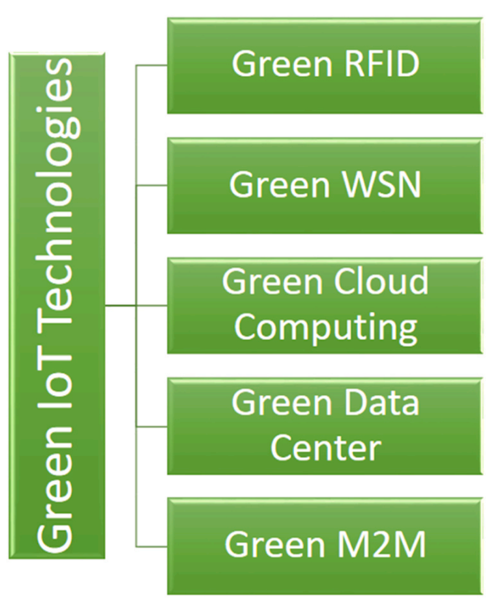

Fig. 5. Green IoT technologies.

environmentally friendly. CC technology offers unlimited computation, storage, and service delivery over the Internet. GCC is further examined to analyze its energy efficiency, utilizing various strategies and ideas to reduce energy requirements. The idea of GCC is to reduce the carbon footprint of cloud computing by using energy-efficient hardware, virtualization, and efficient cooling systems. GCC can be used in various applications, such as e-commerce, social networking, and big data analytics, to offer effective and reliable services while minimizing the carbon footprint (Memić et al., 2022a).

Green Data Center: A technological and storage facility called a "GDC" is intended for the storage, management, and transmission of data. Green data centers incorporate energy-saving methodologies to reduce their carbon footprint. With the increase in Internet users, energy use in data centers has considerably risen. Adopting the GDC through green computing is one option to address problems like high energy consumption and low equipment utilization rate in the IT system, which can help lower energy consumption in the data center. GDC focuses on reliability and performance, energy, and resource management (Zhou et al., 2020). It targets to advance air handling and management technology, determine the optimum settings, associate servers, and improve airflow for enhanced energy efficiency. To enhance energy efficiency and maintain performance, data center operators need to address these interconnected issues. GDC can be used in various applications, such as cloud computing, big data analytics, and e-commerce, to provide efficient and reliable services while minimizing the carbon footprint.

Green M2M: Green M2M is a concept that focuses on reducing the carbon footprint of M2M communication. M2M communication is a technology that enables devices to communicate with each other without human intervention. Green M2M aims to decrease energy usage and increase the lifespan of M2M devices. Green M2M employs several tactics, including the use of effective communication protocols, low-mobility-based optimizations, common energy-saving mechanisms, and group-based strategies (Tan et al., 2024). Green M2M can be used in a variety of applications, including smart cities, smart homes, and industrial automation, to offer efficient and reliable services while minimizing the carbon footprint.

5.1. Demand response and load management strategies

Demand Management is the centralized way of controlling the appliances by disabling through the smart meter when the load consumes more than the threshold value (Hussain and Beg, 2019; Maharjan et al., 2017; Atzeni et al., 2013a, 2013b). This methodology can be implemented through wireless sensor networks which continuously monitor the entire detail of consumption and these sensor node signals are passed to the control unit and then loaded into the server pages. Once the consumption crosses the predefined value, the control unit notifies the user end and also disables the particular load, when the load consumption is below the predefined value or reduction of demand it gets enabled through the control unit. In Fig. 6, represent the detailed operation of demand response is as follows,

As Demand Management is concerned, there exists the interaction between the server control and user end about the demand requirement which is not decided from the initial value that is recorded in the meter but also forecasts the previous backed-up data in the database to ensure enough to predict the period of demand and enables the user, time to operate to prevent overload. With the help of the collected data, the users can be alert about the demand and enable the smart meter to act towards the action of disabling the excess loads.

These excess loads are identified during the consumption monitoring from the database. This method is also called load shedding. Once the demand level drops these loads can start to work their normal operations. The advantage of load shedding helps in the reduction of demand during peak hours and flattening of the load duration curve. This algorithm is programmed in the controller to act towards the particular scenario when the devices make the necessary communication between them to enable the action.

5.2. Energy management system for smart grid

In the forthcoming, the successful implementation of smart grid technology in dynamic environments will require a controlled, reliable, and efficient network design. The primary objective is to address the challenges posed by uncertainty and variability in energy generation, aiming for a stable energy generation system. The power industry has witnessed a significant shift from traditional, large-scale centralized power plants to smaller, distributed energy generators. These distributed energy generators, including solar PV, wind, and other renewable sources, are often accompanied by storage systems (Alsharif et al., 2016). Together, these components form a distributed energy system. Chronological advancements in energy system management have primarily aimed at reducing energy costs while maintaining consumer energy usage levels, especially during peak hours (Abdulsalam et al., 2023). An energy management system plays a major role in ensuring an efficient, reliable, and secure power system by synchronizing and balancing load demand and renewable energy supply under diverse conditions. There are three basic architectures for energy management systems: centralized, distributed, and hierarchical (Abdulsalam et al., 2023). These architectures serve as frameworks for managing and optimizing energy resources in various ways to meet the goals of the energy system, which is illustrated in Fig. 7.

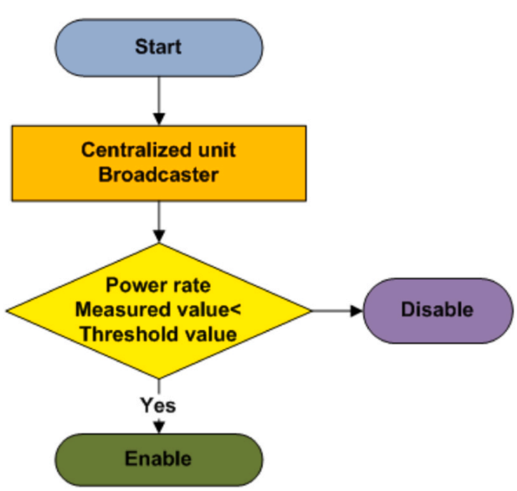

Fig. 6. Flow Chart for Demand Response.

Centralized energy management systems facilitate the synchronization of distributed generators and optimize customer demand, leading to reduced fuel usage. These systems use a central controller to collect data from relevant sources for efficient and reliable operation. On the other hand, distributed energy management systems operate independently, offering benefits such as adaptability, extended functionality, and quicker response times. They can function autonomously at different levels. Table 4, illustrates the various hierarchical energy management systems that employ dedicated control algorithms used at various levels to manage complex domains like power systems and manufacturing, ensuring effective coordination and optimization of smart grid operations.

This research proposes innovative energy management strategies to improve smart grid efficiency and sustainability. These strategies utilize advanced technologies such as machine learning, IoT sensors, and predictive analytics to optimize grid operations and maximize resource usage. Some of the key strategies include:

- **DSM with IoT Integration:** Integrating IoT devices and sensors for real-time energy consumption monitoring. This allows utilities to implement dynamic pricing, demand response programs, and load shifting to optimize energy use and reduce peak demand.
- **Predictive Maintenance and Asset Optimization:** Using predictive maintenance techniques with machine learning and IoT sensors to identify and address equipment failures before they occur. This helps optimize asset performance, minimize downtime, and extend critical infrastructure lifespan.
- **Renewable Energy Integration and Forecasting:** Integrating renewable energy sources like solar and wind power into smart grids using advanced forecasting models. By predicting energy generation more accurately, utilities can manage grid stability, optimize energy production, and reduce reliance on fossil fuels.
- **DER Management:** Adopting distributed energy resource management systems to integrate and coordinate DER assets such as solar panels and energy storage systems. This optimizes DER utilization and coordination with grid demands, enhancing grid flexibility, resilience, and sustainability.

Compared to traditional energy management methods, these new strategies offer several advantages:

- **Real-time Optimization:** They use current data and advanced analytics to adjust grid operations quickly, making energy management more flexible than older methods.
- **Enhanced Efficiency and Resilience:** By integrating IoT sensors, machine learning, and predictive analytics, these strategies help utilities improve grid efficiency, reliability, and resilience, reducing energy waste, outages, and costs.
- **Sustainability and Environmental Impact:** These strategies prioritize sustainability in smart grid operations by promoting the integration of renewable energy sources and energy-efficient technologies. This aims to minimize environmental impact and support a cleaner, greener energy future.

5.3. Predictive analytics and machine learning for energy forecasting and optimization

The smart grid model empowers consumers to gain valuable insights

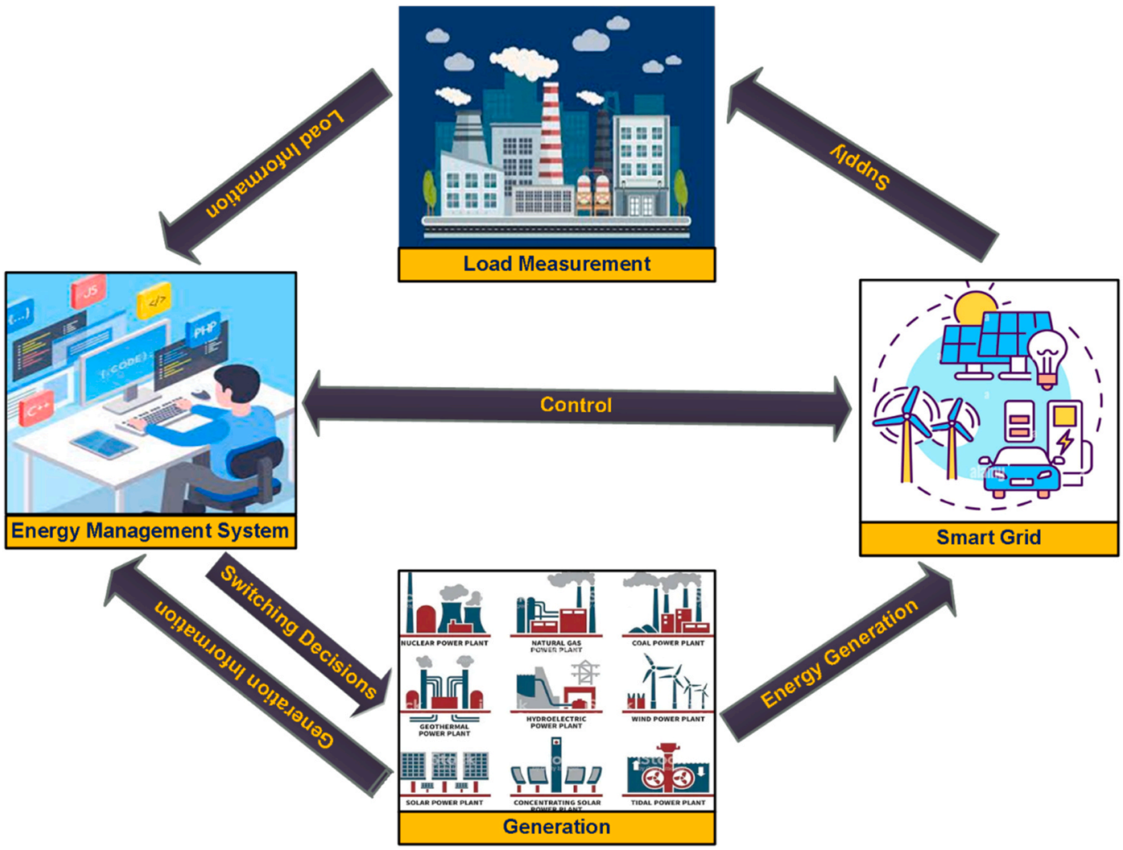

Fig. 7. Energy management system of smart grid.

into their energy usage patterns, allowing them to manage their consumption more efficiently. Demand response plays a critical role, benefiting both industrial and domestic settings, and contributing to the overall effectiveness of the smart grid. Additionally, load forecasting proves to be a valuable tool as it enables power companies to proactively balance supply and demand by predicting the electricity required to meet demand. In recent years, the surge in electricity demand during specific periods of the day has presented numerous challenges, making load forecasting particularly crucial during peak hours. To encourage clients to reduce non-essential energy consumption during these peak times, demand response plays a vital role (Aguiar-Pérez and Pérez-Juárez, 2023; Balaji et al., 2019).

