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Research paper

Technological advancements toward smart energy management in smart cities

Pitchai Pandiyan [a], Subramanian Saravanan [b], Kothandaraman Usha [c], Raju Kannadasan [d], Mohammed H. Alsharif [e], Mun-Kyeom Kim [f,*]

[a] Department of EEE, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India
[b] Department of EEE, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, Tamil Nadu, 641112, India
[c] Department of Electrical and Electronics Engineering, Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam, Chennai, India
[d] Department of Electrical and Electronics Engineering, Sri Venkateswara College of Engineering, Sriperumbudur, 602117, India
[e] Department of Electrical Engineering, College of Electronics and Information Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 05006, Republic of Korea
[f] School of Energy System Engineering, Chung-Ang University, 84 Heukseok-ro, Dongjak-gu, Seoul 06974, Republic of Korea

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A B S T R A C T

This comprehensive review paper examines the technological advancements towards smart energy management in smart cities. It provides an overview of the concept of smart energy management, the challenges faced by cities in managing their energy consumption, and the need for technological advancements to overcome these challenges. The advancements are categorized based on their applications, such as smart grids, smart buildings, and smart transportation, and their benefits are discussed, including increased efficiency, reduced costs, and better sustainability. The paper also presents case studies of successful implementation of smart energy management technologies and discusses the challenges faced during implementation and how they were overcome. In addition, the paper highlights potential research areas and emerging technologies, including block chain, edge computing, IoT, big data analytics, energy harvesting technologies, machine learning, and distributed energy resources (DERs). The importance of technological advancements for smart energy management in smart cities is emphasized, and recommendations for future research and development in the field are provided. Overall, this review paper contributes to the ongoing development of smart cities and provides valuable insights for researchers, industry professionals, and policymakers working towards a more sustainable future.

1. Introduction

The term "smart city" has recently been coined by several authors and research institutes and is being used by many more. In a nutshell, the smart city aims to solve or alleviate challenges caused by fast-growing urbanization and population growth, such as waste management, mobility, and energy supply, by maximizing productivity and optimizing resources. Several categories of smart city intervention areas are discussed in Calvillo et al. (2016). However, one disadvantage of these categorizations is that they focus only on the smart grid, ignoring other important energy sectors such as transportation and facilities.

The energy needs of cities are dynamic and abundant. Therefore, modern cities should develop existing services and introduce innovative technologies in a structured and optimal way, taking advantage of the interface among these energy solutions (Sodiq et al., 2019). Due to the irregular characteristics of renewable energy resources, the requirement for energy-efficient transportation systems, and the increasing load demand, among other things, addressing significant energy issues collectively is crucial.

Stakeholders may use simulation tools to understand urban dynamics and assess the effect of different energy policy options better. However, energy areas are often discussed separately, resulting in suboptimal solutions due to a lack of the "full picture". To effectively address the increasing energy demands of current and future cities, a complete smart city model that encompasses all activities relating to energy without making the model too large or complicated is needed.

One of the most significant challenges faced by cities is managing their energy consumption, which accounts for a significant proportion of urban carbon emissions. This challenge has led

* Corresponding author.
E-mail addresses: pandiyan.p@kpriet.ac.in (P. Pandiyan), s_saravanan@cb.amrita.edu (S. Saravanan), ushak@ssn.edu.in (K. Usha), kannadasanr@svce.ac.in (R. Kannadasan), malsharif@sejong.ac.kr (M.H. Alsharif), mkim@cau.ac.kr (M.-K. Kim).

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Nomenclature

AI	Artificial Intelligence
AIMS-SB	Artificial Intelligence Technique for Monitoring Systems in Smart Buildings
B2V and V2B	Battery to Vehicle / Vehicle to Battery
BEBs	Battery Electric Buses
BECs	Battery Electric Cars
BEES	Battery electrical energy storage
BM	Biomass
BSCSs	Battery Swapping and Charging Stations
CAES	Compressed-Air Energy Storage
CAVs	Connected and Autonomous Vehicles
CCHP	Combined Cooling, Heating, and Power
CO2	Carbon di oxide
CSP	Concentrated Solar Power
CTs	Current Transformers
DEN	District Energy Networks
DERs	Distributed Energy Resources
DG	Distributed Generation
DR	Demand Response
EMS	Energy Management System
ESSs	Energy Storage Systems
EVCS	Electric Vehicle Charging Station
EVPLMS	EV Parking Lot Management Systems
EVRC	Electric Vehicle Route Planning with Recharging
EVs	Electric vehicles
FLC	Fuzzy Logic Controller
FMCDM	Fuzzy Multi-Criteria Decision Making
FODPSO	Fractional Order Darwinian Particle Swarm Optimization
GCA-SC	Green communication approach smart city
GE	Geothermal energy
HEMS	Home Energy Management System
HEVs	Hybrid Electric Vehicles
HUL	Historic Urban Landscape
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communications Technology
IoT	Internet of Things
ITS	Intelligent Transportation Systems
LCOE	Levelized Cost of Energy
LV/MV	Low Voltage / Medium Voltage
MaaS	Mobility-as-a-Service
MG	Multi Generation
MILP	Mixed Integer linear programming
MPPT	Maximum Power Point Tracking
NB-IoT	Narrowband-Internet-of-Things
ORB	Optimum Relation Based
PMUs	Phasor Measurement Units
PSO	Particle Swarm Optimization
PV	Photovoltaic
RE	Renewable Energy
SC and SS	Self-Consumption and Self-Sufficiency
SHEMs	Smart Home Energy Management Systems
SMES	Superconducting magnetic energy storage
SOR	Stimulus-Organism-Response
SWOT-FAHP	Strengths-Weaknesses-Opportunities-Threats analysis and Fuzzy Analytic Hierarchy Process
TCs	Thermal collectors
ToU	Time-of-Use
UAS	Unmanned Aircraft Systems
V2G	Vehicle to Grid
WECS	Wind Energy Conversion System
WSN	Wireless Sensor Network
WT	Wind Turbine

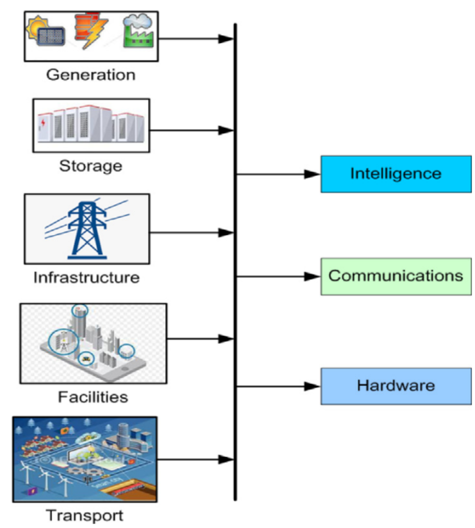

Fig. 1. Energy contribution sectors in the smart city.

to the development of various technological advancements in smart energy management. These advancements offer promising opportunities for optimizing energy consumption, reducing costs, and promoting environmental sustainability. To provide a comprehensive understanding of these advancements, this review paper categorizes them based on their applications, such as smart grids, smart buildings, and smart transportation. The paper will discuss each of these categories in detail, exploring the specific technologies used, their benefits, and their challenges.

In this review work, there are five major intervention areas related to energy: generation, transmission (transportation), distribution (infrastructure), utilities, and storage, which are illustrated in Fig. 1. Many of these fields are interconnected, but they contribute to the power system in various ways: generation generates energy, whereas storage ensures its availability; infrastructure handles energy delivery and user interfaces, and transportation and facilities are the primary end-users of energy because they require it for functioning. Three key layers support the implementation of energy systems: the physical layer (hardware — physical components and devices), the communication layer, and the intelligent layer (management/control). For this reason, multidisciplinary approaches are preferred. The intelligent and physical layers are the primary focus of this study.

The proposed review paper on Technological Advancements toward Smart Energy Management in Smart Cities contributes to the available literature by offering a distinct and original perspective. It stands out by providing a comprehensive overview of the latest advancements in the field, emphasizing their significance for smart energy management in smart cities. Through an examination of potential research areas and emerging technologies such as data analytics, energy harvesting technologies, and distributed energy resources, this paper not only highlights the current state of the field but also presents a roadmap for future research and development. Furthermore, the inclusion of case studies showcasing real-world applications of smart cities and their future developments adds practical relevance and demonstrates the practical implications of these advancements. In summary, this review paper offers a fresh perspective and valuable insights, positioning it as an essential resource for researchers, industry professionals, and policymakers working towards a more sustainable future in smart cities and the same is compared with existing works as listed below (see Table 1).

The review paper will also provide case studies of cities that have successfully implemented these technologies and the benefits they have achieved. These case studies will highlight the challenges faced during implementation and how they were overcome, providing valuable insights for cities considering adopting similar technologies. Finally, the paper will conclude by emphasizing the importance of technological advancements for smart energy management in smart cities. It will provide recommendations for future research and development in the field, highlighting potential areas for growth and emerging technologies that hold promise for the future of smart energy management. The main contributions of the article are listed as follows:

- The paper examines technological advancements towards smart energy management in smart cities
- Overview of smart energy management, challenges faced by cities in managing energy consumption, and need for technological advancements
- Advancements are categorized based on their applications: smart grids, smart buildings, and smart transportation, and their benefits are discussed
- Case studies of successful implementation of smart energy management technologies are presented, along with challenges faced and how they were overcome
- Potential research areas and emerging technologies are highlighted, including block chain, edge computing, IoT, big data analytics, energy harvesting technologies, machine learning, and distributed energy resources
- Emphasizes the importance of technological advancements for smart energy management in smart cities
- Provides recommendations for future research and development in the field
- Overall, the paper contributes to the development of smart cities and provides valuable insights for researchers, industry professionals, and policymakers working towards a more sustainable future.

In summary, this review paper aims to provide a comprehensive overview of the technological advancements made towards smart energy management in smart cities. It emphasizes the critical role that technology plays in promoting environmental sustainability, reducing costs, and improving the quality of life for residents.

The structure of the paper is as follows: Section 2 presents a review of various advanced technologies for smart cities. Section 3 discusses the grid infrastructure, while Section 4 describes various methods for integrating renewable energy. Section 5 focuses on energy storage systems and their operation, while Section 6 outlines the features of smart transportation. Sections 7 and 8 discuss data analytics and facilities of smart cities and buildings. Sections 9 and 10 present case studies of smart cities and their future developments. Section 11 highlights research areas and advanced technologies. Finally, Section 12 concludes the paper by summarizing the technological advancements in smart cities.

2. Review of technological advancements for smart energy management

Smart energy management involves using technology to optimize energy production, distribution, and consumption in a way that promotes efficiency, cost-effectiveness, and sustainability. In smart cities, the integration of technology into energy management is essential to ensure that the growing energy demands of urban areas can be met sustainably (Appio et al., 2019).

However, managing energy consumption in cities presents several challenges. One of the primary challenges is the mismatch between energy supply and demand. As cities continue to grow, their energy demands increase, leading to an energy supply–demand gap. This gap is often addressed by increasing energy production, which can lead to increased carbon emissions and environmental degradation. Additionally, energy infrastructure in cities is often outdated and inefficient, leading to significant energy losses during transmission and distribution. This inefficiency is further exacerbated by a lack of real-time energy monitoring and management systems, which can make it challenging to identify and address energy inefficiencies. Finally, cities must also contend with fluctuating energy prices and a lack of adequate funding for energy infrastructure projects, which can impede the adoption of new energy technologies.