The adoption of modern data-driven techniques becomes essential to address load forecasting challenges effectively. Fig. 8 illustrates how data are processed in machine learning for smart grid forecasting applications. The integration of cutting-edge methods such as Big Data, Deep Learning, Machine Learning, and the Internet of Things (IoT) has elevated the smart grid concept, facilitating improved demand forecasting and automated demand response, as shown in Table 5.

This review highlights the importance of intelligent energy management systems in Green IoT for smart grids. Machine learning algorithms are crucial for predicting and managing energy demand and supply, especially with renewable energy. Various techniques like time series forecasting, predictive analytics, reinforcement learning, and anomaly detection are used to tackle these challenges:

- **Time Series Forecasting:** Algorithms such as ARIMA and STL analyze historical data to accurately predict energy demand and renewable energy generation.
- **Predictive Analytics:** Neural networks, SVM, and random forests integrate various data sources to forecast real-time energy demand and supply.
- **Reinforcement Learning:** Algorithms like DQN and DDPG enable autonomous decision-making in dynamic energy management settings.
- **Anomaly Detection:** Isolation forests and support vector machines identify unusual patterns in energy consumption or generation, helping detect equipment failures or cyber threats early.

5.4. Edge and Fog computing based smart grid system

The edge and fog computing-based smart grid system is discussed in this section. Edge computing forms the basis for distributed intelligence and real-time decision-making in the smart grid infrastructure. Meanwhile, fog computing handles efficient data processing and analytics at the network edge.

5.4.1. Edge computing

One of the main challenges in SG systems lies in the monitoring and control of power grids and distribution systems, which involve remote signaling, metering, and control functionalities. By automating and remotely controlling power grids and electrical equipment, the system facilitates real-time decision-making and prompt detection of electrical issues. The integration of IoT technology in SG applications has introduced the concept of EC devices, as illustrated in Fig. 9. These edge nodes offer enhanced flexibility in data processing, storage, and computation, leading to improved service response times and reduced bandwidth demand on backbone connections (Minh et al., 2022; Sankar et al., 2022; Varma et al., 2020). Moreover, these systems enable real-time analysis of localized power loads, efficient power consumption scheduling, and swift responses to transmission and distribution systems, ultimately enhancing the overall operational efficiency of the SG, as depicted in Table 6.

Table 4
Energy management systems-based algorithms for smart grid application.

Ref	Year	Energy Generation Sources	Data Collection and Monitoring	Energy Management Algorithms	Observation
(Balavignesh et al., 2024)	2024	Solar Energy	Sensor networks	coati optimization algorithm	• The main contribution of this research is creating a new method to efficiently manage energy in a smart grid for scheduling smart home appliances. • Designing and developing the Adaptive COA, an enhanced version of COA that offers significant benefits in maintaining consumer convenience through optimal energy management.
(Aktas et al., 2017)	2017	Solar energy, Battery, Ultracapacitor, Grid	Sensor networks	Smart Energy Management Algorithm	• This study involves designing and analyzing a HESS with a battery and ultra-capacitor unit powered by a solar power system for a 3-phase 4-wire smart grid. • The system's dynamic response is controlled in various operational scenarios using the proposed SEMA. • Additionally, the smart energy management of these units is addressed to ensure energy sustainability and power quality in the smart grid structure.
(Zhang et al., 2024a)	2024	Solar energy, Battery, Fuel cell	Sensor networks	Promoted Remora Optimization algorithm	• This study suggests a better strategy for microgrids that work alone or connect to the main grid, especially those using solar and green energy. • The new method, using the PRO algorithm, aims to fulfill power needs at the lowest cost, maintain a steady DC bus voltage, and protect batteries from overcharging and depletion.
(Baseer and Alsaduni, 2023)	2023	Solar Energy	Sensor networks	Horse Herd Optimization Algorithm	• Renewable intelligent grid architecture is proposed, aimed at facilitating solar power generation. • To improve the performance of solar panels, a boost converter is utilized and its control parameters, such as the duty cycle, inductor values, and capacitor values, are optimized using an advanced optimization algorithm called the Horse Herd Optimization Algorithm.
(Ali et al., 2022)	2022	Solar energy, Wind energy, Energy storage	Sensor networks	Firefly algorithm, TLBO, ACO, GA, Jaya algorithm, rainfall algorithm, hybrid ACO, and TLBO optimization	• The ACTLBO, an ant colony teaching-learning-based optimization model, is created to enable efficient demand-side management in Singapore. It achieves this by intelligently scheduling power usage, taking into account both demand response and the incorporation of non-conventional energy sources. • In addition to energy cost and Peak-to-Average Ratio objectives, the study investigated User Comfort and carbon emission goals while addressing demand-side management challenges. • The proposed ACTLBO algorithm is subjected to comparison with other algorithms, considering multiple metrics such as energy cost, PAR, carbon emissions, and user discomfort minimization.
(Rehman et al., 2021)	2021	Solar energy, Wind energy, controllable heat and power	Sensor networks	the hybrid of GA, PSO, WDO (HGPDO), PSO, WDO, BFO algorithm	• As a solution for energy management, a proposed approach involves the efficient integration of diverse energy-generating technologies, encompassing SE, wind WE, CHP, EVB, BSS, and EPG. • The controllability of these energy sources allows for effective power management. • By optimizing load during peak hours based on flat-rate and day-ahead prices, the aim is to decrease the electricity consumption from the EPG.
(Ali et al., 2021)	2021	Solar energy, Battery	Sensor networks	Hybrid Genetic Ant Colony Optimization	• Introduced HGACO algorithm, an advanced energy management framework • Addressed rebound peak generation, minimizes electricity costs, lowers carbon emissions, and mitigates peak power consumption • Using real-time pricing signals and energy generation from utilities and PV-battery systems dynamically changes client power usage agreements. • Employed HGACO algorithm to solve scheduling model in three scenarios • Optimizes overall scheduling model, providing effective energy management with various photovoltaic-battery system configurations.
(Powroźnik et al., 2021)	2021	Solar energy, Wind energy, Energy storage	IoT Technology	EEM algorithm	• The research employs the EEM algorithm, which is custom-tailored for IoT-enabled smart appliances. • The primary goal of the system is to avert excessive grid load and mitigate high grid voltage values arising from the amplified output of prosumer-based RES. • The EEM algorithm, in combination with smart appliances, helps manage and optimize energy consumption to maintain grid stability in the presence of prosumer RES output.

(continued on next page)

Table 4 (*continued*)

Ref	Year	Energy Generation Sources	Data Collection and Monitoring	Energy Management Algorithms	Observation
(Dinh et al., 2020)	2020	Solar energy, Battery	Sensor networks	PSO and BPSO	• A novel design for HEMS has been put forth, encompassing the incorporation of RES and ESS. • The design considers both the use of power from the main grid and the possibility of electricity sales. • Incorporated comprehensive mathematical calculations utilizing PSO and BPSO techniques to evaluate the daily energy expenditure and PAR.
(Ullah et al., 2020)	2020	wind and solar energy sources	Sensor networks	multi-objective genetic algorithm	• The primary focus of this endeavor is the development of an optimal energy optimization method, aimed at effectively managing a SG combined with RESs. This method takes into account both operation costs and carbon emissions, ensuring a sustainable and efficient operation of the system. • In response to the uncertainty associated with power generation from non-conventional energy sources such as solar and wind, the concept of incentive-based DRPs is proposed, which involves offering price packages. • By implementing incentive-based DRPs, consumers are provided with different price packages, allowing them to participate in energy optimization based on their preferences and choices.
(Hafeez et al., 2020a)	2020	Distributed system	IoT	A combination of the WDO and BFO algorithms is known as the WBFA.	• The proposition involves scheduling the appliances using the WBFA technique to achieve a reduction in the PAR, lower electricity costs, and enhance user comfort. • Through the implementation of this method, energy efficiency is significantly improved, thereby contributing to the enhanced sustainability of residential buildings within IoT-enabled smart cities. • The WBFA-based strategy addresses a key issue with price-based DRP, which is that consumers often lack the knowledge or capability to react appropriately to DPR signals. • The WBFA-based approach automatically responds to demand response signals, effectively bridging the consumer knowledge gap and ensuring seamless adaptability to dynamic energy demands.
(Nge et al., 2019)	2019	Solar energy, Battery	Sensor networks	Real-time energy management system	• In contrast to predictive power scheduling approaches, which need exact predictions of immediate PV power production, the proposed EMS just requires an average estimate of PV power output over the full optimization period. • A comparison between the proposed EMS method and the predictive brute-force Dynamic Programming methodology demonstrates its superior effectiveness.
(Ullah et al., 2019)	2019	Distributed system	IoT	Bio-Inspired Energy Optimization Algorithms	• The study introduced two bio-inspired energy optimization algorithms, namely the BFA and GOA, for power scheduling in a single office setting. • The simulation results indicate that in comparison to unscheduled energy consumption using the day-ahead pricing scheme, the customer's power bill can be reduced by more than 34.69% and 37.47% with GOA and BFA scheduling, respectively. • Moreover, through the implementation of GOA and BFA scheduling techniques, the PAR can be significantly reduced by 56.20% and 20.87%, respectively, thereby fostering a more pronounced enhancement in both energy efficiency and cost-effectiveness.

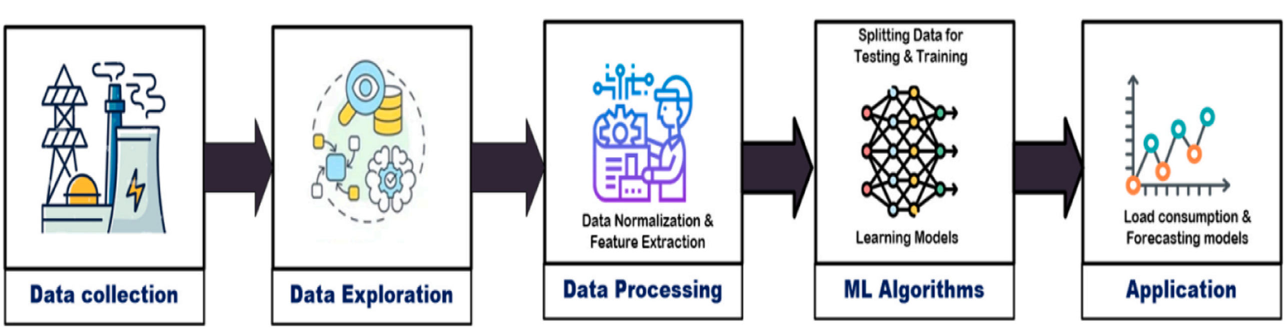

Fig. 8. Basic operation of machine learning (Balaji et al., 2019).

Table 5
Various artificial intelligence-based smart grids.