To overcome these challenges, technological advancements are needed to optimize energy production, distribution, and consumption in smart cities. These advancements include the integration of renewable energy sources, the development of smart grids, the use of energy-efficient buildings and appliances, and the implementation of real-time energy monitoring and management systems. These technological solutions offer promising opportunities for optimizing energy consumption, reducing costs, and promoting environmental sustainability. In recent years, technological advancements have made significant progress in addressing the challenges of smart energy management in smart cities. Here are some of the major technological advancements in the field:

1. *Smart Grids:* Smart grids use advanced sensors, communication technologies, and intelligent algorithms to monitor and manage energy distribution across the grid. They enable real-time monitoring of energy supply and demand, allowing for the optimization of energy distribution to reduce waste and improve efficiency.
2. *Renewable Energy Sources:* The integration of renewable energy sources, such as solar, wind, and geothermal power, is another critical advancement in smart energy management. These sources of energy are sustainable, cost-effective, and help reduce carbon emissions.
3. *Energy Storage:* The development of efficient and affordable energy storage systems has also been crucial in smart energy management. Energy storage enables excess energy generated from renewable sources to be stored and used when energy demand is high, ensuring a constant and reliable energy supply.
4. *Smart Buildings*: Buildings account for a significant proportion of energy consumption in cities, and the development of energy-efficient buildings is critical for smart energy management. Smart buildings use advanced energy management systems, such as intelligent lighting and

Table 1
Compartive study realting the Smart cities.

References	Domains: Smart grid	Renewable energy	Energy storage	Smart buildings	Electric vehicle	Smart home	Data analytics	Salient points discussed
Proposed work	✓	✓	✓	✓	✓	✓	✓	• This review paper stands out by incorporating case studies that demonstrate real-world applications of smart cities and their future prospects, showcasing the practical implications of these advancements. It offers valuable insights, making it an essential resource for researchers, industry professionals, and policymakers striving for a sustainable future in smart cities.
Jafari et al. (2023)	✓			✓	✓			• Examining development of energy management in transportation systems, power grids, and micro grids using digital twin technology • Highlighting the benefits of digital twin in energy management within urban environments
ur Rehman et al. (2023)				✓		✓	✓	• Exploring limitations of grid regulation in smart energy networks • Impeding broader scale deployment of smart energy networks in smart cities • Addressing challenges hindering the implementation of smart energy networks in urban environments
Orumwense and Abo-Al-Ez (2023)				✓		✓	✓	• Focus on smart cities, smart homes and buildings, and smart industries • Highlighting the role of IoT as a developing technology in improving energy systems
Kim et al. (2021)	✓			✓		✓	✓	• Investigating the themes of smart homes and cities with a combination of quantitative and qualitative analyses • Assessing barriers impeding the development of sustainable smart cities from the perspective of smart homes
Bhushan et al. (2020)	✓				✓		✓	• Researching the adoption of block chain technology to enhance efficiency, security, and performance of smart cities • Surveying the application of block chain in different smart community domains, including healthcare, transportation, smart grid, supply chain management, financial systems, and data center networks
Kirimtat et al. (2020)				✓	✓		✓	• Addressing the main research question regarding the status and potential of smart city concepts • Emphasizing the role of new IoT technologies and applications in motivating advancements in smart cities
Xu et al. (2020)	✓							• Providing an overview of efforts and progress made in the field of smart energy systems research • Offering a comprehensive analysis of the latest developments in optimizing the design and operation of smart energy systems
O'Dwyer et al. (2019)			✓	✓	✓		✓	• Summarizing the current state of computational intelligence in smart energy management • Providing insights on overcoming existing barriers • Recognizing the need for intelligent approaches in managing and coordinating various supply, conversion technologies, and demand applications. • Highlighting the potential of widespread sensor deployment and computational intelligence algorithms to tackle the complexities of integrating diverse energy systems.
Farmanbar et al. (2019)	✓	✓	✓					• Reviewing the progress of micro/nano grids, renewable energy applications, energy storage technologies, and smart water grids • Clarifying the importance of integrating these technologies for the successful implementation of smart cities

HVAC systems, to optimize energy consumption and reduce waste.
5. *Electric Vehicles:* Electric vehicles (EVs) have the potential to reduce carbon emissions and improve air quality in cities. The development of EV charging infrastructure and the integration of renewable energy sources to power these vehicles is essential for smart energy management.
6. *Smart Home:* A smart home is a house equipped with internet-connected devices for controlling, automating, and optimizing functions such as temperature, lighting, security, and entertainment. It provides convenience, energy efficiency, and improved quality of life for residents.
7. *Data Analytics:* The use of data analytics in smart energy management is another critical advancement. It enables the collection, analysis, and interpretation of energy consumption data to identify inefficiencies, optimize energy use, and reduce costs.

In general, these technological advancements offer a range of benefits, including increased efficiency, reduced costs, and better sustainability. By integrating these technologies into energy management systems, smart cities can optimize energy production, distribution, and consumption to create more liveable, sustainable, and efficient urban environments.

3. Grid infrastructure

In this work, urban power grids are referred to as "infrastructure". Besides the smart-grid model, which only includes district energy networks, electric energy is a fascinating example of smart grid infrastructure, providing electrical and thermal energy to a variety of interconnected services (Mancarella and Chicco, 2011). The electricity grid is a city's energy backbone, which is responsible for safely and reliably transmitting energy from generating stations to consumers. However, traditional grids may have technical issues such as a deficiency in communication infrastructure, control systems, and unidirectional protections. Conventional grids may not be equipped to meet the growing demand and distributed generation. As a result, literature related to grids often focuses on ways to make the most of existing infrastructure while preventing excessive investments.

A smart grid infrastructure may be characterized by a variety of approaches, like the smart-city model. The goal of the smart grid is to enable real-time bidirectional communication among all participating entities using modern ICT technology. The elements of a smart grid provide data such as self-energy production or consumption as well as follow the directions to load scheduling, contractual obligations, and costs. Authors (smart grid, 2013) presented the major features of a smart grid, which include the ability to satisfy the increasing consumer load demand without constructing new infrastructure, with self-healing capability and micro grids to exchange power and work independently and separately.

3.1. Smart-grid technology research and applications

There is a significant amount of literature on the smart grid that addresses a wide range of issues. In this study, power electronics, control systems, communication protocols, business models, and regulations are discussed. In addition to economic factors, investments in infrastructure are also a significant concern. The research work cited in Mendez et al. (2006) presented models for long-term investment in smart grids that measure the impact of EVs or DG on a distribution network. Likewise, energy markets and appropriate control for smart grids are also discussed. For example, Karnouskos (2011) investigated the energy market, facilities needed for demand-response strategy, and regulatory mechanisms. On the other hand, this work fails to demonstrate technical specifications but models the smart grid concept perfectly.

Several European initiatives are examined in other examples, as reported in Ding et al. (2012), which investigates a market-price system for smart grids. Another relevant research area in infrastructure is the incorporation of renewable energy sources. Cossent et al. (2011) reported the effects on the grid. EV integration and energy storage are also presented extensively because EVs pose a significant challenge to future power grids. Villar et al. (2012a) discussed the implications of a strong EV penetration in energy market prices and utility operations. Hable et al. (2010) analyzed the number of electric vehicles that can be linked in a German grid area. San Román et al. (2011) proposed business models, roles of the agents, and a conceptual regulatory structure for charging electric vehicles.

Smart metering comes to the subsequent stage in this process, and several studies have documented the benefits of such a system. Choi et al. (2009) estimated the energy savings attained by changing the consumers' perspective. On the other hand, McHenry (2013) not only discussed the benefits but also addressed the limitations, dangers, and general ambiguity of the technology. Keebler (2012) investigated the effects of electromagnetic compatibility (EMC) on the smart grid and also addressed power quality and reliability issues. Rodriguez-Calvo et al. (2012) reported the influence of smart LV/MV substations in enhancing supply consistency in various configurations that distribute services across the entire network (see Table 2).

Micro grids equipped with smart-grid capabilities have been designed to simulate and demonstrate control systems and distributed generation technologies. For example, the LABEIN commercial feeder located in Spain includes 6 kW of wind turbines, over 5 kW of photovoltaic (PV) fittings, a 50 kW micro turbine, two 55 kW diesel backup generators, and different types of electric storage devices.

Most of the research listed in this section is summarized in Table 6. Although widespread implementation of smart-grid technology is still years away, trends evident in the literature suggest that these methodologies are gaining attention in several cities and have the potential to become popular.

3.2. Smart grid

Smart grids are advanced energy distribution networks that incorporate advanced sensors, communication technologies, and intelligent algorithms to optimize energy use and improve energy efficiency (Abdulsalam et al., 2023; Kiran et al., 2022). Fig. 2, shows the layout of the smart grid with latest technologies. The integration of these technologies enables smart grids to monitor energy usage in real-time, reduce energy waste, and support renewable energy integration.

Advanced sensors are a critical component of smart grids. They can monitor energy usage at different points in the grid and provide real-time data on energy consumption and production. This data is transmitted to the utility company, which can use it to make decisions on energy generation and distribution. The commonly used sensors in smart grids are phasor measurement units (PMUs), fault current sensors, temperature sensors, voltage sensors, current transformers (CTs), power quality sensors, gas sensors, pressure sensor and humidity sensor.

Communication technologies such as 5G networks and Wi-Fi enable the transmission of data between different components of the smart grid. This facilitates the monitoring of energy usage and allows for more efficient energy distribution. Intelligent algorithms are used to analyze the data collected by sensors and

Table 2
Smart infrastructure application.

Reference	Concern	Focus	Inference
Cossent et al. (2011)	Impact on distributed energy resource	Regulation of integration of distributed generation and Renewable energy sources	Proposes many recommendations and remedies for the integration of renewable energy for defining smart grid infrastructure.
Hable et al. (2010)	Impact on distributed network–EV	Integration of multiple EVs in an existing distribution network	Proposes a methodology to reduce impact overloading in the existing grid by charging multiple EVs.
San Román et al. (2011)	Impact on network infrastructure–EV	A framework for developing an EV charging business model	A regulatory system that is effective for EV charging
Choi et al. (2009)	Smart metering	An energy-saving methodology using smart metering	Effective communication protocol with the end-user reduces energy consumption by 15%.
McHenry (2013)	Power quality	Power quality impacts through electromagnetic compatibility	The dip in the power quality through the major impact of a smart grid is proposed
Keebler (2012)	Power security	Substation automation	Improvement of security and reliability of smart grid protocols is recommended.

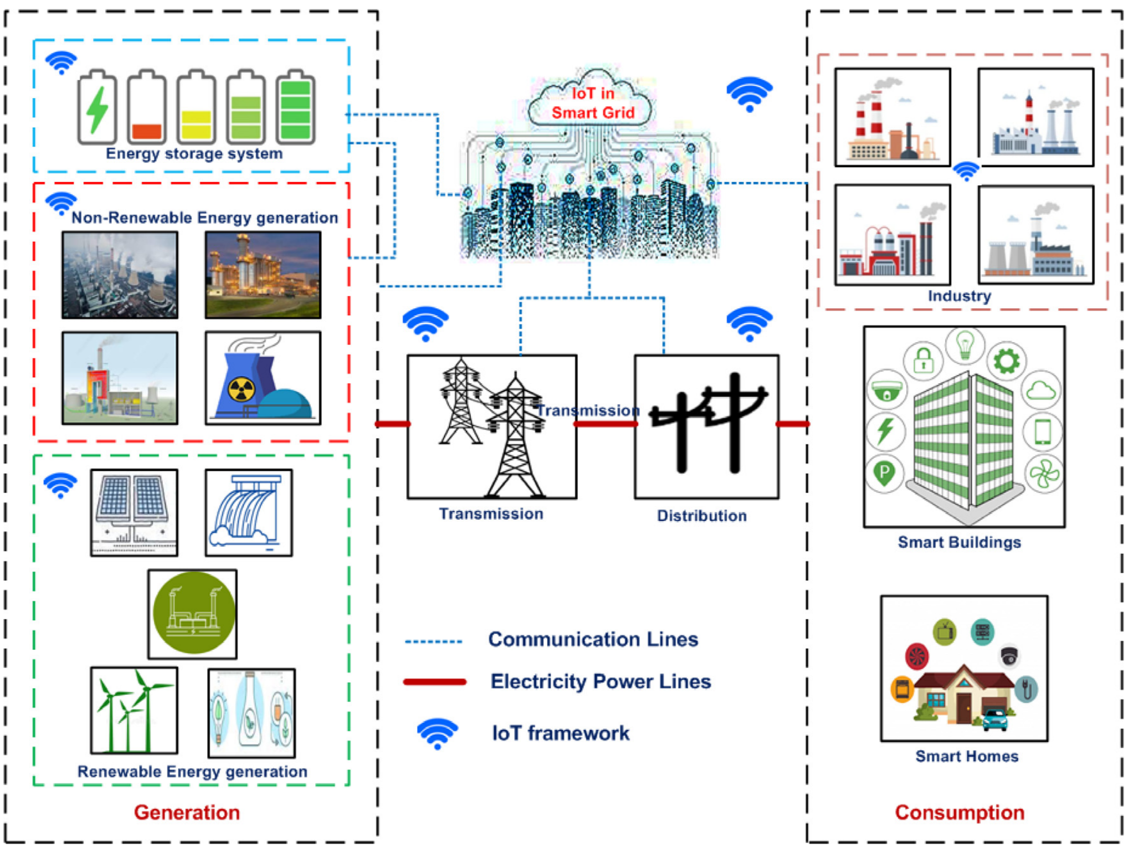

Fig. 2. Model of smart grid design.

provide insights into energy usage patterns. This information can be used to optimize energy distribution, reduce energy waste, and prevent blackouts.

One of the main advantages of smart grids is their ability to support renewable energy integration. Advanced sensors can monitor renewable energy production from sources such as solar and wind and provide real-time data on their availability. This enables utilities to adjust energy production and distribution in response to changes in renewable energy availability.

4. Renewable energy integration

Renewable energy sources are those that are replenished naturally and can be used indefinitely without running out. Renewable energy integration refers to the process of incorporating renewable energy sources such as solar, wind, hydro, geothermal, and biomass into the existing energy infrastructure which is explained in this section. Fig. 3, shows the various renewable energy integration. The goal is to reduce carbon emissions, promote sustainable energy practices, and enhance energy security (Hoang and Nguyen, 2021).

Solar PV panels: Photovoltaic (PV) panels are made of semiconductor materials that convert solar radiation into DC electricity. Solar PV-based energy generation has been extensively researched and is commonly used in small-scale generation units due to its significant cost savings, particularly in the context of competitive levelized cost of energy (LCOE) prices (Aquila et al., 2021).

Thermal collectors (TCs) and Photovoltaic thermal collectors (PV/T): TCs absorb sunlight to capture heat energy, providing a

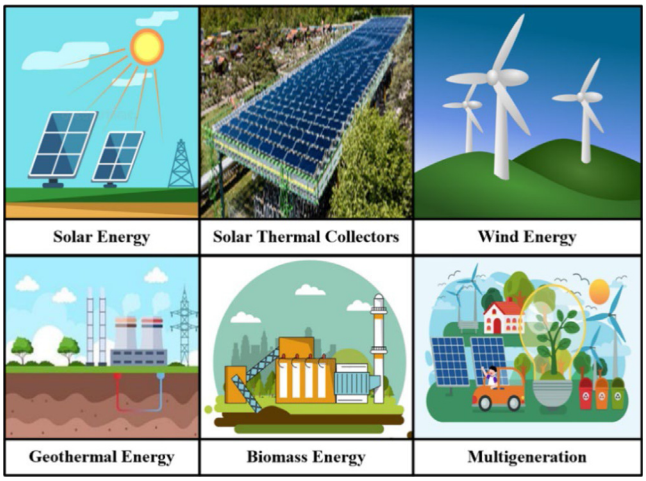

Fig. 3. Various renewable energy resources.

consistent source of heat for heating water or an appropriate heat transfer fluid, especially in applications that require constant use, controlled temperature, or a steady flow of heat. On a small scale, TCs can be cost-effective and used as concentrated solar power plants (CSP) for energy production (Usaola, 2012), often combined with thermal power generation. Although this type of energy generation has a low LCOE, it is not suitable for implementation in urban areas. PV/T operates similarly to standard PV cells but also delivers heat energy to heat water or other fluids. Although very efficient, there are currently no commercial modules available on the market, and they are only available in limited quantities.

Wind turbines (WT): WTs harness energy from wind to generate electrical or mechanical power, and are well-established and commonly used for utility-scale power generation due to their cost-effectiveness. However, due to wind variability, they may need to be supplemented by other renewable energy sources and storage for small-scale applications (Brenden et al., 2009).

Biomass (BM) : There has been increasing attention given to biomass in recent years as a flexible power generation source that can be used directly for heat energy through combustion or indirectly through conversion into liquid or gaseous biofuels for low-cost electricity or heat. However, sustainable production of biomass crops is necessary. Recent European reforms aim to limit the use of first-generation biofuels derived from sugar and oil crops and transition to second-generation biomass derived from recycled materials, woody crops, farm waste, and residues for sustainability (Zhang et al., 2020)

Geothermal energy (GE): GE is generated from the Earth's thermal energy flux and can be used for low to medium thermal energy generation or high thermal energy generation (co-generation). However, reliable geothermal energy generation is possible only in a limited number of locations with suitable ground conditions, making it relatively expensive to implement (Hammons, 2003)

Multi-generation (MG): Multi-generation, also known as poly-generation has emerged as an innovative solution for maximizing the use of non-renewable energy sources by generating multiple forms of energy from a single fuel source. This approach has been successful in reducing carbon dioxide (CO2) emissions while increasing overall productivity. While small-scale implementation may be expensive, the long-term benefits of multi-generation make it a promising option for sustainable energy generation. For example, although hydrogen fuel cell energy generation may only be feasible in certain locations, the energy produced can have a high value and contribute to a cleaner energy future.

Table 3 represents the various renewable energy integration in the smart cities. One of the primary challenges of renewable energy integration is the variability and intermittency of renewable energy sources. For example, solar energy production is affected by weather conditions such as clouds and rain, and wind energy production is affected by wind speed and direction. These fluctuations can make it difficult to balance energy supply and demand in real-time. To address this challenge, smart cities are increasingly relying on advanced technologies such as energy storage systems, demand response programs, and microgrids. Energy storage systems can store excess energy produced by renewable energy sources during times of low demand and discharge it during peak demand periods. Demand response programs involve adjusting energy demand based on supply availability, and microgrids are localized energy systems that can operate independently of the main grid.

Moreover, smart cities are leveraging the Internet of Things (IoT) and artificial intelligence (AI) to optimize renewable energy integration. IoT devices such as smart meters and sensors can monitor energy consumption and production in real-time and provide data insights for energy management. AI algorithms can use this data to predict energy demand, optimize energy use, and improve energy efficiency. By using these advanced technologies, cities can better manage the variability of renewable energy sources and increase the penetration of renewables in their energy mix, leading to a more sustainable and resilient energy future.

In a smart city, various generation technologies are effectively implemented. The significant characteristics of these technologies are summarized in Table 4.

5. Energy storage systems (ESSs)

Energy Storage Systems (ESSs) are utilized to store a variety of energy, such as thermal, electrical, and kinetic energy which shown in Fig. 4. ESSs primarily serve two functions in smart cities: supporting renewable energy integration and distributing load demand according to needs. By accumulating generated energy from sustainable energy resources, ESSs can save money in the long term (Maharjan et al., 2010) and contribute to the net load demand. Similarly, electrical ESSs can engage in demand-response strategies by locally controlling the load demand characteristics curve and smoothing out valleys and peaks. This could help cover new energy loads, such as electric vehicles (EVs) and DC buildings.

5.1. Storage technologies

Energy storage technologies play a crucial role in smart energy management in smart cities by providing flexibility and stability to the grid, and enabling efficient use of renewable energy sources. Some examples of energy storage technologies used in smart cities include batteries, pumped hydro storage, and thermal energy storage.

Batteries: Batteries have long been used in various applications, primarily to store electricity as chemical energy. They are composed of one or more electrochemical cells that can include lithium-ion, lead–acid, sodium-sulfur, and sodium-nickel chloride. However, they have some significant drawbacks, such as potential environmental risks, high costs, and short life cycle, and current and voltage limitations. Despite this, the cost of many batteries has decreased dramatically in recent years and is expected to continue.

Super Capacitors: For medium-scale power quality systems, quick response and the delivery of a large amount of energy in

Table 3
Various renewable energy operations in smart cities.

Ref	Year	Location of study	Type of renewable technologies	Purpose	Observation
Thamarai and Naresh (2023)	2023	India	Biogas system	Smart self-power generating garbage management system	• Smart waste collection setup designed for apartment households • Deep learning-based classification system used to segregate household waste into organic and inorganic waste • Waste management and power generation system to generate power from organic waste • IoT-based garbage notification system using Raspberry Pi controller to dispose of inorganic waste • Disposal of inorganic waste from apartments to the municipality Garbage Collecting Vans for recycling.
Fachrizal et al. (2022)	2022	Uppsala, Sweden	Photovoltaic system	PV powered charging station with smart charging schemes	• Proposed an optimal PV-EV sizing framework for workplace charging stations • Assessment of optimal operation for EVCS with smart charging schemes • Tested on Swedish conditions and irradiance on Oahu, Hawaii • Investigation of potential synergy between PV generation and EV charging • Quantification of SC and SS measures • Impact of EV smart charging schemes on optimal sizing • Sensitivity analysis of optimal sizing in different climatic regions
Sarkar et al. (2022)	2022	India	Photovoltaic system	Guidelines for PV network installation standards and cost estimation	• Objective: Create awareness about PV system standards and codes • Detailed presentation of available standards and organizations responsible for making them • Conducted extensive market survey to evaluate cost break-up of various subsystems • Helps stakeholders make decisions on type of PV system to be installed (with/without battery, single inverter or string of inverters, etc.) • Provided vital information for more reliable PV system design • Emphasis on adherence to standards for smart cities.
Mahesha et al. (2022)	2022	India	Photovoltaic system	Sustainable cooling and heating in smart cities	• The study aims to find renewable energy solutions that are technically feasible and practical for poor communities to improve their living conditions and quality of life • Naïve Bayes classifier is used to classify input data to find situations for maintaining the climate and reducing environmental burden in smart cities. • Elimination of waste is crucial for efficiency and sustainability in smart cities • Smart cities can achieve energy savings, economic growth, productivity, environmental protection, and climate change mitigation • Impoverished towns face challenges in achieving smart and sustainable city goals due to lack of funds and technology
Hsu et al. (2022)	2022	Taiwan	Renewable energy system	Green communication approach for the smart city	• Proposed a green communication method for smart cities (GCA-SC) using renewable energy systems. • Employed preserved streaming video using hybrid Adaptation and Power Algorithms and Delay-tolerant Streamed Algorithms to address communication issues. • GCA-SC optimizes IoT compliant electronics' energy usage, storage capacity, variation, and grid power ratio in intelligent city environments.

(continued on next page)

Table 3 (*continued*).

Ref	Year	Location of study	Type of renewable technologies	Purpose	Observation
Abu-Rayash and Dincer (2021)	2021	Canada	Photovoltaic system	Integrate the solar energy for electricity, cooling and heating	• Integrated solar-based energy system for cities • Included renewable energy sources and energy storage solutions • Provided heating, cooling, and electricity for city applications • Uses district energy network • Absorption refrigeration system converts to useful cooling and air conditioning
Katyal et al. (2021)	2021	Madurai, Tamil Nadu, India	Wind energy conversion system	Short term wind speed forecasting using hybrid neural network	• Novel approach for optimizing neural network parameters using DOE • Experiments conducted by varying neural network parameters related to network architecture using 18 years of collected MERRA data (2000–2018) from Madurai, Tamil Nadu, India • Aimed at improving short term forecasting accuracy
Malar et al. (2020)	2020	India	Wind energy conversion system	IoT based sustainable wind green energy for smart cites	• Proposed a MPPT based on FODPSO and FLC for WECS. • IoT is used to monitor the state of the turbine for reliable communication between turbine and control center. • The algorithm aims to improve stagnation problems and optimize convergence rate.
Hassan et al. (2020)	2020	Egypt	Multigeneration system	Integration of adsorption chillers into different configurations of combined cooling, heating, and power (CCHP) systems	• Introduced the CCHP and thermally-driven cooling systems • CCHP systems integrated with solar-driven adsorption chillers • Multigeneration systems driven by IC engines, gas turbines, and fuel cells
Abdullah et al. (2018)	2018	Yemen	Wind energy conversion system	WECS based maximum power point tracking approach for smart cities	• Proposed a new MPPT algorithm based on hybridization of ORB and PSO methods • Algorithm is sensorless, converges quickly, and requires no prior knowledge of system parameters • Algorithm's improved performance in terms of tracking efficiency is validated through simulation using MATLAB/Simulink • Simulation results confirm that the proposed algorithm has better performance in terms of tracking efficiency and energy extracted.