Ref	Year	Location of Study	Purpose	AI Methods/ Process	Observation
(Wesley et al., 2024)	2024	India	Energy management system	(LSTM)-based (ANN)	• This work uses LSTM-ANN to ensure a stable, high-quality power supply at different load buses. • Also, an AI-based operating system is introduced to manage energy effectively in different conditions. • To improve voltage quality, a 7-level aligned multilevel inverter is added to the system. • Compared to PI and Fuzzy controllers, the LSTM-ANN controller enhances power quality during sudden system changes.
(Rabie et al., 2024)	2024	Egypt	Predict the Stability	Optimum Load Forecasting Strategy	• This paper introduces a new load forecasting strategy called OLFS for accurate and fast load predictions. • OLFS consists of two main phases: the Data Preprocessing Phase and Load Forecasting Phase. • In the Data Preprocessing Phase, two main processes, feature selection, and outlier rejection, are used to prepare the electrical dataset input before training the load forecasting model.
(Alsirhani et al., 2023)	2023	Saudi Arabia	Predicting the stability	MLP-ELM	• Utilized principal component analysis as a feature extraction method in conjunction with the MLP-ELM approach. • Presented the results for smart grid stability and provided an empirical evaluation.
(Arumugham et al., 2023)	2023	India	Non-conventional Energy Prediction Program for Demand-Side Management	Multi-Objective Ant Colony Optimization	• A comprehensive model was constructed, capable of accurately replicating a microgrid. This model forecasts demand and supply, dynamically schedules power transfer to meet specific requirements, and delivers actionable insights into the smart grid system's performance. • Developed a demand response program that utilizes cost-saving incentive-based payment packages.
(Aguiar-Pérez and Pérez-Juárez, 2023)	2023	Spain	Demand Forecasting	Recurrent Neural Networks and Deep learning	• Deep Learning algorithms were applied for demand forecasting, and the study also offers valuable insights into the significance of demand forecasting and related variables within the context of smart grids. • It is critical to maintain a balance between supply and demand to ensure an efficient power system. • Accurate load forecasting, particularly in the short term, plays a crucial role in facilitating effective demand response.
(Tong et al., 2023)	2023	China	Scheduling control method	Deep learning	• Introduced a deep learning-based intelligent scheduling control solution for smart grids. • The proposed solution employs the LSTM algorithm to extract pertinent features and forecast coal consumption for specific scenarios. • Historical data from the power company is used to model and train the LSTM algorithm for accurate coal consumption prediction.
(Mazhar et al., 2023)	2023	Pakistan	IoT device installation in smart buildings and the grid	Machine Learning	• The study explored the combination and functioning of SGs, IoT, and ML components, utilizing a straightforward architecture with layered entities that communicate with each other via connections for predicting building energy demand. • Emphasized the importance of SGs and smart meters for obtaining real-time energy data. • An examination of IoT and its functioning is also included in the study.
(Alquthami et al., 2022)	2022	Saudi Arabia	Load forecasting	Machine Learning	• A comparative analysis of machine learning methods for short-term load forecasting was conducted, with a specific focus on forecast error and accuracy. • The study reveals that, compared to other methods, the decision tree classifier consistently delivers significantly better results based on implementation and analysis.
(Alrasheedi and Almalaq, 2022)	2022	Saudi Arabia	Short-Term Load Forecasting	Deep Learning	• Developed the hybrid DL methods to enhance problem-relevant features, achieve accurate power consumption forecasting, and develop reliable forecasting models. • The main goal is to obtain a better understanding of the interactions between different characteristics and qualities in the context of Saudi Smart Grids.
(Ibrahim et al., 2022)	2022	USA	Short-Term Load Forecasting	Machine Learning	• The study centers on short-term load forecasting (STLF), an area that has garnered substantial attention in recent years. • The study extensively explores various machine learning approaches and presents findings from a challenging case study conducted in Panama.
(Tiwari et al., 2022)	2022	India	Prediction of Power Consumption	Machine Learning	• Multiple machine learning-based models were developed to assume the stability of the grid in a dynamic environment. • The proposed model's forecast can be utilized to regulate the power in advance and prevent grid failure events.Top of FormBottom of Form

(continued on next page)

Table 5 (*continued*)

Ref	Year	Location of Study	Purpose	AI Methods/ Process	Observation
(Chahal et al., 2022)	2022	India	Predict the Stability	Optimized ANN	• The article compares multiple prediction models using criteria such as accuracy, precision, recall, F1-score, and ROC curve. • Feature scaling and data augmentation techniques have been utilized to improve the performance of the dataset. • The results obtained from the expanded dataset are found to be better compared to the standard dataset.
(Cebekhulu et al., 2022)	2022	South Africa	Energy Demand–Supply Prediction	Machine Learning	• The study assessed datasets comprising system hourly demand, solar generation, and wind generation, sourced from the Eskom database. • ML algorithms considered in the study generally underperformed, particularly on the dataset for wind power generation due to their highly stochastic nature. • Based on these findings, the study recommends that any of the straightforward machine learning methods examined can be employed for demand/supply forecasting. Nonetheless, it emphasizes that thorough hyperparameter tuning is crucial to optimize their performance.
(Syed et al., 2021)	2021	USA	Short-Term Load Forecasting	Deep Learning	• A distinctive hybrid clustering-based deep learning strategy is proposed for STLF at the level of distribution transformers. • The clustering process is conducted using a k-Medoid-based approach, effectively grouping distribution transformers according to their shared energy consumption patterns. Subsequently, forecasting models are produced for different clusters of load profiles. • This method reduces training time as fewer models are required for multiple distribution transformers.
(Jamil et al., 2021)	2021	South Korea	Peer-to-Peer Energy Trading	Blockchain and Machine Learning	• The energy trading between consumers and prosumers is enhanced through the optimization of power flow and the implementation of energy crowdsourcing. • Energy marketing is carried out through day-ahead, real-time management, and scheduling of distributed energy resources, ensuring that the smart grid's load demand is appropriately supplied. • Data mining techniques are employed for time-series analysis of historical energy usage data to uncover and analyze hidden trends. • The insights gained from time-series analysis support energy management in making informed decisions for future planning and effective management of energy resources.
(Hafeez et al., 2020b)	2020	Pakistan	Electrical Energy Consumption Forecasting	Deep Learning	• The study introduces a novel deep learning model, founded on a FCRBM, for forecasting electrical energy usage in the context of a smart grid. It employs the ReLU activation function and a multivariate autoregressive approach.
(Kaur et al., 2022)	2020	Australia	Energy Forecasting	Deep Learning	• The research looks at the suitability of classical point forecasting approaches, which include statistical, machine learning, and deep learning techniques, for energy forecasting in SG systems. • Furthermore, the study investigates hybrid approaches and data pre-processing strategies to increase energy forecasting performance.

5.4.2. *Fog computing*

Fog computing assumes a pivotal role in advancing smart grid technologies, effectively tackling significant challenges. With the proliferation of IoT devices, fog computing extends cloud capabilities to the network's edge, as depicted in Fig. 10. This enables local data processing, reducing latency and accelerating decision-making. Table 7, illustrates the various techniques of fog computing used for smart grid systems. Fog nodes situated near end-users analyze real-time data from smart meters and distributed energy resources, optimizing network traffic and reducing costs. Moreover, fog computing ensures secure and private data processing, safeguarding sensitive information, and ensuring uninterrupted services during network disruptions (Shah et al., 2019). Fog computing improves SG operations by integrating cloud computing by providing low-latency, dependable, and secure data processing capabilities at the network's edge.

Fog and edge computing play vital roles in enhancing distributed intelligence within smart grids. They enable real-time data processing, analysis, and decision-making closer to where data is generated. By decentralizing computing resources, they empower smart grid applications to respond rapidly to dynamic conditions, optimize energy management, and improve system reliability.

Compared to centralized computing models, fog and edge computing offer several advantages:

- **Reduced Latency:** Processing data locally minimizes latency, enabling faster response times for critical grid applications.
- **Bandwidth Efficiency:** Data filtering and processing closer to the source reduce the volume of data transmitted, improving bandwidth efficiency and reducing network congestion.
- **Improved Reliability:** Decentralizing resources reduces reliance on centralized data centers, enhancing system reliability and resilience.
- **Enhanced Privacy and Security:** Local data processing minimizes the transmission of sensitive information over the network, improving data privacy and security.

6. Case studies and success stories

The case studies delve into the significant advancements in green IoT for smart grids, illuminating the path towards a sustainable energy sector. Each case study showcases the transformative potential of Green

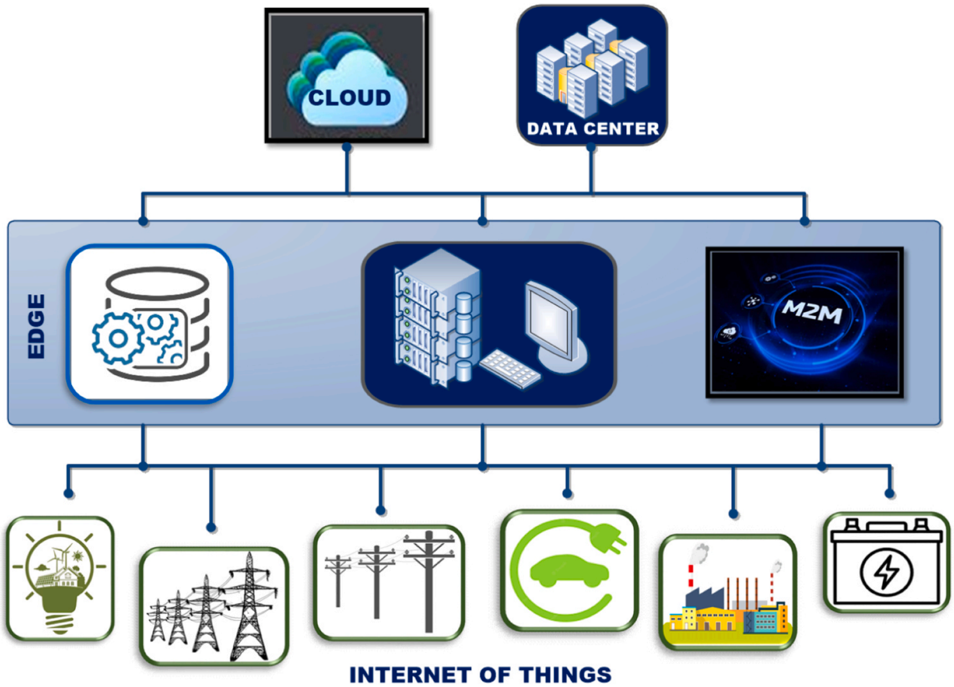

Fig. 9. Edge computing-based smart grid.

IoT technologies, illustrating their role in optimizing the incorporation of renewable energy sources, enabling efficient demand response, enhancing building energy efficiency, managing microgrids, and addressing critical cybersecurity and data privacy challenges. By harnessing the power of IoT and data analytics, smart grids empowered with Green IoT capabilities are establishing the groundwork for a greener, more robust, and sustainable energy future. These case studies exemplify the profound impact of Green IoT in revolutionizing the energy landscape and paving the way toward a cleaner and more resilient world. Table 8 below illustrates the various latest technologies incorporated into the smart grid.

The case studies presented in this article demonstrate the significant impact of Green IoT technologies in real-world smart grid applications. These solutions integrate IoT devices and data analytics to optimize renewable energy use, enable efficient demand response, enhance building energy efficiency, manage microgrids, and address cybersecurity challenges. They underscore the effectiveness of Green IoT in transforming energy management practices and promoting sustainability in smart grid operations.

- **Optimized Energy Management:** Green IoT solutions help utilities adjust energy consumption patterns, minimize peak demand, and maximize renewable energy use through IoT sensors, data analytics, and automation.
- **Enhanced Grid Resilience:** Real-time monitoring and predictive maintenance provided by Green IoT solutions help utilities identify and address issues before they escalate, reducing downtime and improving system reliability.
- **Promotion of Sustainability:** Green IoT solutions reduce energy consumption, carbon emissions, and environmental impact through renewable energy integration, energy efficiency initiatives, and demand-side management programs.
- **Advanced Energy Storage Solutions:** Implementing energy storage systems to enhance grid stability and mitigate the intermittency of renewable sources.
- **Smart Grid Automation:** Deploying smart grid automation technologies for real-time monitoring, predictive analytics, and automated energy flow control, reducing operational costs.
- **Public-Private Partnerships:** Collaborating with private sector partners and leveraging public-private partnerships to secure funding and accelerate the deployment of Green IoT solutions.
- **Policy Support and Regulatory Frameworks:** Enacting supportive policies and regulatory frameworks to incentivize renewable energy integration, promote Green IoT adoption, and facilitate a transition to a sustainable energy ecosystem.