Table 4
Different distributed energy sources.

Type	Generated power		Efficiency	General application
	Electric	Thermal		
PV	Y	N	Low	Consumer-level
Hybrid PV–Wind	Y	N	Mid–Low	Consumer, Power plant
Wind	Y	N	Low	Power plant, Standalone
Hybrid PV–Thermal	Y	Y	High	Power plant
Biomass	Y	Y	Moderate	Power plant, Consumer
Geothermal	Y	Y	High	Power plant

a short interval are necessary. This can be achieved through the use of super capacitors, flywheels, and superconducting magnetic energy storage. Mufti ud din et al. (2009) developed a capacitor consisting of two layers that can charge and discharge at extremely high currents.

Superconducting magnetic energy storage (SMES): It is a type of energy storage system that stores electrical energy in a magnetic field created by the flow of direct current in a superconducting coil. The energy is released by discharging the stored magnetic field through the same superconducting coil. SMES is a highly efficient and reliable energy storage technology that is used for power quality applications and grid stability. Ali et al. (2010) proposed the use of a superconducting coil that stores electrical energy from the generated magnetic field by applying direct current.

Flywheels: Flywheels are a type of energy storage system that store energy as rotational kinetic energy. They consist of a rotating disk or cylinder that is connected to a motor or generator. Flywheels are often used in applications that require rapid energy delivery, such as in power quality systems or hybrid vehicles. Sebastián and Peña-Alzola (2015) reported the use of a mechanical rotary device that stores kinetic energy for power quality and grid

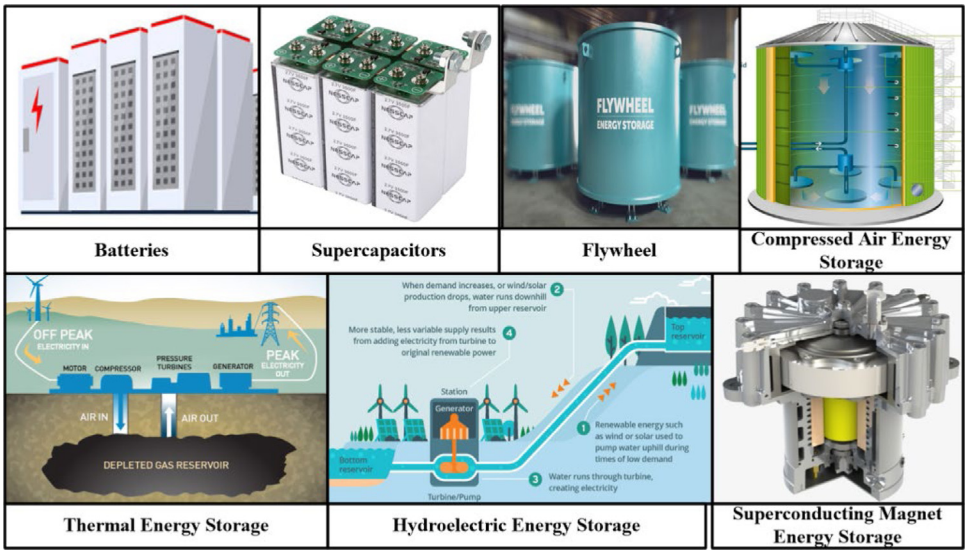

Fig. 4. Various energy storage systems.

Table 5
Classification of ESS based on discharge time.

Sl.no	Types of ESS	Discharge time	Applications
1.	PQ storage	1 to 30 s	End-user PQ and reliability
2.	Distributed generation storage	0.5 to 4 h	Distributed renewable energy integration, transmission deferral, peak shaving, etc.
3.	Bulk storage	1 to 8 h	Spinning reserve or load leveling

stability. These systems have longer lifecycles than battery technologies but are more expensive and can only supply electricity for short periods.

Hydro-pumping/hydroelectric storage: Hydro-pumping/hydroelectric storage is a widely adopted energy generation technique in many countries. It generates electricity by pumping water (potential energy of water) to a higher elevation from a lower reservoir and passing it through a turbine. While this technology is frequently used by grid operators and utilities for load balancing, it has significant drawbacks in small-scale applications, including topographic and environmental constraints, and large unit sizes.

Thermal storage systems (TSS): TSS store thermal energy in a tank using a fluid or other substance. The most prevalent application of TSS in smart cities is for water tanks that can satisfy thermal energy demand in both commercial and residential buildings (Ma et al., 2012). Molten salt tanks have recently been used for high-temperature thermal energy storage for energy production in CSP, primarily at the utility-scale.

Compressed-air energy storage (CAES): It is another option for storing energy at the utility scale. Compressed air is stored as energy in a storage vessel, usually located in an underground cavern. Similar to hydro-storage systems, the CAES system is often constrained by topographic constraints.

From the descriptions of the different technologies, it is clear that not all ESSs are suitable for all applications, as they vary in power or storage capacity, response time, cost, and size. ESS applications are divided into three categories based on the discharge period: power quality storage, DG storage, and bulk storage. Table 5 gives the details about the discharge time for each category with its applications. Table 6 reviews ESS innovations and suggests the best promising usages (González-Gil et al., 2013).

5.2. Applications and ESSs models

ESSs have a wide range of applications across various technologies, with significantly different sizes and capabilities. Madlener and Latz (2013) examine the economic viability of CAES for enhancing wind energy grid integration in Germany on a large scale, while battery management systems are frequently used for incorporating renewable energy resources on a small to medium scale (Koohi-Kamali et al., 2014). Other ESS innovations focus on power efficiency, such as the hybrid wind-diesel power-generating unit with a flywheel storage unit for isolated microgrid applications (Kiran et al., 2022; Ramachandran and Chandrakala, 2019), or the super-capacitor-based energy storage in power systems for load frequency modulation (Hassan et al., 2020).

Hybrid energy storage systems that combine various storage methods are being developed to overcome the limitations of individual devices and enhance overall results. Xing-guo et al. (2012) investigated the advantages of hybrid ESSs in microgrid applications, while de Oliveira et al. (2012) examined a hybrid battery-flywheel storage system for EVs with a focus on power electronics and control requirements. Plug-in electric vehicles are another significant application of ESSs, with numerous studies focusing on charge/discharge strategies and smart-charging control (García-Villalobos et al., 2014).

Smart-charging techniques have various purposes, including integrating renewable energy through electric vehicle (EV) technology (Villar et al., 2014), examining the grid effect of high EV penetration in real-world distribution areas (Fernandez et al., 2010), and analyzing the effect of strong EV dissemination on energy prices (Villar et al., 2012b). Beer et al. (2012) analyzed the economic viability of installing utilized EV batteries as a static energy storage unit for a microgrid, while Fernández et al. (2013)

Table 6
Comparison of energy storage system.

Type	Efficiency	Response time	Life cycle	Application
Battery	75%	Medium	200–300	Distributed generation
Flywheel	95%	Low	15 000–20 000	Bulk Storage
Supercapacitor	95%	Low	35 000–50 000	Bulk storage
Superconducting magnet energy storage	95%	Low	10^4–10^5	Bulk storage
Hydroelectric	75%	High	10^5–10^6	Distributed generation
Compressed air energy storage	70%	High	10^5–10^6	Distributed generation

Table 7
Summary of ESS applications.

Reference	Energy storage system application	Analysis	Inference
Liu et al. (2020a)	Batteries	Li-ion batteries are utilized for both mobile and stationary applications	Mobile applications of batteries corresponding to long-term behavior, profitability, and efficiency are analyzed.
Chen et al. (2020)	Super capacitor	Investigated with Fuel cell, battery, and Supercapacitor	Supercapacitor reduces the energy and peak demand of the system.
Wang et al. (2021)	Flywheel	Fast charging application	For electric vehicle applications, a capacity configuration approach for the flywheel ESSs in fast-charging stations is introduced.
Hu et al. (2020)	Electric vehicles	Energy management system (EMS) for EV with hybrid ESS	An adaptive wavelet- Fuzzy logic control strategy based on driving pattern recognition is proposed since the driving cycle has a considerable impact on the output of EMS.
Yuan et al. (2020)	Thermal storage	Model for distributed energy resource	The maximum increase in the primary energy efficiency by the thermal energy system is only 3.69%.
Fan et al. (2020)	Hydroelectric	Model for distributed energy resource	The pumped-hydro energy storage system using one goal has an efficiency of 82.8%.
Zeynalian et al. (2020)	Compressed air energy storage	Model for ESS	The cogeneration principle focused on CAES and post-combustion CO_2 capture
Kong and Miyatake (2020)	Superconducting magnet energy storage	Superconducting magnetic energy storage for regenerative energy recovery in Urban train transport	MES is very promising due to its fast response, high storage density, high power density, and efficient energy utilization.
Liu et al. (2020b)	Distributed energy	Wind-based BESS	Microgrid power smoothing by removing the unpredictability nature of renewable energy generation
Rajamand (2020)	Power quality storage	Model for distributed energy resource to improve PQ	ESS can stabilize the power exchange at peak hours. Its position and size optimization can greatly increase the microgrid's performance

presented a comprehensive degradation model of Li-ion batteries for EV applications and suggested charging techniques to optimize the battery life cycle. Thermal storage research focuses on the efficient use and regulation of thermal energy in buildings, including electric thermal ESS controlled by electricity price signals (Daryanian et al., 1991) and dynamic predictive control systems with water thermal storage. Co-generation systems and solar thermal collectors systems for residential and industrial use also frequently provide thermal storage, as discussed in Chicco and Mancarella (2008).

The kinds of literature discussed in this section are summarized in Table 7. The emphasis of each work differs greatly, but two key applications are mainly focused. One is renewable energy integration which includes studies on power system security and quality. The second one is the integration of electric vehicles (EVs) which includes effects on the grid as well as vehicle-to-grid [V2G] integration.

5.3. *Energy system models for smart cities*

Bhattacharyya and Timilsina (2010) reported energy-system models that are constantly evolving to include paradigms, new technologies, and environmental concerns. This type of model is widely adopted in power-system planning and management, but only from an energy standpoint. Soroudi and Ehsan (2010) proposed a model for expanding the planning of the distribution network that takes into account the location, timing, size of DG investments, and network resources. Celli and Pilo (2001) investigated the best DG distribution in a distribution network. Karnouskos and De Holanda (2009) presented the activity of power systems that simulates a smart grid using software tools to replicate the complex behavior of a smart city model while only considering electrical energy. Foley et al. (2010) modeled the electric system using stochastic programming that entails optimizing an objective function by considering some limitations. Furthermore, other strategies focused on game theory (GT), artificial intelligence (AI) and genetic algorithms (GA) are also applicable. Table 8 illustrate the various case study on battery operation in smart cities.

5.3.1. Models of urban planning and energy

Aside from electricity-based network scheduling and service models, urban planning has a significant impact on a city's energy consumption and emissions. Urban development systems have long lifecycles and long-term effects on residents and the community, making urban planning models critical for achieving long-term growth. Yeo and Yee (2014) proposed a model for assessing a site's potential for a sustainable energy generation plant by establishing the best locations and form of energy generation for specific areas. A case study was performed for a residential district in Korea to determine its applicability. Marić et al. (2016) suggested information-technology-based strategies to enhance energy efficiency in urban planning. Using 3-D modeling and geographic information systems (GIS) to design buildings provides an advantage of terrain configuration, wind effects, and orientation towards the sun. Lenhart et al. (2015) noted that most cities focus on energy efficiency and renewable energy, but only a few cities have a unified policy that fosters synergy across multiple scales of energy-related activities in urban planning. Additionally, CO2 emissions are still not considered in urban area planning and management.

5.3.2. Developing energy-system models in the context of smart cities

From the literature review, it appears that modeling an entire energy system for an urban area is a challenging task, but certain aspects of each intervention area are particularly important to focus on. This section defines the elements that should be considered when modeling such systems and offers some guidelines for doing so.

The general block diagram of the energy system model is shown in Fig. 5, which includes components from all of the intervention areas examined, as well as the primary necessary inputs and planned outputs represented on the left and right of the block diagram. There are several techniques that can be used for planning and operation, including iterative, analytical, and hybrid techniques. The different approaches to distributed energy resources can be classified (Upadhyay and Sharma, 2014).

The quality of the results is greatly influenced by the input data utilized in the model, so careful consideration should be given to its selection. It is worth noting that while certain inputs are intimately connected to the outcome, each one is necessary for the others to have the desired effect.

6. Smart transportation

Smart transportation is a crucial component of smart cities and plays a vital role in managing energy consumption. With the increasing urbanization and population growth in cities, transportation systems are facing challenges in terms of congestion, air pollution, and carbon emissions. To address these challenges, smart transportation technologies are being developed and implemented in many cities around the world (Mohd Shari and Malip, 2023).

Fig. 6, illustrate the various smart transportation layout. Energy management systems (EMS) play a crucial role in the smart transportation sector, optimizing the energy consumption of vehicles and infrastructure. In the context of electric vehicles (EVs) (Chandrakala, 2021), EMS involves monitoring and controlling the energy storage and distribution systems to optimize the charging and discharging cycles. This includes advanced algorithms for vehicle-to-grid (V2G) communication, which enables EVs to act as a distributed energy storage system and feed energy back into the grid during peak hours.

EMS for smart transportation also involve optimizing the energy consumption of other forms of transportation infrastructure, such as traffic lights and public transportation systems. Smart traffic management systems can use real-time data to adjust traffic light timing and reduce energy waste caused by traffic congestion. Similarly, public transportation systems can optimize routes and schedules to reduce energy consumption and emissions (Gayathri and Chandrakala, 2014).

Moreover, energy-efficient infrastructure for transportation, such as EV charging stations and smart highways, can also be integrated with EMS to ensure optimal use of energy resources. For instance, intelligent charging stations can adjust the charging rate based on the current demand and availability of energy from renewable sources. Smart highways can include solar panels and sensors that generate and collect data on energy production and consumption to improve energy efficiency. Some of the components in smart transportation include Intelligent Transportation Systems (ITS), Electric vehicles (EVs), Connected and Autonomous Vehicles (CAVs), Smart Traffic Management System, Mobility-as-a-Service (MaaS) and Real-time data analytics.

6.1. Electric vehicles

The transportation sector is a significant consumer of energy and a major contributor to urban air pollution, which has a significant impact on public health. Improving transportation systems in cities has a direct impact on residents' quality of life, and future private and public transportation systems should be made safer and cleaner by using low-emission vehicle technology and designing better travel routes to save time and energy (Mohamed et al., 2019).

Replacing gasoline-powered public or private EVs/HEVs is a common way to reduce CO_2 and other polluting emissions. Studies have shown that EVs' storage capacity, grid effect, and charge control are important factors to consider in energy storage systems (ESSs), which are discussed here.

The use of hydrogen (H_2) as a fuel with steam as the only exhaust gas is a new research direction for the transportation industry. However, building a hydrogen-supply system is a challenge and requires significant investment in hydrogen-generation plants, storage tanks, charging stations, and more. Another option is to use hydrogen-fueled electric batteries (fuel cells) in EVs. However, the main disadvantages are the sustainability of the compounds and the high cost, which is currently about ten times that of gasoline per kilowatt-hour of electricity.

The third option is to replace fossil fuels with biofuels. The potential for net CO_2 fixation is a key driver of this method and also acts as a carbon sink. Biofuels are usually combined with gasoline or diesel directly. Table 9 compares the types of vehicles examined using details derived from Chevrolet (2014). It is worth noting that a thorough examination of the potential environmental advantages of alternative-fuel vehicles requires a comprehensive life-cycle study. For example, Klocke et al. (2012) investigated and evaluated the proposed engine's environmental effects through a product-life-cycle assessment of an electric drive for automotive applications.

Electric vehicles (EVs) are becoming increasingly popular as a sustainable mode of transportation in smart cities. They have the potential to reduce greenhouse gas emissions and improve air quality. However, their adoption depends on the availability of charging infrastructure and the ability of the power grid to handle their increased demand.

To address this challenge, various technological advancements have been made in the field of EVs. One such advancement is the

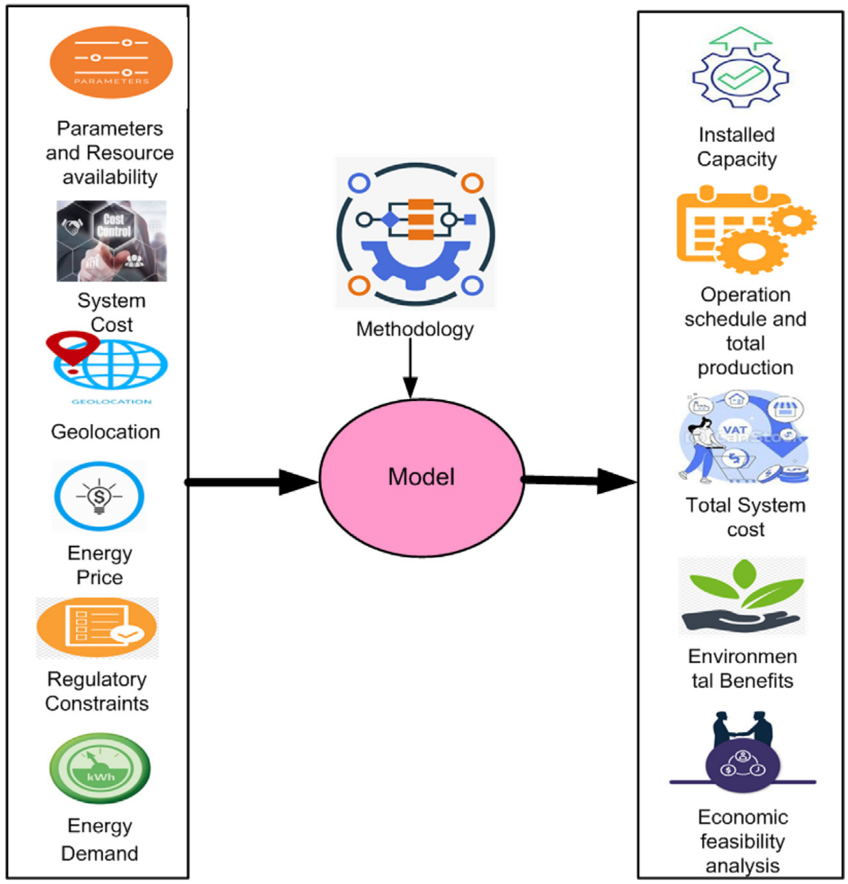

Fig. 5. Model of popular energy system design.

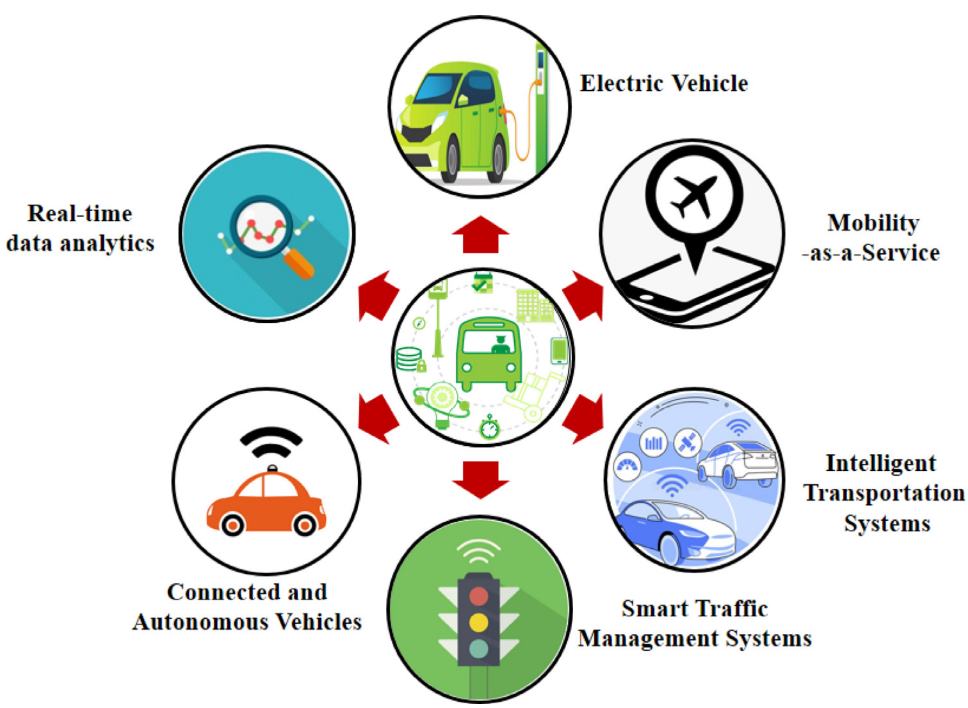

Fig. 6. Smart transportation layout.

Table 8
Case study on various battery operation in smart cities.

Ref	Year	Location of study	Smart Grid/City/building	Purpose	Technologies/ Process	Observation
Lin et al. (2023)	2023	China	Smart communities	Battery charging	Demand response strategies	• Proposes two community-level DR strategies using EVs 1. battery-charging EVs 2. battery-switching EVs with community battery energy storage for peak shaving • Cost optimization done with optimization parameters including demand limits and battery energy storage system capacity • Stochastic bottom-up demand model for households and probabilistic model for EV load prediction are used • Redistributed time-of-use tariff implemented in optimization.
Oad et al. (2023)	2023	China	smart grid	Vehicle to grid	Big data based predictive analysis	• Focused on integration of EVs to smart grids and cities through smart contracts. • Analysis of V2G and related technologies for identifying research gaps and future perspectives. • Consideration of user charging demand and grid load level for peak reduction and valley cutting. • Analysis provides a guide for charging price and ensures stability of the grid through demand response of each user.
Chan (2023)	2023	China	Smart cities	Electric vehicle	Battery swapping and Charging stations (BSCSs) approach	• Replacement of depleted portable battery modules with fully charged ones at BSCSs around town • Elimination of the need for multiple costly infrastructures and chargers • Convenience of recharging at various locations • Reduction of recharge time • Elimination of bulky secondary power banks
Huang et al. (2022)	2022	Sweden	Smart building	EV charging	A particle swarm optimization, Rainflow Counting algorithm	• Investigated EV battery cycling degradation using the Rainflow Counting algorithm • Optimized charging/discharging of EVs using the GA to minimize peak power demand and peak renewable exports of building communities with B2V and V2B applications • Systematically studied the impacts of EV smart charging on EV battery cycling degradation • Simulated and analyzed different EV driving scenarios using real building data.
Astrain et al. (2021)	2022	Spain	Smart city	Electric buses	Smart city lighthouse STARDUST project	• Integration of electric bus sensor data into city platform for battery state monitoring • Optimization of charging station operation and bus charging cycles. • Real-time communication system needed for energy management strategies • Optimization of charging needs, including machine learning modules for pattern recognition and reducing decision-making times.

(continued on next page)

development of fast charging stations that can charge EVs in a matter of minutes. These stations are equipped with advanced sensors and communication technologies that allow for real-time monitoring of the charging process and ensure efficient use of energy.

Another advancement is the use of vehicle-to-grid (V2G) technology, which allows EVs to not only draw power from the grid but also supply excess power back to the grid when needed. This can help to balance the power demand and supply, particularly during peak hours, and reduce the strain on the grid.

Table 8 (*continued*).