Throughout the case studies, several challenges were identified and successfully addressed to ensure the effective implementation of Green IoT solutions in smart grid applications:

- **Integration Complexity:** Initial challenges in integrating diverse IoT devices and communication networks were overcome through meticulous planning and robust network design.
- **Cybersecurity Risks:** Stringent measures, such as advanced security protocols and encryption mechanisms, were implemented to mitigate cybersecurity risks and protect critical grid infrastructure.
- **Data Management:** Challenges in managing vast amounts of data were tackled using cloud computing and advanced data management techniques to enable real-time insights and informed decision-making.
- **Data Security and Privacy Concerns:** Robust cybersecurity measures and data protection protocols were emphasized to address data security and privacy concerns.
- **Interoperability and Integration Challenges:** Strategies such as standardization efforts and interoperable protocols were employed to overcome challenges related to interoperability and data integration.
- **Regulatory and Policy Hurdles:** The need for regulatory reforms, incentive programs, and stakeholder engagement was highlighted to facilitate the adoption of sustainable energy technologies.
- **Intermittency and Grid Stability:** Challenges in maintaining grid stability due to the variability of renewable energy sources were addressed.
- **Integration of Smart Grid Technologies:** Significant upgrades to existing grid infrastructure were required to integrate Green IoT

Table 6
Edge computing with other techniques used for smart grid application.

Ref	Year	Location of Study	Purpose	Technologies/ Process	Observation
(Hu et al., 2024)	2024	China	Service scheduling strategy	Edge Computing	• A service scheduling framework is introduced for Edge Computing in the smart grid. • The issue of service scheduling is split into two parts: prioritizing microservices and selecting cores. • Microservice prioritization establishes the order for scheduling microservices to meet execution constraints. • Core selection assigns microservices to appropriate cores for execution.
(Xiao et al., 2024)	2024	China	energy-efficient access	Edge Computing	• The paper introduces a new edge-assisted computation mode to improve decryption's computational efficiency. • This mode cuts down the computational costs for data users, making data access more efficient. • By incorporating edge computing, the computational load gets distributed, enhancing performance and responsiveness in smart grid situations.
(Guerrero et al., 2023)	2023	Spain	General-Purpose Distributed Analytic Platform	Edge Computing and Computational Intelligence	• Description of an edge computing-based distributed analytic platform for distributed networks • Utilization of a DAE to divide and distribute calculation tasks among nodes • Partial results can be sent without sharing the original data, ensuring data privacy • The investigation focuses on three computational intelligence algorithms, namely GA, GA with Evolution Control, and PSO, for the purpose of task decomposition and distribution. • Enables real-time decision-making and faster computation closer to data sources
(Alorf, 2023)	2023	Saudi Arabia	Scheduling the Energy Consumption	Edge-Cloud Computing	• Proposed a model based on edge-cloud computing for scheduling energy demand with reward-based energy usage. • Prioritize consumer preferences when operating appliances. • A distributed system is developed based on non-cooperative game theory, aimed at reducing communication overhead between edge nodes. • Reduce latency in scheduling grid appliances.
(Zhu et al., 2023)	2023	China	Data Poisoning Attack	Edge Computing	• The study proposes a framework for online data poisoning attacks grounded in the online regression task model. • Contaminate the sample data stream gradually entering the cache to manipulate the model. • The study suggests a point selection method based on sample loss within the proposed framework.
(Pang et al., 2022)	2022	China	Forecast Model	Edge Computing	• The goal is to reduce needless resource use in intelligent PGSs. • Utilized EC technology for PGS load forecasting and PGS load forecasting model optimization.
(Liu et al., 2022)	2022	China	Power Line Inspection	Double-Layer Mobile Edge Computing	• The study developed a new power line inspection method for smart grid networks using mobile edge computing technology. • The proposed approach involves double-layer architecture. • The upper layer comprises UAVs equipped with MEC hardware for the local processing of inspection footage. • Terrestrial base stations handle less critical tasks. • Alternating optimization approach utilized to address cost reduction challenge.
(Minh et al., 2022)	2022	Vietnam	grid management	Edge Computing, IoT	• An in-depth review of edge computing for IoT-enabled smart grid systems is offered. The study identifies the challenges and unresolved issues in this domain. Additionally, the smart grid is considered the future energy system in the era of the Internet of Things.
(Slama, 2022)	2022	Saudi Arabia	Prosumer, AI scheduling	Edge Computing	• Identified the challenges and unresolved issues in the field. • The smart grid is contemplated as the future energy system in the era of the Internet of Things.
(Bourhnane et al., 2021)	2021	Morocco	SBCs to process data stemming	Edge Computing	• Presented the construction of an edge platform for processing smart grid data using SBCs. • The deployment of SBCs in the Smart Grid is motivated by the objectives of achieving energy efficiency and cost-effectiveness. • The platform is tested using a distributed job that utilizes Hadoop's MapReduce programming model to average random numbers.
(Zhang et al., 2021)	2021	China	Security Protection Technology of Electrical Power System	Edge Computing	• The study introduced a multiservice-integrated security protection architecture designed specifically for power grid edge computing. • Encryption and access authentication technologies are employed for edge computing in the power grid. • The study effectively addressed security concerns in power grid edge computing while also harnessing the value of edge computing in power grid applications. • Defense measures are deployed to bolster device security, network security, data security, and application security within power grid edge computing.

(*continued on next page*)

Table 6 (*continued*)

Ref	Year	Location of Study	Purpose	Technologies/ Process	Observation
(Hu et al., 2024)	2020	Taiwan	Smart meters	Edge Computing	• The purpose is to provide users with sufficient time to evaluate their usage and determine the need for an adequate supply from the utility. • The suggestion is to incorporate the Edge MDMS and Cloud-MDMS as inference and training models, aiming to reduce latency and offset the increased latency in comparison to the conventional centralized system.
(Adeniran et al., 2020)	2020	South Florida	Optimization	Edge Computing	• This study presented an edge-enabled smart grid architecture. • The edge layer of the smart grid is established, integrating optimization formulas to determine the placement and connectivity pattern of edge servers with Phasor Measurement Units in the system.
(Sun et al., 2020)	2020	China	Energy consumption optimisation	Edge Computing, IoT	• Proposed a paradigm for mobile edge computing and an offloading strategy considering renewable energy. • The model takes into account work offloading, and the stochastic nature of renewable energy arrival, and introduces a task computing offloading method based on renewable energy. • The approach integrates the alternating direction method of the multipliers algorithm to accommodate the distinctive characteristics of renewable energy.
(Yao et al., 2019)	2019	China	Cost-Efficient Tasks Scheduling	Edge Computing	• The costs of data processing tasks in smart grid scenarios, executed by edge computing systems, were meticulously analyzed. • The primary objective is to efficiently schedule jobs to fulfill task completion requirements while simultaneously minimizing the cost of the edge computing system. • In response to the cost optimization problem, a green greedy algorithm is proposed as a viable solution.
(Siddiqui et al., 2019)	2019	Pakistan	Adaptive Data Processing Framework	Edge Computing	• The EADP method is proposed, which categorizes data segments into IoT and non-IoT categories. • The technique utilizes the End of File process between runtime executions to ensure the successful production of segment files. • EADP also suggests a replica generation technique that employs hassle-free data analytics to reduce network stress and facility grid load.
(Sirojan et al., 2019)	2019	Australia	Real-time Smart Meter Data Analytics	Edge Computing	• A demonstrated embedded edge computing paradigm showcases its ability to enhance functionality and overcome the drawbacks of smart meters. • The integration of data analytics with smart meters proves to be highly effective in reducing accuracy, latency, and bandwidth requirements for smart grid applications.

technologies for real-time monitoring and control of renewable energy sources.

- **Investment and Financing:** Economic challenges associated with upfront costs were tackled through innovative financing mechanisms and investment strategies.

7. Sustainability in green IoT for smart grids

Green IoT technologies contribute to advancing sustainability within smart grids by facilitating more efficient energy management, enhancing grid reliability, and promoting the integration of renewable energy sources. By leveraging IoT devices and data analytics, smart grids can optimize energy distribution, reduce wastage, and enable proactive maintenance, leading to reduced carbon emissions and environmental impact (Maksimovic, 2018). Specific impactful technologies highlighted include:

- **Smart Meters and Advanced Metering Infrastructure:** Real-time monitoring of energy consumption allows utilities to identify inefficiencies and implement demand-side management strategies, empowering consumers to make informed decisions.
- **Demand Response Systems:** IoT-enabled systems dynamically adjust electricity consumption to balance supply and demand, optimizing grid operations and avoiding costly infrastructure upgrades.
- **Distributed Energy Resources:** IoT facilitates the integration and management of renewable energy sources, maximizing their use and enhancing grid resilience.
- **Predictive Maintenance:** IoT sensors enable predictive maintenance of grid infrastructure, minimizing downtime and reducing maintenance costs.
- **Grid Automation and Control:** IoT-enabled systems automate operational processes, improving system reliability and minimizing outage durations. The integration of Green IoT technologies into smart grids promises to advance sustainability goals by optimizing energy usage, reducing emissions, and enhancing grid resilience, highlighting their potential impact in driving the transition to a more sustainable energy future.

7.1. *Challenges faced in implementing sustainability in green IoT for smart grids*

As societies worldwide grapple with climate change, resource depletion, and environmental degradation, the need for sustainable energy solutions has never been more critical. Sustainability guides the development and deployment of smart grids, aiming for more resilient, efficient, and environmentally responsible energy systems (Gorea et al., 2023; Kirmani et al., 2022).