Ref	Year	Location of study	Smart Grid/City/building	Purpose	Technologies/ Process	Observation
Gorla and Chamola (2021)	2021	India	Smart cities	Battery lifetime estimation	Battery statistic estimation (BSE) algorithm	• Proposed accurate battery lifetime estimation for solar-powered systems with different PV panel and battery size configurations. • Modelled the impact of various design parameters, including PV panel size, battery power, and solar irradiation, on battery lifetime. • Steady-state probabilities for different states in the framework are evaluated, which plays a critical role in estimating battery lifetime. • Proposed work used for cost-optimal resource provisioning, and its performance is compared to that using empirical data and an existing benchmark.
Heinisch et al. (2021)	2021	Sweden	Smart city	Smart electric vehicle charging	City energy system optimization	• Investigated the implications of integrating Smart and Inflexible charging strategies for BECs and BEBs in the city energy system. • Assessed the ability of BECs and BEBs to utilize locally produced, low-carbon electricity and the dependence on charging strategies. • Analyzed the impact of various BEC charging strategies and sector-coupling on the optimal operation and design of the electricity and district heating sectors in the city.
Lasla et al. (2020)	2020	Qatar	Smart cities	Electric vehicle charging	Block chain energy trading	• Proposed energy trading platform is designed to work with the existing utility billing system, which simplifies the adoption of peer-to-peer energy trading. • Evaluated various pricing schemes for efficient energy allocation, including Vickrey, first-price, and periodic double auction mechanisms. • Developed a testing framework for a private Ethereum network to validate the performance of the trading platform in supporting the growing number of EVs and their charging requests.
Zhang et al. (2018)	2018	China	Smart cities	EV charging	Electric Vehicle Route Planning with Recharging (EVRC) approach	• Study focused on EVRC models to find the most time-efficient path for EVs. • The proposed solution considers the location, serving time, frequency, and charge quantity of charging stations. • The objective is to optimize the path of EVs and minimize charging time.

Table 9
Energy System modeling, description, and Source.

Input	Description	Impact
Parameter & Resource availability	Performance parameters and availability of resources when available	Performance of the system
System cost	Analyze of cost of smart grid infrastructure	Profitability of the system, benefit for producers and consumers
Geo-location characteristics	Analyze generation from renewable energy like PV and wind energy	Production from a remote location, effective transmission, and distribution
Energy prices	Effective pricing and cost-efficient	Consumer benefits through various methodologies such as schedule/ dynamic pricing
Regulatory constraints	Framework to commission smart grid infrastructure	Operating constraints consideration for regulations
Energy demand	Load–Demand characteristics	Sizing of generation based on load demand, installation, and transmission consideration

Moreover, intelligent algorithms are being developed to optimize the charging process and manage the load on the grid. These algorithms take into account factors such as energy prices, EV battery capacity, and grid capacity to determine the optimal time and rate of charging.

In addition, EVs are being integrated into smart transportation systems to improve mobility and reduce congestion. For example, EVs can be integrated with intelligent traffic management systems to optimize routes and reduce travel time.

6.2. EV charging infrastructure

With the increasing demand for environmentally friendly transportation options, the integration of electric vehicles (EVs) has become a priority for many cities around the world. However, the widespread adoption of EVs faces several challenges, including limited range and the availability of charging infrastructure.

To overcome these challenges, cities are developing and implementing smart transportation solutions, including the integration of EV charging infrastructure and battery swapping systems. EV charging infrastructure is critical for the widespread adoption of electric vehicles in cities. Electric vehicle charging stations can be integrated into existing parking facilities, public areas, and even residential buildings, providing convenient charging options for EV owners. Advanced communication technologies can also be employed to optimize the utilization of charging stations, such as real-time monitoring and management of charging station availability and power consumption (Khan et al., 2022a).

Moreover, the use of battery swapping systems can also provide an efficient alternative to traditional charging methods. Battery swapping involves replacing an EV's depleted battery with a fully charged one, reducing the time required for charging and enabling EVs to travel longer distances without the need for lengthy charging stops. Battery swapping stations can be located at strategic locations throughout the city, allowing for easy access to EV owners.

To fully realize the potential benefits of smart transportation, it is essential to integrate EV charging infrastructure and battery swapping systems into a larger smart transportation network. This network can utilize advanced algorithms and machine learning techniques to optimize the use of available charging resources, minimize waiting times for EV owners, and reduce the overall environmental impact of transportation.

6.3. Smart traffic systems

One of the critical components of smart transportation is the implementation of smart traffic management systems, which utilize advanced technologies to optimize traffic flow and reduce congestion. One of the most promising technologies for smart traffic management is the use of intelligent traffic signals. These signals use sensors and real-time data analysis to adjust signal timing based on traffic conditions, reducing delays and improving traffic flow. Additionally, intelligent traffic signals can prioritize buses and emergency vehicles, further reducing congestion and improving the reliability of public transportation (Balamurugan et al., 2014).

Another technology that can help improve smart transportation in cities is the use of connected and autonomous vehicles. These vehicles can communicate with each other and with the infrastructure, allowing for smoother traffic flow and reduced congestion. Additionally, connected and autonomous vehicles can help reduce emissions and improve fuel efficiency, further contributing to sustainable transportation. Next technology is the use of dynamic message signs. These signs provide real-time information to drivers about traffic conditions, accidents, and road closures, allowing them to make informed decisions about their route and travel time (Manimurugan and Almutairi, 2023).

In addition to improving traffic flow, smart traffic management systems can also help reduce emissions and improve air quality. By minimizing the amount of time vehicles spend idling in traffic, these systems can reduce the amount of harmful pollutants released into the atmosphere. Furthermore, smart transportation systems can also incorporate advanced parking management systems. Smart parking systems utilize sensors and real-time data analysis to direct drivers to available parking spots, reducing the time spent searching for parking and improving traffic flow in parking areas. This can help reduce congestion and improve air quality by minimizing the amount of time drivers spend idling in search of parking.

6.4. Smart parking

Parking is another major issue with private transportation in urban cities. The traffic generated by cars during rush hours looking for available parking spaces can account for up to 40% of total traffic conditions. To address this issue, Wang and He (2011) proposed smart parking systems that help drivers quickly locate and reserve available parking spaces. Autonomous vehicle research is currently underway (Parent, 2007). Transportation automation aims to increase the efficiency and safety of mobility, with freeways and highways being the first targets.

6.5. Urban public transportation

In many cities, regional transit systems such as metro are the primary mode of public transportation for providing the necessary quantity and quality of service. Various techniques for energy conservation in urban railway systems have been reported in reviewed works. González-Gil et al. (2014) reviewed such solutions, identifying five key groups: traction efficiency, energy-efficient driving, regenerative braking, smart management, and measurement and comfort functions. They suggested that regenerative braking can save a significant amount of energy due to the metro's layout, with multiple and regular stops. Another public transportation trend is the shift from diesel to electric or hybrid buses. Lajunen (2014) analyzed the costs and pollution benefits of urban electric buses and concluded that plug-in hybrid electric buses (PHEB) have the greatest potential to reduce emissions and energy consumption.

7. Data analytics

Data analytics plays a crucial role in smart energy management in smart cities. With the increasing amount of data generated by various sensors and devices, it is essential to have a mechanism to analyze and interpret the data to make informed decisions. Data analytics enables the processing of large datasets to identify patterns, relationships, and anomalies that can be used to optimize energy usage and reduce wastage (Li et al., 2023).

The data collected from various smart systems, such as smart buildings and smart transportation, can be analyzed to identify energy consumption patterns and areas of improvement. Machine learning algorithms can be used to predict energy usage and optimize energy systems accordingly. Predictive maintenance algorithms can be used to identify potential equipment failures in advance, reducing the downtime and improving energy efficiency.

Moreover, data analytics can also be used to analyze data from weather stations, traffic sensors, and other sources to predict energy demand and supply. This can enable the smart grid to adjust the energy supply to meet the demand effectively. Additionally,

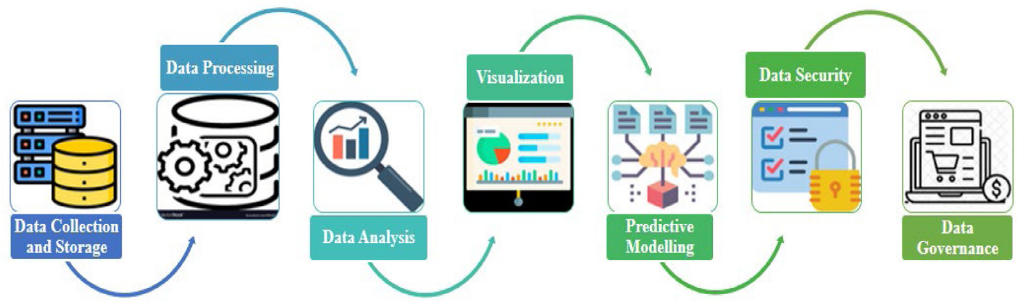

Fig. 7. Components of data analytics.

data analytics can also be used to monitor energy consumption and carbon emissions to promote sustainable practices and reduce the environmental impact of energy usage. The components of the data analytics is illustrated in Fig. 7. Data analytics plays a vital role in enabling smart energy management in smart cities, by providing insights into energy usage patterns and enabling efficient energy usage.

7.1. Advanced energy consumption data collection

Advanced energy consumption data collection refers to the use of advanced technologies to gather and analyze data related to energy consumption in smart cities. This data is used to make informed decisions about energy usage and identify areas where energy efficiency can be improved.

One example of advanced data collection technology is smart meters. These meters can be installed in residential and commercial buildings to monitor and collect energy usage data in real-time (Carrera et al., 2021). This data can be used to optimize energy consumption and identify areas for energy savings. Additionally, smart meters can enable dynamic pricing, where the cost of energy can be adjusted based on demand, encouraging users to reduce energy consumption during peak hours.

Other advanced data collection technologies include sensors and Internet of Things (IoT) devices. These can be used to monitor energy usage in various parts of a city, such as streetlights, public transportation, and public buildings. This data can be analyzed to identify patterns and trends in energy consumption, which can be used to optimize energy usage and identify areas where energy efficiency can be improved.

Advanced energy consumption data collection is a crucial component of smart energy management in smart cities. By gathering and analyzing data related to energy consumption, city officials and energy providers can make informed decisions about energy usage and identify areas for improvement. This can lead to increased energy efficiency, reduced costs, and improved sustainability.

7.2. Data analysis and interpretation tools

Smart energy management in smart cities requires the ability to collect and analyze data related to energy consumption patterns, as well as the ability to interpret that data to make informed decisions. This is where data analysis and interpretation tools come into play. These tools use advanced algorithms and machine learning techniques to analyze large amounts of energy consumption data and identify patterns and trends that can be used to optimize energy usage (Kaginalkar et al., 2023).

One of the key benefits of data analysis and interpretation tools is that they can provide real-time insights into energy consumption patterns, allowing cities to quickly identify areas where energy is being wasted or where energy efficiency improvements can be made. These insights can also be used to predict future energy consumption patterns, which can help cities to better plan for future energy needs and develop more accurate energy forecasts.

There are several types of data analysis and interpretation tools that are commonly used in smart energy management in smart cities. These include:

1. Energy analytics platforms: These platforms collect and analyze data from various sources, such as smart meters, building management systems, and weather forecasts, to provide real-time insights into energy consumption patterns.
2. Predictive analytics tools: These tools use machine learning algorithms to analyze historical energy consumption data and identify patterns and trends that can be used to predict future energy consumption patterns.
3. Energy visualization tools: These tools provide visual representations of energy consumption data, making it easier for city officials to identify energy waste and optimize energy usage.
4. Fault detection and diagnostics (FDD) tools: These tools use machine learning algorithms to identify and diagnose problems in building energy systems, such as HVAC systems, allowing city officials to quickly identify and fix energy inefficiencies.

As such, continued research and development in this area will be essential to advancing the state of smart energy management in smart cities.

8. Facilities

Facilities are described as residential, and commercial buildings as well as small-scale utilities, but not the industrial sector, which does not exist within the city limits. Buildings are the most electricity consumers in a city. These facilities account for roughly 3 quarters of overall emissions from greenhouse gases in cities depending upon the energy usage.