- **Environmental Considerations:** Smart grid development aims to reduce environmental impacts and combat climate change. Traditional energy systems heavily relying on fossil fuels contribute to greenhouse gas emissions, air pollution, and habitat destruction. Smart grids can integrate renewable energy sources like solar, wind, and hydroelectric power, reducing reliance on fossil fuels and cutting carbon emissions. By optimizing energy distribution and

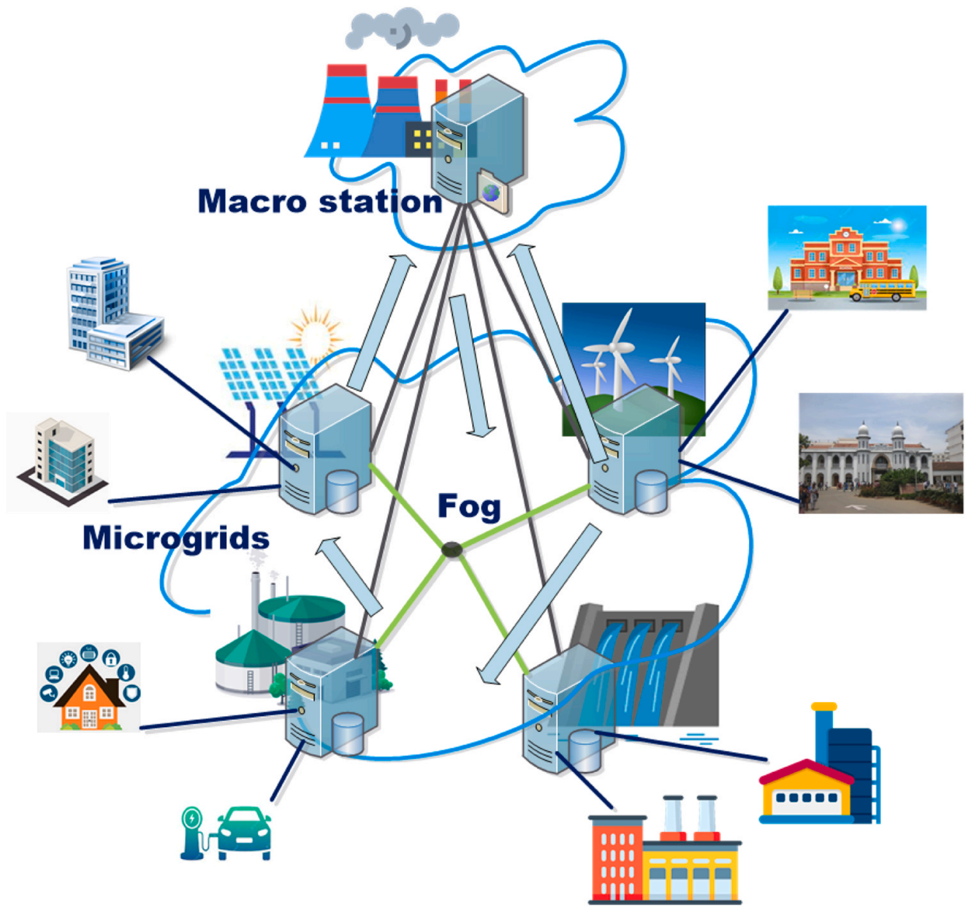

Fig. 10. Fog computing-based smart grid.

consumption, smart grids minimize waste and environmental harm, promoting a cleaner and more sustainable energy future.

- **Economic Benefits:** Sustainability in smart grids offers significant economic advantages. Transitioning to renewables and implementing energy efficiency measures can cut energy costs, boost energy security, and spur economic growth. Smart grid technologies streamline energy management, balance loads, and respond to demand, leading to savings for consumers and utilities. Investing in sustainable energy infrastructure creates jobs, fosters innovation, and drives economic development.
- **Social Equity and Resilience:** Sustainability in smart grid development also focuses on social equity and resilience. Access to affordable, reliable, and clean energy is crucial for human well-being and economic prosperity. Smart grids can improve energy access and affordability, especially for underserved communities. By decentralizing energy production and involving consumers in energy markets, smart grids enhance energy democracy and resilience, reducing vulnerability to disruptions and ensuring equitable access to essential services.
- **Long-Term Viability:** Sustainability in smart grid development ensures the long-term viability and resilience of energy systems. Embracing sustainable practices like energy efficiency and renewable energy integration helps smart grids adapt to changing environmental conditions, technological advancements, and regulatory frameworks. Sustainable energy systems are more resilient to shocks, ensuring continuity of service and minimizing societal disruptions caused by natural disasters, cyber-attacks, or geopolitical instability.

8. Future directions and research trends

The integration of real-time IoT into a smart grid, coupled with effective protocols, presents future challenges and disputes. These problems impede the achievement of a sustainable future, including scalability, data security, ensuring reliable algorithm performance in unfavorable conditions, and enhancing operator proficiency in AI tools. It is imperative to address the specific scientific challenges to overcome these limitations and meet the evolving requirements of the smart grid. The following difficulties outline some of the significant challenges that need to be addressed:

8.1. Investment in SG infrastructure

The implementation of smart grid infrastructure has been initiated by several countries as a means to reduce carbon emissions. These nations are actively involved in projects aimed at assessing the feasibility of the network. Construction of SG infrastructure has already commenced in countries like Australia, South Korea, and Japan. However, the primary concern lies in the initial investment required, which is further compounded by the ongoing maintenance costs of the entire network. Therefore, it is recommended to conduct a comprehensive financial evaluation before committing to such a significant infrastructure investment (Qays et al., 2023). To establish the SG infrastructure, a developing country would need to allocate an initial investment, the estimation of which will be provided here. Additionally, it will provide a general overview of the maintenance expenses and any additional costs necessary to ensure the network operates efficiently.

Table 7
Fog computing with various techniques used for smart grid.

Ref	Year	Location of Study	Purpose	Methods/ Process	Observation
(Sonker et al., 2024)	2024	India	Cyber security	Fog computing, IoT	• The paper suggests an intrusion detection system based on fog computing to boost WSN security. • It aims to balance accurate data transmission with sensor energy limits while ensuring effective intrusion detection and optimal network resource use.
(Zhang et al., 2024b)	2024	China	Cyber security	Fog computing	• In the next-gen power grid, the smart grid must meet security, efficiency, and real-time monitoring needs. • Fog computing's low latency and distributed nature enhance communication efficiency and user satisfaction in smart grids. • It excels in energy efficiency while maintaining robust security.
(Jamshed et al., 2023)	2023	Glasgow	fixed scheduling and event-driven data services	Fog computing, cloud computing	• A two-step optimal allocation technique for Fog nodes in the power grid has been developed. The main aim is to minimize end-to-end latency and reduce capital investment costs by considering the power grid structure and spatial distribution of data traffic. • Optimized the allocation of Fog nodes for efficient network performance. • Reduced end-to-end latency and lowered capital investment costs.
(Li et al., 2022a)	2022	China	privacy-preserving multi-level aggregate signcryption	Privacy-preserving techniques, Quantum key pool, and Mobile fog computing	• A groundbreaking multi-level aggregate signcryption and query technique for the Smart Grid has been reported. • Addressing challenges related to key distribution and random number generation • Potential utilization of both classical and quantum-based facilities, with current underutilization of expensive quantum facilities.
(Akram et al., 2021)	2021	Australia	Efficient Resource Utilisation	Fog computing, cloud computing	• Introduced a novel approach: combining simulated annealing with BPSO for inertia weight modification • In this method, an essential component is the modification of the search space's dimensions to identify the best solution
(Mahmood et al., 2021)	2021	Pakistan	Digital Certificate Verification Scheme	Fog Computing	• The emphasis lies on keeping resources close to the edge, which significantly enhances the security of smart grid networks.
(Shahzad et al., 2021)	2021	Pakistan	Optimal Fuzzy Energy Trading System	Fog Computing	• The research introduces a method for achieving optimal energy marketing within a fog-enabled smart grid setup, utilizing fuzzy logic. In this context, existing systems encounter various challenges concerning network latency, computational overhead, information accessibility, scalability, and overall performance. • Some methods have practical limitations, such as the requirement for specialized transmission lines for energy trading • Many existing systems are based on the dedicated producer-consumer paradigm
(Forcan and Maksimović, 2020)	2020	Bosnia and Herzegovina	Smart Grid monitoring	Cloud-Fog	• Involved in the creation of communication system models dedicated to monitoring the voltage profile and calculating power losses within the Smart Grid. • Investigated communication system models based on both cloud and cloud fog approaches for real-time monitoring within the SG.
(Hussain et al., 2020)	2020	India	Optimal location	Fog Computing for Big Data Analytics	• A review is provided, focusing on the various BDA techniques and their application in an IoT-enabled smart grid network. • Highlights the core ideas, practices, and specifications of BDA approaches in SG applications, using the data-generating scenario of a Dutch power system as an example.
(Liu et al., 2019)	2019	China	privacy-preserving scheme	Fog Computing	• The formulation of an innovative smart grid architecture has been accomplished, centered on the integration of platforms for both fog and cloud computing. • The proposition entails outsourcing finely-grained, encrypted usage data to the cloud as a preventive measure against potential misuse by the service provider. • Makes effective use of fog nodes' low communication latency in the architecture • Enables dynamic regulation of electricity production and distribution by the service provider
(Chekired et al., 2019)	2019	France	Energy Storage	Fog Computing	• Presenting a novel decentralized Fog architecture for the smart grid, aimed at minimizing scheduling and completion delays for EV energy demands. • Proposed an EV plug-in system founded on calendar planning principles, geared towards optimizing the scheduling of EV demand and accurately forecasting future energy flows.

8.2. Restructuring of the business model

The organization's model has undergone significant changes due to the execution of the new smart grid. The introduction of new technologies has transformed the customer's perspective and enabled the establishment of a decentralized power supply network. As a result, company procedures are also evolving (Pal et al., 2021). It is crucial to implement new protocols to effectively communicate the benefits to

Table 8
Several case studies on smart grid.

Ref.No.	Year	Location	Type of Technologies/ Grid	Process Utilized	Observation
(Bhattarai et al., 2023)	2023	Nepal	Smart Grid	• Electrifying the transport sector • Power system • Harnessing bioenergy • Integrating renewable sources	The smart grid possesses immense potential to revolutionize the power sector in developing nations endowed with abundant renewable energy sources. Moreover, it serves as a promising solution to address energy-related obstacles prevalent in similar contexts.
(Succetti et al., 2023)	2023	Italian Island – Ponza	Smart Grid, Machine Learning, and deep learning	• Energy storage system • Renewable sources, • Electrifying the transport sector	The objective is to anticipate forthcoming alterations in the electrical grid by employing autoregressive and deep learning methodologies, thereby offering valuable insights into the economic ramifications of energy demand and supply dynamics through the incorporation of renewable energy sources and energy storage technologies.
(Amani et al., 2023)	2023	Australian	Distribution grid	• Electric vehicle • Energy Storage systems	The report highlights the importance of considering the distribution and integration of PV, BESS, and EV technologies for effective grid management
(Rochd et al., 2021)	2021	Benguerir — Morocco	Smart campus, AI-based IoT	Home energy management system	A cutting-edge Smart Home Energy Management System was conceptualized, developed, and deployed, leveraging the integration of renewable energy sources to significantly enhance energy efficiency in residential buildings.
(Sospiro et al., 2021)	2021	China, the US, and the EU	Smart Grid	• Distributed generation, • Energy storage System • EV charging infrastructure • Smart electricity markets	The study highlights the benefits of electric energy utilization, with a particular emphasis on integrating renewable sources.
(Ahmed et al., 2020)	2020	–	Smart Grid & Machine Learning	Renewable Energy sources	Through the application of ML and the integration of diverse formulations and metrics, the EMM facilitates proficient energy trading and elevates the seamless integration of renewable energy sources within both the smart grid and Energy districts.
(Satuyeva et al., 2019)	2019	Kazakhstan	Smart Grid, Energy 4.0: IoT	Power monitoring system	Energy 4.0 offers companies the opportunity to develop innovative business models and sustainable energy generation and distribution approaches.

customers. The utility business model should be implemented at the distribution level to seamlessly integrate load management and power generation.

8.3. Authentication

Energy providers must validate the smart meters to prevent billing complications. Establishing a secure connection between smart devices becomes more challenging when they are managed by different organizations. To ensure the proper working of the system and prevent any misuse, it is essential to maintain the distinctiveness of IoT components in the smart grid system. Only authorized employees or programs should be granted accreditation to perform necessary actions and access resources.

8.4. Cyberattacks

IoT-enabled transformers and other physical assets, including AMI, are integral parts of the smart grid system. Consequently, cyberattacks targeting the smart grid pose a significant threat to the infrastructure and the proper functioning of these assets. As the development of IoT-enabled SG applications, the importance of protecting against cyberattacks becomes even more critical (Li et al., 2022b). In this regard, strict adherence to established codes of practice such as the Electrical Equipment Safety System, Security for IoT customers, and IEEE 802.15 is crucial under federal law.

8.5. Interoperability

Heterogeneous communication techniques play a pivotal role in meeting the multifaceted demands of IoT-enabled smart grid systems. Unlike conventional telecommunication standards, the contemporary communication norms in IoT-enabled SG systems require seamless interoperability across interfaces, messages, and processes. However, achieving this interoperability poses a formidable challenge owing to the involvement of multiple suppliers and the existence of legacy systems, which impede the establishment of efficient business rules (Pal et al., 2021). Consequently, for IoT-enabled SG systems, it becomes imperative to arrive at a consensus regarding the adoption and interpretation of diverse technologies and standards, even those that may not have a direct association with IoT.

8.6. Data privacy innovation

The deployment of the smart grid raises significant privacy concerns for customers as it collects sensitive information about them, including their energy usage patterns and Personally Identifiable Information. Thorough research in the field of data aggregation is necessary to safeguard privacy and ensure that only authorized personnel can access customer data. Implementing techniques such as encryption, aggregation, and steganography in smart grids is crucial for addressing security issues. Future advancements in technology should prioritize reliability, secure storage, proper disposal methods, and robust data protection measures (Li et al., 2023).

8.7. Need for standards and regulatory frameworks

Enhancing the comprehension of privacy practices necessitates the provision of clear, concise, and consistent privacy notifications. Professionals should work towards developing standardized norms for data sharing across communities. When implementing big data solutions, utilities must adhere to regulatory frameworks that govern their operations. These frameworks should include comprehensive disclosure requirements, detailing the intended use, storage duration, and any thirdparty involvement in data sharing. Regulatory compliance must encompass the management of big data applications and also consider cyber-security aspects to ensure effective control and protection (Ponnusamy et al., 2021).

8.8. Monitoring, real-time control and operation

The smart grid exhibits continuous year-round operation, adhering to its preconceived design plan while retaining the capacity to dynamically optimize its functions in response to operational data. Nonetheless, the formidable hurdles of scalability and computational complexities arise when handling substantial volumes of data. Hence, it is imperative for forthcoming research endeavors to be dedicated to resolving these challenges. To estimate the reliability and scalability of smart grids, the formulation of precise criteria becomes indispensable for discerning suitable indicators and tools. Furthermore, the meticulous identification of energy conservation potential through astute feedback pertaining to facility and operational facets serves to further accentuate the manifold benefits conferred by the smart grid.

8.9. Innovative computational analytics

In the intricate realm of the smart grid, a diverse array of optimization techniques, spanning from foundational to cutting-edge algorithms, are harnessed. Effectively managing the processing and handling of data in smart grids often demands the application of distributed and parallel intelligence. The development of robust computational analytics assumes paramount importance, enabling precise identification of long-term consumption and production trends. In light of the inherent complexities of optimization, machine learning emerges as a pivotal technology in this domain. Yet, further investigation is warranted to ascertain suitable ML, DL, and RL algorithms that can augment the efficacy of the smart grid system (Qays et al., 2023; Pal et al., 2021; Li et al., 2022b, 2023; Ponnusamy et al., 2021).

As the world transitions towards more sustainable and resilient energy systems, the convergence of green Internet of Things (IoT) technologies with smart grids has emerged as a promising paradigm for optimizing energy efficiency, enhancing grid reliability, and reducing carbon emissions. In this context, the article "A Comprehensive Review of Advancements in Green IoT for Smart Grids: Paving the Path to Sustainability" provides a timely and insightful analysis of the latest developments at the intersection of these two domains. While the article's key contributions shed light on the current state-of-the-art, it is imperative to look ahead and identify innovative future directions that can further propel the field toward achieving its sustainability goals. In response to the reviewer's call for updated and innovative future directions, the following suggestions are proposed:

- Proposing novel approaches for further integration of green IoT technologies with smart grids, focusing on leveraging advances in edge computing and decentralized energy management systems to enhance grid resilience and efficiency.
- Advocating for the development of predictive analytics and machine learning algorithms tailored specifically for smart grid applications, with a focus on real-time energy forecasting, demand response optimization, and anomaly detection to enable more proactive and adaptive grid management strategies.
- Suggesting innovative research avenues in the realm of renewable energy integration, such as exploring the potential of blockchain technology for facilitating peer-to-peer energy trading and incentivizing renewable energy generation at the community level, thus fostering a more decentralized and sustainable energy ecosystem.
- Encouraging interdisciplinary collaborations between researchers, policymakers, and industry stakeholders to address socio-technical challenges associated with the adoption of green IoT-enabled smart grids, including issues related to data privacy, cybersecurity, and equitable access to energy resources.
- Promoting the development of holistic sustainability frameworks that incorporate environmental, social, and economic considerations into smart grid planning and decision-making processes, with an emphasis on fostering inclusive and equitable energy transitions that benefit all stakeholders.
- Exploring the role of emerging technologies such as quantum computing and advanced materials in reimagining the future of smart grid infrastructure, with a focus on enhancing energy storage capabilities, optimizing grid topology, and enabling seamless integration of distributed energy resources into the grid.

By embracing these innovative future directions, the article can contribute to advancing the state-of-the-art in green IoT-enabled smart grids and paving the way towards a more sustainable and resilient energy future.

9. Conclusions

Future smart grids are poised to address the challenges allied with classical one-directional information and power flow networks, such as the escalating energy consumption and the interoperability of diverse devices within the network. The integration of IoT technology supports smart grids with cutting-edge IoT devices for system monitoring, analysis, and control. This study presents a comprehensive state-of-the-art overview of green IoT-assisted SG systems and emphasizes several challenges that necessitate in-depth investigation and prototyping for resolution.

Additionally, the paper highlighted the challenges encountered during execution and how they were overcome while presenting case studies of towns that successfully integrated green technologies. The review paper concludes by emphasizing potential study topics and cutting-edge technologies such as artificial intelligence, the Internet of Things, edge computing, and fog computing. The value of technology developments in green IoT for smart grids is emphasized in this conclusion, as they have the potential to significantly enhance cities' energy efficiency and pave the way for a more sustainable future. Forthcoming research and development should concentrate on addressing implementation issues, emerging advanced technologies, and nurturing collaboration between businesses, academia, and government to advance smart grid solutions.

CRediT authorship contribution statement

Mun-Kyeom Kim: Writing – review & editing, Funding acquisition, Conceptualization. **P. Pandiyan:** Writing – original draft, Validation, Methodology, Conceptualization. **S. Saravanan:** Resources, Investigation. **Raju Kannadasan:** Writing – review & editing, Conceptualization. **S. Krishnaveni:** Visualization, Validation. **Mohammed H. Alsharif:** Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the

Ministry of Education (2020R1A2C1004743).

References

Abdulsalam, K.A., Adebisi, J., Emezirinwune, M., Babatunde, O., 2023. An overview and multicriteria analysis of communication technologies for smart grid applications. e-Prime-Advances in Electrical Engineering. Electron. Energy 3, 100121.

Adeniran, A., Hasnat, M.A., Hosseinzadeh, M., Khamfroush, H., Rahnamay-Naeini, M., 2020. Edge layer design and optimization for smart grids (November). In 2020 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm). IEEE, pp. 1–6 (November).

Aguiar-Pérez, J.M., Pérez-Juárez, M.Á., 2023. An Insight of Deep Learning Based Demand Forecasting in Smart Grids. Sensors 23 (3), 1467.

Ahmed, W., Ansari, H., Khan, B., Ullah, Z., Ali, S.M., Mehmood, C.A.A., Nawaz, R., 2020. Machine learning based energy management model for smart grid and renewable energy districts. IEEE Access 8, 185059–185078.

Akram, J., Tahir, A., Munawar, H.S., Akram, A., Kouzani, A.Z., Mahmud, M.P., 2021. Cloud-and Fog-Integrated Smart Grid Model for Efficient Resource Utilisation. Sensors 21 (23), 7846.

Aktas, A., Erhan, K., Ozdemir, S., Ozdemir, E., 2017. Experimental investigation of a new smart energy management algorithm for a hybrid energy storage system in smart grid applications. Electr. Power Syst. Res. 144, 185–196.

Akyildiz, Ian F., Su, W., Sankarasubramaniam, Y., Cayirci, E., Mar. 2002. Wireless Sensor Networks: A Survey. Comput. Netw. Elsevier J. vol. 38 (4), 393–422.

Albreem, M.A., Sheikh, A.M., Alsharif, M.H., Jusoh, M., Yasin, M.N.M., 2021. Green Internet of Things (GIoT): Applications, practices, awareness, and challenges. IEEE Access 9, 38833–38858.

Ali, S., Khan, I., Jan, S., Hafeez, G., 2021. An optimization based power usage scheduling strategy using photovoltaic-battery system for demand-side management in smart grid. Energies 14 (8), 2201.

Ali, S., Rehman, A.U., Wadud, Z., Khan, I., Murawwat, S., Hafeez, G., Samuel, O., 2022. Demand response program for efficient demand-side management in smart grid considering renewable energy sources. IEEE Access 10, 53832–53853.

Aljadani, N., Gazdar, T., 2022. A Novel Security Architecture for WSN-Based Applications in Smart Grid. Smart. Cities 5 (2), 633–649.

Alorf, A., 2023. Edge-Cloud Computing for Scheduling the Energy Consumption in Smart Grid. Comput. Syst. Sci. Eng. 46 (1), 273–286.

Alquthami, T., Zulfiqar, M., Kamran, M., Milyani, A.H., Rasheed, M.B., 2022. A performance comparison of machine learning algorithms for load forecasting in smart grid. IEEE Access 10, 48419–48433.

Alrasheedi, A., Almalaq, A., 2022. Hybrid Deep Learning Applied on Saudi Smart Grids for Short-Term Load Forecasting. Mathematics 10 (15), 2666.

Al-Rubaye, S., Cosmas, J., 2018. Provisioning unlicensed LAA interface for smart grid applications. 5G. Netw.: Fundam. Requir., Enabling Technol., Oper. Manag. 603–624.

Alsamhi, S., Ma, O., Ansari, M.S., & Meng, Q. (2018). Greening internet of things for smart everythings with a green-environment life: a survey and future prospects. arxiv 2018. arXiv preprint arXiv:1805.00844.

Alsharif, Mohammed H., Anabi Hilary Kelechi, Abu Jahid, Raju Kannadasan, Manish Kumar Singla, Jyoti Gupta, Zong Woo Geem, 2024b. "A comprehensive survey of energy-efficient computing to enable sustainable massive IoT networks,". Alex. Eng. J. 91.

Alsharif, M.H., Jahid, A., Kannadasan, R., Kim, M.-K., 2024a. Unleashing the potential of sixth generation (6G) wireless networks in smart energy grid management: A comprehensive review. Energy Rep. vol. 11, 1376–1398.

Alsharif, M.H., Jahid, A., Kelechi, A.H., Kannadasan, R., 2023. Green IoT: A review and future research directions. Symmetry 15 (3), 757.

Alsharif, M.H., Kannadasan, R., Jahid, A., Albreem, M.A., Nebhen, J., Choi, B.J., 2021. "Long-term techno-economic analysis of sustainable and zero grid cellular base station,". IEEE Access vol. 9, 54159–54172.

Alsharif, Mohammed H., Md Sanwar Hossain, Abu Jahid, Muhammad Asghar Khan, Bong Jun Choi, Samih, M.Mostafa, 2022. , "Milestones of Wireless Communication Networks and Technology Prospect of Next Generation (6G),". Comput., Mater. Contin. 71 (3).

Alsharif, Mohammed H., Nordin, Rosdiadee, Mahamod Ismail, 2014. Classification, Recent Advances and Research Challenges in Energy Efficient Cellular Networks. Wirel. Pers. Commun. 77 (2).

Alsharif, Mohammed H., Nordin, Rosdiadee, Mahamod Ismail, 2016. Green wireless network optimisation strategies within smart grid environments for Long Term Evolution (LTE) cellular networks in Malaysia. Renew. Energy 85.