8.1. Smart buildings

Smart buildings are an essential part of smart cities that aim to improve energy efficiency, reduce energy consumption, and increase sustainability (Ahsan and Khan, 2022). These buildings are equipped with various technological advancements such as intelligent lighting systems, HVAC systems, and energy management systems that work together to optimize energy use which are shown in Fig. 8.

Energy Management: In smart buildings, energy management is a crucial component of efficient operation. An energy management system can monitor and control energy usage throughout

Fig. 8. Various components of smart buildings.

the building, optimizing the use of energy-consuming devices such as heating and cooling systems, lighting, and appliances. Smart energy management systems can even predict energy usage patterns and adjust energy consumption accordingly to minimize waste and reduce costs. By implementing these systems, smart buildings can significantly reduce their carbon footprint and operating costs.

Water Management: Water management systems can monitor and control water usage throughout the building, identifying leaks, and optimizing water consumption to reduce waste. These systems can even analyze water usage patterns to identify opportunities for further optimization. Smart water management systems can also contribute to a more sustainable building operation by reducing water usage and costs.

Lighting: Smart lighting systems use advanced sensors and algorithms to optimize lighting levels, reducing energy consumption while ensuring adequate lighting for building occupants. These systems can also integrate with occupancy sensors and building management systems to further optimize energy usage and reduce operating costs. In addition to contributing to energy efficiency, smart lighting systems also enhance occupant comfort and productivity by providing optimal lighting levels for various tasks and activities.

HVAC: HVAC (Heating, Ventilation, and Air Conditioning) systems play a crucial role in ensuring the comfort and well-being of occupants in buildings. Smart HVAC systems use advanced sensors and algorithms to optimize temperature and air quality while minimizing energy consumption (Woods, 2014). These systems can also be integrated with energy management systems to optimize energy usage and reduce operating costs. In smart buildings, HVAC systems play a vital role in ensuring occupant comfort and well-being while also contributing to energy efficiency.

Smart Mobility: Smart buildings can be integrated with smart mobility solutions to provide seamless and efficient transportation to occupants. This can include features like real-time traffic updates, ride-sharing services, and optimized parking solutions. By leveraging smart mobility solutions, smart buildings can reduce congestion and environmental impact, while also improving the overall quality of life for occupants.

EV Charging: With the growing popularity of electric vehicles (EVs), smart buildings are increasingly integrating EV charging stations into their infrastructure. Smart EV charging stations can monitor and optimize charging processes, providing fast and efficient charging while minimizing energy consumption. These stations can also be integrated with energy management systems to optimize energy usage and reduce operating costs.

Monitoring and Control: Monitoring and control systems are critical components of smart buildings, providing real-time monitoring and control of various building systems. These systems can integrate with other smart building components, such as energy management, water management, and HVAC systems, to optimize overall building performance.

Elevators: Elevators are critical components of tall buildings, allowing occupants to move quickly and efficiently between floors. Smart elevators use advanced algorithms to optimize elevator usage, reducing wait times, and energy consumption. These elevators can also be integrated with occupancy sensors and building management systems to improve overall building efficiency.

Waste Management: Smart buildings can also optimize waste management through the use of smart waste systems. This can include features like automated waste sorting, recycling programs, and real-time waste tracking. By optimizing waste management, smart buildings can reduce their environmental impact and improve their overall sustainability.

Security: Security is an essential aspect of smart buildings, ensuring the safety and protection of occupants and assets. Smart security systems use advanced sensors, cameras, and algorithms to monitor and analyze security threats. These systems can alert building managers to potential security breaches and provide real-time video monitoring for enhanced situational awareness.

Fire: Fire safety is a critical aspect of building design and operation. Smart buildings integrate advanced fire safety systems that use sensors and algorithms to detect potential fire hazards and alert building occupants and authorities in real-time. These systems can also provide real-time monitoring and analysis of fire safety systems, ensuring they are operating correctly.

Renewable Energy: Smart buildings can also integrate renewable energy sources like solar and wind power. This can be achieved through the use of smart grids and energy storage systems. By generating and storing their own energy, smart buildings can reduce their reliance on the grid and improve their overall energy efficiency.

Online Technical Service: Smart buildings can also benefit from online technical service solutions. This can include features like remote monitoring and troubleshooting, predictive maintenance, and real-time data analytics. By leveraging these solutions, smart buildings can reduce downtime and maintenance costs, while also improving overall efficiency.

Enterprise System Integration: Smart buildings can also be integrated with enterprise systems like HR, finance, and supply chain management. This can enable seamless data sharing and communication across all aspects of the organization, leading to better decision-making and overall efficiency.

8.2. Smart home

Energy management systems in smart homes play a crucial role in optimizing energy consumption and reducing energy bills. Fig. 9. represents the integrate a variety of sensors and devices, including weather and temperature monitoring systems, Wi-Fi routers, media players, CCTV cameras, audio devices, laptops, TVs, mobile phones, and lighting controls, to provide a comprehensive view of the home's energy consumption patterns (Ma et al., 2023). The systems use advanced algorithms and machine learning techniques to analyze this data and provide insights into the energy consumption patterns, which can then be used to optimize energy usage.

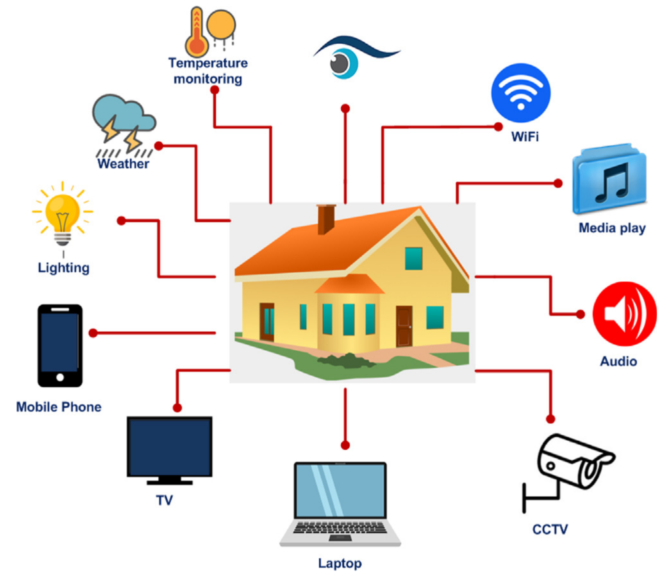

Fig. 9. Elements of the smart home.

The weather and temperature monitoring sensors allow the system to adjust the home's heating and cooling systems based on the current weather conditions, ensuring optimal comfort while minimizing energy usage. The Wi-Fi router and media player sensors can be used to detect whether someone is home and adjust the energy usage accordingly. CCTV cameras and audio devices can be used to monitor activity in the home and adjust energy usage based on occupancy, while laptops, TVs, and mobile phones can be used to detect when someone is in a particular room and adjust lighting and HVAC accordingly.

Energy management systems in smart homes also allow users to set custom energy usage profiles and schedules, which can be adjusted based on changing circumstances and illustrate in Table 10. For example, if a user is going to be away from home for an extended period, the system can adjust the energy usage to minimize waste (Koltsaklis et al., 2022). Overall, energy management systems in smart homes offer a powerful tool for reducing energy waste and optimizing energy consumption.

8.3. Minimizing energy usage in smart buildings

There are several significant issues in smart buildings when it comes to minimizing energy usage without sacrificing consumer comfort. The first step to resolve this issue is to ensure effective energy systems are installed in buildings. Optimized maintenance and service can save up to 20% to 30% of a building's energy consumption while leaving the structure and system unchanged.

Demand response is another common subject in achieving energy goals. Most buildings today are passive energy consumers, but the building's function must shift to active participation from a passive, unresponsive energy user in the energy system to achieve the desired energy goals. A demand-response plan can help to evolve the new paradigm that takes advantage of distributed generation (DG) technologies and energy-storage systems.

Microgrid variants have been reported in the reviewed works, varying primarily in size and type of utilization. The nanogrid concept occurs on a small scale, including a group of houses, a small building, or a single one. The definition of nanogrid is a small, independent DC power system that provides reliable electricity to local loads through ESS and DG. However, the nanogrid approach often uses an AC power system, as described in Guan

Table 10
Various smart home energy management system.

Ref	Year	Location of study	Components	Purpose	Observation
Selvaraj et al. (2023)	2023	Bostwana	Renewable energy sources	Energy management and monitoring system	• AIMS-SB is an AI technique for energy management in smart buildings. • AIMS-SB helps manage energy consumption and production in a sustainable way. • The strategy involves efficient implementation of renewable energy sources. • The experimental results showed that improved accuracy and efficiency compared to existing methods.
Be-heshtikhoo et al. (2023)	2023	Iran	Renewable energy, Electric vehicle	Demand-side energy management system	• Proposed Type-2 fuzzy logic controllers make decisions about generated energy, energy supply for own consumption, and controllable loads. • Number and distribution of membership functions selected based on real input data from Tehran, Iran.
Khan et al. (2022b)	2023	Kuwait	Smart home, IOT	Transfer learning (TL)	• Application of TL in smart home networks to reduce energy consumption and discomfort. • Knowledge transfer at various levels from source domain to target domain and vice versa. • Performance evaluation in various scenarios measuring average energy consumption and discomfort.
Javadi et al. (2021b)	2021	Iran	Home Appliances	Self-scheduling model	• Proposed a linear penalizing mechanism for shifted time slots of scheduled appliances to calculate the discomfort index. • Presented a MILP multi-objective model for the HEMS self-scheduling problem to minimize energy cost and discomfort index. • Evaluated different time-based Demand Response programs in the self-scheduling problem to help tariff designers choose the most efficient one. • Assessed the impacts of the Electrical Energy Storage (EES) device on the self-scheduling problem to study the effects of such devices.
Javadi et al. (2021a)	2021	Portugal	PV and battery system	Self-scheduling framework, using risk-constrained optimization model	• Introduced a novel MILP model for risk-constrained self-scheduling problem of a residential prosumer • Reduced the electricity bill by managing electrical energy consumption • Utilized self-generation assets to reduce the end-user's need to purchase energy during peak hours • Proposed a comprehensive MILP model for all types of loads and energy storage system
Aliero et al. (2021)	2021	Malaysia	Internet of Things, Energy generation technologies, home appliance	Demands and services	• Investigated the energy generation technology and its coupling with Smart Home Energy Management Systems (SHEMs). • Highlighted the need to expand renewable energy sources to reduce reliance on fossil fuels and addressed the global warming concerns. • Emphasized the role of energy management systems in balancing energy demand and supply in building sectors.
Javadi et al. (2020a)	2020	Iran	PV and Batteries	Self-scheduling	• Proposed the stochastic MILP model for HEMS self-scheduling problem • Effective strategy to reduce computational burden and can be embedded in HEMS devices • Incentivizing self-generation and energy-saving to lower bills • Important contribution for evaluating the potential effectiveness of hybrid systems with BEES and PV panels

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Table 10 (*continued*).

Ref	Year	Location of study	Components	Purpose	Observation
Almeida et al. (2020)	2020	Portugal	PV, Electric Vehicle	Economic analysis parking lots	• Investigated the coordinated use of HEMSs and EVPLMSs for economic benefits. • Conducting a cost–benefit analysis from the point of view of EV owners. • Utilizing HEMS at home and EVPLMS at work for the analysis. • Performing analysis on case studies based on real neighborhoods and faculty in Porto, Portugal.
Javadi et al. (2020c)	2020	Portugal	Inverter-based Heating, Ventilation and Air Conditioning System	Optimal scheduling of the home appliances	• Investigated the modeling of inverter-based HVAC systems as an interruptible load in the daily self-scheduling problem. • Proposed a HEMS to manage the daily operation of controllable home appliances and fixed loads. • Developed a MILP model for both controllable and interruptible appliances using binary decision variables. • Meeting the preferences of end-users in the self-scheduling problem.
Javadi et al. (2020b)	2020	Portugal	Iot, home appliances	Self-Scheduling	• Multi-objective optimization using both electricity bill and user's Discomfort Index as objectives, considering Time-of-Use (ToU) tariffs • Use of fuzzy decision making, specifically Epsilon-Constraint Method, to account for trade-off between cost and comfort • Proposed solutions aimed to lie on the Pareto front of various solutions.

et al. (2010). There is no specific concept for a microgrid on a medium scale (small town or district), but applications of this microgrid offer a diverse set of technologies. The most notable case is district energy networks (DEN), which are used to distribute electricity produced in an integrated location across the district for commercial and residential purposes. DEN has conventionally been utilized solely for heating, but with developments in cogeneration, electrical energy is added to cooling.