Alsirhani, A., Alshahrani, M.M., Abukwaik, A., Taloba, A.I., Abd El-Aziz, R.M., Salem, M., 2023. A novel approach to predicting the stability of the smart grid utilizing MLP-ELM technique. Alex. Eng. J. 74, 495–508.

Amani, A.M., Sajjadi, S.S., Al Khafaf, N., Song, H., Jalili, M., Yu, X., McTaggart, P., 2023. Technology balancing for reliable EV uptake in distribution grids: An Australian case study. Renew. Energy 206, 939–948.

Amin, S.M., 2011. Smart grid: Overview, issues and opportunities. advances and challenges in sensing, modeling, simulation, optimization and control. Eur. J. Control 17 (5-6), 547–567.

Arumugham, V., Ghanimi, H.M., Pustokhin, D.A., Pustokhina, I.V., Ponnam, V.S., Alharbi, M., Sengan, S., 2023. An Artificial-Intelligence-Based Renewable Energy Prediction Program for Demand-Side Management in Smart Grids. Sustainability 15 (6), 5453.

Atzeni, I., Ordonez, L.G., Scutari, G., Palomar, D.P., Fonollosa, J.R., 2013a. "Demand-side management via distributed energy generation and storage optimization,". IEEE Trans. Smart Grid vol. 4 (2), 866–876.

Atzeni, I., Ordonez, L.G., Scutari, G., Palomar, D.P., Fonollosa, J.R., 2013b. "Noncooperative and cooperative optimization of distributed energy generation and storage in the demand-side of the smart grid,". IEEE Trans. Signal Process. vol. 61 (10), 2454–2472.

Balaji, A.J., Harish Ram, D.S., Nair, B.B., 2019. A deep learning approach to electric energy consumption modeling. J. Intell. Fuzzy Syst. 36 (5), 4049–4055.

Balavignesh, S., Kumar, C., Sripriya, R., Senjyu, T., 2024. An enhanced coati optimization algorithm for optimizing energy management in smart grids for home appliances. Energy Rep. 11, 3695–3720.

Baseer, M.A., Alsaduni, I., 2023. A Novel Renewable Smart Grid Model to Sustain Solar Power Generation. Energies 16 (12), 4784.

Benhamaid, S., Bouabdallah, A., Lakhlef, H., 2022. Recent advances in energy management for Green-IoT: An up-to-date and comprehensive survey. J. Netw. Comput. Appl. 198, 103257.

Bharany, S., Badotra, S., Sharma, S., Rani, S., Alazab, M., Jhaveri, R.H., Gadekallu, T.R., 2022. Energy efficient fault tolerance techniques in green cloud computing: A systematic survey and taxonomy. Sustain. Energy Technol. Assess. 53, 102613.

Bhattarai, T.N., Ghimire, S., Mainali, B., Gorjian, S., Treichel, H., Paudel, S.R., 2023. Applications of smart grid technology in Nepal: status, challenges, and opportunities. Environ. Sci. Pollut. Res. 30 (10), 25452–25476.

Bourhnane, S., Abid, M.R., Zine-dine, K., Elkamoun, N., Benhaddou, D., 2021. Cluster of single-board computers at the edge for smart grids applications. Appl. Sci. 11 (22), 10981.

Cebekhulu, E., Onumanyi, A.J., Isaac, S.J., 2022. Performance analysis of machine learning algorithms for energy demand–supply prediction in smart grids. Sustainability 14 (5), 2546.

Chahal, A., Gulia, P., Gill, N.S., Chatterjee, J.M., 2022. Performance analysis of an optimized ANN model to predict the stability of smart grid. Complexity 2022.

Chekired, D.A., Khoukhi, L., Mouftah, H.T., 2019. Fog-computing-based energy storage in smart grid: A cut-off priority queuing model for plug-in electrified vehicle charging. IEEE Trans. Ind. Inform. 16 (5), 3470–3482.

Chen, X., Liu, J., Li, X., Sun, L., Zhen, Y., 2011. Integration of IoT with smart grid. In IET international conference on communication technology and application (ICCTA 2011) (October). IET, pp. 723–726 (October).

Dinh, H.T., Yun, J., Kim, D.M., Lee, K.H., Kim, D., 2020. A home energy management system with renewable energy and energy storage utilizing main grid and electricity selling. IEEE Access 8, 49436–49450.

Etxegarai, A., Bereziartua, A., Dañobeitia, J.A., Abarrategi, O., Saldaña, G., 2018. "Impact of Price-Based Demand Response Programs for Residential Customers,". First IEEE Int. Conf. Smart Grid Commun. 1-1.

Evans, D., 2011. The internet of things. How Evol. Internet Is. Chang. Everything, White, Cisco Internet Bus. Solut. Group (IBSG) 1, 1–12.

Forcan, M., Maksimović, M., 2020. Cloud-fog-based approach for smart grid monitoring. Simul. Model. Pract. Theory 101, 101988.

Geetha, B.T., Kumar, P.S., Bama, B.S., Neelakandan, S., Dutta, C., Babu, D.V., 2022. Green energy aware and cluster based communication for future load prediction in IoT. Sustain. Energy Technol. Assess. 52, 102244.

Gorea, C., Chiorean, D.L., Vlasa, I., Porumb, R., Bică, D., 2023. Integration of Renewable Energy Sources into Smart Grids: A Study on Impact and Solutions for Efficient Integration of Renewable Energy Sources, Such as Solar and Wind Energy, into Existing Electrical Grids (October). In International Conference Interdisciplinarity in Engineering. Springer Nature Switzerland, Cham, pp. 496–514 (October).

Guerrero, J.I., Martín, A., Parejo, A., Larios, D.F., Molina, F.J., León, C., 2023. A General-Purpose Distributed Analytic Platform Based on Edge Computing and Computational Intelligence Applied on Smart Grids. Sensors 23 (8), 3845.

Hafeez, G., Alimgeer, K.S., Wadud, Z., Shafiq, Z., Ali Khan, M.U., Khan, I., Derhab, A., 2020b. A novel accurate and fast converging deep learning-based model for electrical energy consumption forecasting in a smart grid. Energies 13 (9), 2244.

Hafeez, G., Wadud, Z., Khan, I.U., Khan, I., Shafiq, Z., Usman, M., Khan, M.U.A., 2020a. Efficient energy management of IoT-enabled smart homes under price-based demand response program in smart grid. Sensors 20 (11), 3155.

Hassaine, L., Olías, E., Quintero, J., Barrado, A., 2014. Power control for grid connected applications based on the phase shifting of the inverter output voltage with respect to the grid voltage. Int J. Electr. Power Energy Syst. 57 (0), 250–260.

Hu, K., Qu, J., Cai, Z., Li, X., Liu, Y., Zheng, J., 2024. Service scheduling strategy for microservice and heterogeneous multi-cores-based edge computing apparatus in smart girds with high renewable energy penetration. Front. Energy Res. 12, 1358310.

Hussain, M.M., Beg, M.S., Alam, M.S., 2020. Fog computing for big data analytics in IoT aided smart grid networks. Wirel. Pers. Commun. 114 (4), 3395–3418.

Hussain, M.M., Beg, M.S., 2019. Fog computing for internet of things (IoT)-aided smart grid architectures. Big Data Cogn. Comput. 3 (1), 8.

Ibrahim, B., Rabelo, L., Gutierrez-Franco, E., Clavijo-Buritica, N., 2022. Machine learning for short-term load forecasting in smart grids. Energies 15 (21), 8079.

Jamil, F., Iqbal, N., Ahmad, S., Kim, D., 2021. Peer-to-peer energy trading mechanism based on blockchain and machine learning for sustainable electrical power supply in smart grid. Ieee Access 9, 39193–39217.

Jamshed, M.A., Ismail, M., Pervaiz, H., Atat, R., Bayram, I.S., Ni, Q., 2023. Reinforcement learning-based allocation of fog nodes for cloud-based smart grid. e-Prime-Advances in Electrical Engineering. Electron. Energy 4, 100144.

Kaur, D., Islam, S.N., Mahmud, M.A., Haque, M.E., Dong, Z.Y., 2022. Energy forecasting in smart grid systems: recent advancements in probabilistic deep learning. IET Gener., Transm. Distrib. 16 (22), 4461–4479.

Khan, N., Sajak, A.A.B., Alam, M., Mazliham, M.S., 2021. Analysis of green IoT (May). In: In Journal of Physics: Conference Series, Vol. 1874. IOP Publishing, 012012 (May).

Kim, Y.J., Thottan, M., Kolesnikov, V., Lee, W., 2010. A secure decentralized data-centric information infrastructure for smart grid. IEEE Commun. Mag. 48 (11), 58–65.

Kimani, K., Langat, K., Oduol, V., 2022. Machine to Machine (M2M) Communications for Dynamic Pricing in Smart Grid Networks (March). Proc. Sustain. Res. Innov. Conf. 109–117.

Kirmani, S., Mazid, A., Khan, I.A., Abid, M., 2022. A survey on IoT-enabled smart grids: technologies, architectures, applications, and challenges. Sustainability 15 (1), 717.

Li, K., Shi, R., Wu, M., Li, Y., Zhang, X., 2022a. A novel privacy-preserving multi-level aggregate signcryption and query scheme for Smart Grid via mobile fog computing. J. Inf. Secur. Appl. 67, 103214.

Li, Y., Wang, R., Li, Y., Zhang, M., Long, C., 2023. Wind power forecasting considering data privacy protection: A federated deep reinforcement learning approach. Appl. Energy 329, 120291.

Li, Y., Wei, X., Li, Y., Dong, Z., Shahidehpour, M., 2022b. Detection of false data injection attacks in smart grid: A secure federated deep learning approach. IEEE Trans. Smart Grid 13 (6), 4862–4872.

Li, M., Yang, L., Yu, F.R., Wu, W., Wang, Z., Zhang, Y., 2019. Joint optimization of networking and computing resources for green M2M communications based on DRL (December). In 2019 IEEE Global Communications Conference (GLOBECOM). IEEE, pp. 1–6 (December).

Li Na, Chen Xi, Wu Fan, Li Xiangzhen, 2010. Study of Hierarchical Information Aggregation Technology on the Internet of Things for Smart Grid. Inf. Commun. Technol. vol 2, 20–27.

Liu, J.N., Weng, J., Yang, A., Chen, Y., Lin, X., 2019. Enabling efficient and privacy-preserving aggregation communication and function query for fog computing-based smart grid. IEEE Trans. Smart Grid 11 (1), 247–257.

Liu, S., Zhang, X., Xiao, H., Li, Z., Zhang, H., 2022. Double-Layer Mobile Edge Computing-Enabled Power Line Inspection in Smart Grid Networks. Information 13 (4), 167.

Lopez-Ardao, J.C., Rodriguez-Rubio, R.F., Suarez-Gonzalez, A., Rodriguez-Perez, M., Sousa-Vieira, M.E., 2021. Current trends on green wireless sensor networks. Sensors 21 (13), 4281.

Maharjan, S., Zhang, Y., Gjessing, S., Tsang, D.H., 2017. "User-centric demand response management in the smart grid with multiple providers,". IEEE Trans. Emerg. Top. Comput. vol. 5 (4), 494–505.

Mahmood, S., Gohar, M., Choi, J.G., Koh, S.J., Alquhayz, H., Khan, M., 2021. Digital certificate verification scheme for smart grid using fog computing (FONICA). Sustainability 13 (5), 2549.

Maksimovic, M., 2018. Greening the future: Green Internet of Things (G-IoT) as a key technological enabler of sustainable development. Internet things big data Anal. -Gener. Intell. 283–313.

Malik, A., Kushwah, R., 2022. A survey on next generation IoT networks from green IoT perspective. Int. J. Wirel. Inf. Netw. 29 (1), 36–57.

Massoud Amin, S., 2011. Smart grid: overview, issues and opportunities. Adv. Chall. Sens., Model., Simul., Optim. Control. Eur. J. Control. 5–6, 547–567.

Mazhar, T., Irfan, H.M., Haq, I., Ullah, I., Ashraf, M., Shloul, T.A., Elkamchouchi, D.H., 2023. Analysis of Challenges and Solutions of IoT in Smart Grids Using AI and Machine Learning Techniques: A Review. Electronics 12 (1), 242.

Memić, B., Čaušević, S., Džubur, A.H., Begović, M., 2022b. Green IoT in terms of system approach. In 2022 45th Jubilee International Convention on Information, Communication and Electronic Technology (MIPRO) (May). IEEE, pp. 7–11 (May).

Memić, B., Džubur, A.H., Avdagić-Golub, E., 2022a. Green IoT: sustainability environment and technologies. Sci., Eng. Technol. 2 (1), 24–29.

Migabo, E.M., Djouani, K.D., Kurien, A.M., 2020. The narrowband Internet of Things (NB-IoT) resources management performance state of art, challenges, and opportunities. IEEE Access 8, 97658–97675.

Minh, Q.N., Nguyen, V.H., Quy, V.K., Ngoc, L.A., Chehri, A., Jeon, G., 2022. Edge Computing for IoT-Enabled Smart Grid: The Future of Energy. Energies 15 (17), 6140.

Nge, C.L., Ranaweera, I.U., Midtgård, O.M., Norum, L., 2019. A real-time energy management system for smart grid integrated photovoltaic generation with battery storage. Renew. Energy 130, 774–785.

NIST, Introduction to NISTIR 7628 Guidelines for Smart Grid Cyber Security. ⟨http://www.nist.gov/smartgrid/upload/nistir-7628_total.pdf⟩ (last accessed April 10th, 2014).

Pal, R., Chavhan, S., Gupta, D., Khanna, A., Padmanaban, S., Khan, B., Rodrigues, J.J., 2021. A comprehensive review on IoT-based infrastructure for smart grid applications. IET Renew. Power Gener. 15 (16), 3761–3776.

Pang, X., Lu, X., Ding, H., Guerrero, J.M., 2022. Construction of Smart Grid Load Forecast Model by Edge Computing. Energies 15 (9), 3028.

Ponnusamy, V.K., Kasinathan, P., Madurai Elavarasan, R., Ramanathan, V., Anandan, R. K., Subramaniam, U., Hossain, E., 2021. A comprehensive review on sustainable aspects of big data analytics for the smart grid. Sustainability 13 (23), 13322.

Powroźnik, P., Szcześniak, P., Piotrowski, K., 2021. Elastic energy management algorithm using IoT technology for devices with smart appliance functionality for applications in smart-grid. Energies 15 (1), 109.

Priyanka, E.B., Thangavel, S., Gao, X.Z., 2021. Review analysis on cloud computing based smart grid technology in the oil pipeline sensor network system. Pet. Res. 6 (1), 77–90.

Qays, M.O., Ahmad, I., Abu-Siada, A., Hossain, M.L., Yasmin, F., 2023. Key communication technologies, applications, protocols and future guides for IoT-assisted smart grid systems: A review. Energy Rep. 9, 2440–2452.

Rabie, A.H., Saleh, I., A, Elkhalik, S.H.A., Takieldeen, A.E., 2024. An Optimum Load Forecasting Strategy (OLFS) for Smart Grids Based on Artificial Intelligence. Technologies 12 (2), 19.

Ram, S.K., Sahoo, S.R., Das, B.B., Mahapatra, K., Mohanty, S.P., 2023. Eternal-thing 2.0: Analog-Trojan-resilient Ripple-less Solar Harvesting System for Sustainable IoT. ACM J. Emerg. Technol. Comput. Syst. 19 (2), 1–25.

Rehman, A.U., Hafeez, G., Albogamy, F.R., Wadud, Z., Ali, F., Khan, I., Khan, S., 2021. An efficient energy management in smart grid considering demand response program and renewable energy sources. IEEE Access 9, 148821–148844.

Rochd, A., Benazzouz, A., Abdelmoula, I.A., Raihani, A., Ghennioui, A., Naimi, Z., Ikken, B., 2021. Design and implementation of an AI-based & IoT-enabled Home Energy Management System: A case study in Benguerir—Morocco. Energy Rep. 7, 699–719.

Sajak, A.A.B., Ahmad, M.N.I., Dao, H., 2024. Green IoT Based on Tropical Weather: The Impact of Energy Harvesting in Wireless Sensor Network. J. Adv. Res. Appl. Sci. Eng. Technol. 40 (1), 35–44.

Sanchez-Hidalgo, M.A., Cano, M.D., 2018. A survey on visual data representation for smart grids control and monitoring. Sustainable Energy. Grids Netw. 16, 351–369.

Sankar, V., Devi, M.N., Jayakumar, M., 2022. Data Augmented Hardware Trojan Detection Using Label Spreading Algorithm Based Transductive Learning for Edge Computing-Assisted IoT Devices. IEEE Access 10, 102789–102803.

Satuyeva, B., Sauranbayev, C., Ukaegbu, I.A., Nunna, H.K., 2019. Energy 4.0: towards IoT applications in Kazakhstan. Procedia Comput. Sci. 151, 909–915.

Shah, A.S., Nasir, H., Fayaz, M., Lajis, A., Shah, A., 2019. A review on energy consumption optimization techniques in IoT based smart building environments. Information 10 (3), 108.

Shahzad, K., Iqbal, S., Mukhtar, H., 2021. Optimal fuzzy energy trading system in a fog-enabled smart grid. Energies 14 (4), 881.

Siddiqui, I.F., Qureshi, N.M.F., Chowdhry, B.S., Uqaili, M.A., 2019. Edge-node-aware adaptive data processing framework for smart grid. Wirel. Pers. Commun. 106, 179–189.

Sirojan, T., Lu, S., Phung, B.T., Ambikairajah, E., 2019. Embedded edge computing for real-time smart meter data analytics (September). In 2019 International Conference on Smart Energy Systems and Technologies (SEST). IEEE, pp. 1–5 (September).

Slama, S.B., 2022. Prosumer in smart grids based on intelligent edge computing: A review on Artificial Intelligence Scheduling Techniques. Ain Shams Eng. J. 13 (1), 101504.

Sonker, S.K., Raina, V.K., Sagar, B.B., Bansal, R.C., 2024. Fog computing-based IoT-enabled system security for electrical vehicles in the smart grid. Electr. Eng. 1–17.

Sospiro, P., Amarnath, L., Di Nardo, V., Talluri, G., Gandoman, F.H., 2021. Smart Grid in China, EU, and the US: State of Implementation. Energies 14 (18), 5637.

Srivastava, S., Shukla, H.K., Singh, S.V., Singh, R.B., 2021. Greens IOT its Green. enabling Environ.

Succetti, F., Rosato, A., Araneo, R., Di Lorenzo, G., Panella, M., 2023. Challenges and Perspectives of Smart Grid Systems in Islands: A Real Case Study. Energies 16 (2), 583.

Sun, H., Liu, M., Qing, Z., Li, X., Li, L., 2020. Energy consumption optimisation based on mobile edge computing in power grid internet of things nodes. Int. J. web grid Serv. 16 (3), 238–253.

Syed, D., Abu-Rub, H., Ghrayeb, A., Refaat, S.S., Houchati, M., Bouhali, O., Bañales, S., 2021. Deep learning-based short-term load forecasting approach in smart grid with clustering and consumption pattern recognition. IEEE Access 9, 54992–55008.

Tabaa, M., Monteiro, F., Bensag, H., Dandache, A., 2020. Green Industrial Internet of Things from a smart industry perspectives. Energy Rep. 6, 430–446.

Tan, F., Pang, S., Cao, Y., Chen, H., Lv, T., 2024. Energy-efficient device-to-device communications for green internet of things using unmanned aerial vehicle-mounted intelligent reflecting surface. Drones 8 (4), 122.

Tingjie, L., 2010. The origin and development of things of internet. Inf. Commun. Technol. 2.

Tiwari, S., Jain, A., Yadav, K., Ramadan, R., 2022. Machine learning-based model for prediction of power consumption in smart grid. Int. Arab J. Inf. Technol. 19 (3), 323–329.

Tong, Z., Zhou, Y., Xu, K., 2023. An intelligent scheduling control method for smart grid based on deep learning. Math. Biosci. Eng. 20, 7679–7695.

Tuysuz, M.F., Trestian, R., 2020. From serendipity to sustainable green IoT: Technical, industrial and political perspective. Comput. Netw. 182, 107469.

Ullah, K., Ali, S., Khan, T.A., Khan, I., Jan, S., Shah, I.A., Hafeez, G., 2020. An optimal energy optimization strategy for smart grid integrated with renewable energy sources and demand response programs. Energies 13 (21), 5718.

Ullah, I., Khitab, Z., Khan, M.N., Hussain, S., 2019. An efficient energy management in office using bio-inspired energy optimization algorithms. Processes 7 (3), 142.

Varjovi, A.E., Babaie, S., 2020. Green Internet of Things (GIoT): Vision, applications and research challenges. Sustain. Comput.: Inform. Syst. 28, 100448.

Varma, R.S.N., Swaroop, P.J., Anand, B.K., Yadav, N., Janarthanan, N., Sarath, T.V., 2020. IOT based intelligent trash monitoring system with route optimization method. Int. J. Electr. Eng. Technol. 11 (4), 65.

Wang, K., Li, H., Feng, Y., Tian, G., 2017. "Big data analytics for system stability evaluation strategy in the energy Internet,". IEEE Trans. Ind. Inf. vol. 13 (4), 1969–1978.

Wesley, B.J., Babu, G.S., Kumar, P.S., 2024. Design and control of LSTM-ANN controllers for an efficient energy management system in a smart grid based on hybrid renewable energy sources. Eng. Res. Express 6 (1), 015074.

Xiao, P., Yang, S., Zhang, Z., Wang, H., 2024. Edge-assisted and energy-efficient access control for dynamic users group in smart grids. Peer-to-Peer Netw. Appl. 1–9.

Yao, J., Li, Z., Li, Y., Bai, J., Wang, J., Lin, P., 2019. Cost-efficient tasks scheduling for smart grid communication network with edge computing system (June). In 2019

15th International Wireless Communications & Mobile Computing Conference (IWCMC). IEEE, pp. 272–277 (June).
Zhang, T., Chen, L., Han, W., Lin, H., Xu, A., Zhou, Z., Zhang, Y., 2021. Security Protection Technology of Electrical Power System Based on Edge Computing (January). In 2021 IEEE International Conference on Power Electronics, Computer Applications (ICPECA). IEEE, pp. 254–258 (January).
Zhang, H., Ma, Y., Yuan, K., Khayatnezhad, M., Ghadimi, N., 2024a. Efficient design of energy microgrid management system: a promoted Remora optimization algorithm-based approach. Heliyon 10 (1).
Zhang, J., Zhang, W., Wei, X., Liu, H., 2024b. EPri-MDAS: An efficient privacy-preserving multiple data aggregation scheme without trusted authority for fog-based smart grid. High. -Confid. Comput., 100226
Zhou, Z., Liu, F., Chen, S., Li, Z., 2020. A truthful and efficient incentive mechanism for demand response in green data centers. IEEE Trans. Parallel Distrib. Syst. 31 (1), 1–15.
Zhu, C., Leung, V.C., Shu, L., Ngai, E.C.H., 2015. Green internet of things for smart world. IEEE Access 3, 2151–2162.
Zhu, Y., Wen, H., Zhao, R., Jiang, Y., Liu, Q., Zhang, P., 2023. Research on data poisoning attack against smart grid cyber–physical system based on edge computing. Sensors 23 (9), 4509.