Lastly, passive systems can be used as a supplement. This approach is implemented to absorb, distribute and store thermal energy inside the building system. A wide range of design elements should be considered, including thermal mass, thermal insulation, the position of the window, glass variants, and shading form. These factors are collectively called a building envelope. Due to the high installation cost to modify the existing buildings, the majority of these changes can only be considered for new structures.

8.4. Applications and research in facilities

Several studies have been conducted on home automation in terms of comfort management and energy conservation. Pulselli et al. (2009) focused on control strategies for smart buildings, particularly in air conditioning and heat ventilation systems.

In recent years, microgrid-related research and demand response have progressed significantly. Adda et al. (2012) described controlling DC applications using power electronics converter, namely VSI. Guan et al. (2010) proposed storage, scheduling, and controlling renewable energy sources using mixed-integer programming to optimize energy prices in buildings when dynamic energy demand and costs are taken into account. Thermal load control in district energy networks is discussed in Ma et al. (2012) to enhance energy efficiency.

The building envelope has been extensively studied in the passive-systems field, resulting in significant contributions towards energy savings in air conditioning and heating. Pulselli et al. (2009) presented an environmental assessment of three separate wall envelopes, taking into account various climate conditions as well as economic benefits. Li et al. (2009) compare various shading, thermal isolations, and windows for humid and hot locations. Modeling the effects of window design in restaurant and hotel buildings is discussed in Sozer (2010). To get a cost-efficient model, most of these considerations should be applied during the construction phase.

The literature in this section is summarized in Table 11, which is categorized according to the type of facility. The focus of smart buildings is energy conservation, passive systems, and comfort management. Microgrid research prioritizes DG control and demand-response schemes, while district energy networks are concerned with load control and energy efficiency. Several European initiatives in the telecommunications and facilities areas have been commissioned to address demand response, energy-efficient buildings and districts, and connectivity problems.

9. Case studies

Smart cities have become a growing trend in many countries, incorporating the latest technologies to improve the quality of life for its citizens. One of the significant areas of focus in smart cities is energy management, which plays a crucial role in sustainable development. Several cities around the world are already working towards becoming smart cities, including Italy, China, Spain, New York, Taiwan, and India. These countries are incorporating the latest technologies in various applications such as smart transportation, air quality monitoring, cultural attributes, medical diagnosis, and disaster management. The primary goal of smart cities is to reduce human effort and effectively utilize technologies to provide people with safe and sophisticated living conditions. Table 12 illustrates the latest trends and advancements in various sectors of smart cities.

Table 11
Summary of facilities.

Reference	Type	Purpose	Inference
Gholamian et al. (2020)	Smart building	Energy storage and integration of hybrid photovoltaic-thermal collector panels	The proposed system is analyzed for a smart building that comprises controllers to guide the steam following the ambient temperature.
Carli et al. (2020)	Smart microgrid	Controlled load and source sharing	The energy planning of a smart microgrid with controllable and uncontrollable electrical equipment as well as the PV panels and battery power storage is proposed using Model Predictive Control
Imran et al. (2020)	Smart distributed energy source and storage	Renewable energy integration and ESS in smart grid	Hybrid energy storage system, PV, and EVs in the smart grid (SG) for enhanced and reliable energy management system.
Shokravi et al. (2020)	Smart Vehicle	Potential use of smart vehicle	Ad hoc vehicle networks are smart to interconnect vehicle networks that can analyze in real-time ways traffic parameters such as vehicle type, speed, location, and direction.

9.1. Challenges faced during implementation

Implementing smart energy management technologies in smart cities can be challenging, as there are several obstacles that must be overcome. Here are some of the common challenges faced during implementation, as well as some strategies for overcoming them:

1. **High Implementation Costs:** One of the main challenges of implementing smart energy management technologies is the high upfront costs. This can be particularly challenging for cities with limited budgets. However, many cities have overcome this challenge by partnering with private companies or leveraging grant funding to finance the implementation of these technologies.
2. **Limited Data Access:** Another challenge is the limited availability of data needed to optimize energy usage. This can be overcome by implementing smart meters and other sensors to gather data on energy consumption, as well as using data analytics to analyze and optimize energy usage.
3. **Resistance to Change:** Implementing new technologies can be met with resistance from stakeholders who are hesitant to change their established practices. This can be overcome by involving stakeholders in the planning and implementation process, and by demonstrating the benefits of the new technologies through pilot projects and other initiatives.
4. **Technical Complexity:** Smart energy management technologies can be complex, requiring specialized knowledge and expertise to implement and maintain. This challenge can be overcome by partnering with technology experts and building internal capacity through training and other initiatives.
5. **Privacy and Security Concerns:** Smart energy management technologies require the collection and storage of sensitive data, raising concerns about privacy and security. This challenge can be overcome by implementing robust data security measures, such as encryption and access controls, and by being transparent about data collection and usage policies.

Overall, while implementing smart energy management technologies in smart cities can be challenging, these challenges can be overcome through partnerships, pilot projects, stakeholder engagement, and technical expertise. By addressing these challenges, cities can unlock the benefits of smart energy management technologies, including increased efficiency, reduced costs, and better sustainability.

10. Future directions for smart energy management in smart cities

As technology continues to evolve and smart cities become more prevalent, the future of smart energy management looks promising. Here are some of the future directions for smart energy management in smart cities:

Integration of Renewable Energy Sources: One of the key future directions for smart energy management in smart cities is the integration of renewable energy sources, such as solar and wind power. As renewable energy becomes more affordable and accessible, cities can use it to power their smart grids and reduce their reliance on fossil fuels.

Development of Energy Storage Solutions: As cities move towards greater reliance on renewable energy sources, the development of energy storage solutions will become increasingly important. Energy storage systems, such as batteries and pumped hydroelectric storage, can store excess energy from renewable sources and release it when it is needed, providing a reliable source of energy.

Adoption of Electric Vehicles: The adoption of electric vehicles (EVs) is another future direction for smart energy management in smart cities. By promoting the use of EVs and investing in charging infrastructure, cities can reduce emissions and improve air quality.

Implementation of Microgrids: Microgrids are localized energy systems that can operate independently of the main power grid. By implementing microgrids in smart cities, cities can improve grid resilience and reduce the risk of power outages.

Smart Metering and Time-of-Use Pricing: Smart metering allows for real-time tracking of energy usage and enables time-of-use pricing, which charges consumers based on the time of day they use energy. By implementing smart metering and time-of-use pricing, cities can incentivize consumers to shift their energy usage to off-peak hours, reducing strain on the grid during peak periods.

Energy Efficiency in Buildings: Buildings account for a significant portion of energy usage in cities, and improving their energy efficiency is a key future direction for smart energy management. Technologies such as smart thermostats, automated lighting, and energy-efficient building materials can reduce energy consumption in buildings.

Implementation of Demand Response Programs: Demand response programs allow utilities to incentivize consumers to

Table 12
Various case studies on smart cities.

Ref. No.	Year	Location	Type of facility	Technologies/Process utilized	Observation
Anedda et al. (2023)	2023	Cagliari (Italy)	Monitoring Public and Private Mobility, Smart Traffic	Internet of things, Sensors, Camera, Wi-Fi access point, Machine learning	• Social IoT approach used to monitor and manage pedestrian and vehicular flows in the city (public and private). • Real-time monitoring done through cameras and mobile/fixed sensors. • Vehicular flow analysis enables real-time management of traffic light timings in the port area and Roma Street area, resulting in significant reductions in traffic flow times. • Artificial intelligence (AI) is used to analyze instantaneous and average speed, traffic type, and flow direction undertaken by vehicles and pedestrians on a daily basis.
Yang and Lee (2023)	2023	Busan and Sejong in South Korea	Smart city and remote services	Stimulus–organism–response framework	• Study compares two smart cities in South Korea. • Determine the differences in citizens' perceptions of factors influencing acceptance of remote smart city services. • Uses the SOR (Stimulus-Organism-Response) framework to analyze behavioral differences among smart city citizens.
Essayeh and Morstyn (2023)	2023	Perth West	Microgrids	Renewable Energy, mixed-integer non-linear programming model	• Presents an optimal sizing model for a grid-connected microgrid • Considers both renewable system investment costs and grid connection costs • Accounts for the flexibility of distributed assets in the planning phase • Shows that flexibility can decrease renewable system investment costs • Indicates that the decrease in storage system costs will be key in adopting renewable systems.
Ilić et al. (2022)	2022	Belgrade, capital city of the Republic of Serbia	Unmanned Aircraft Systems for smart city transformation	SWOT analysis and Fuzzy Analytic Hierarchy Process	• Proposed SWOT-FAHP model for transforming the Belgrade city. • Aims to utilize Unmanned Aircraft Systems (UAS) as a disruptive technology with potential in urban areas • Prioritizes the needs of citizens of the capital city • Each strategy focuses on the human element in a dynamic urban environment • The urban environment is becoming more challenging each day
Zhang et al. (2022)	2022	Wuhu, China	Big data analytics	Information and Communications Technology (ICT)	• The study proposes a framework for using big data to make a city smarter, focusing on the case of Wuhu. • The framework illustrates the process of orchestrating big data for development, offering innovative insights for researchers and practitioners. • The study contributes to both theoretical developments and practical insights in the use of big data for smart city development. • With the maturity of smart cities, a potential fourth phase could emerge in the future. • Regular case studies of successful smart cities should be conducted to reflect new knowledge and update the framework accordingly.
Hsiao et al. (2019)	2021	Taiwan	IoT by Innovation Mode	Internet of Things (IoT), Big data and the cloud platform	• Innovation management framework presented to support sustainable smart city development using IoT. • IoT service innovation model with eight steps: team composition, idea generation, idea screening, development concept selection, design and development, testing, commercialization, and service quality. • Steps applied to market, policy, and technical sides. • Elaborated breakdown of activities for each step recommended.

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Table 12 (*continued*).

Ref. No.	Year	Location	Type of facility	Technologies/Process utilized	Observation
Dhingra and Chattopadhyay (2021)	2021	Alwar walled city in India	Smart socio-cultural attributes	Fuzzy approach	• Concludes better performance of socio-cultural attributes of HUL. • Recommended to capitalize on the existing social and cultural capital of old cities worldwide. • Disadvantage of fuzzy logic is the challenge of justifying the membership function. • Recommend future research to use allied Fuzzy Multi-Criteria Decision Making (FMCDM) techniques such as fuzzy AHP. • Future researchers should also consider a hybrid fuzzy logic approach, which uses both subjective and objective datasets.
Chen et al. (2021)	2021	–	Cyber security	Internet of Things, Deep Learning	• Participants' current mitigating strategies, perceived needs, and preferences for infrastructural upgrades described • Qualitative descriptive and case study designs used for data collection • Interviews used to portray multiple views, but subject to biases and poor articulation • Focus groups used to examine emergence of new concepts or themes in group setting.
Yan et al. (2020)	2020	China	Self-organizing system framework, Smart transportation systems	Information and Communications Technology (ICT), Smart Cell	• The proposed evaluation system for smart cities integrates self-organization and distributed governance concepts. • The framework helps in understanding the structural characteristics of smart cities as intricate systems. • It is based on self-organization theory and can lead the way in developing sustainable and healthy smart cities. • The study uses China's smart transportation systems as a case study. • The case study offers insights for future smart city development.
Şerban and Lytras (2020)	2020	Europe	Smart renewable energy sector	Artificial intelligence, Renewable energy	• Renewable energy (RE) is essential for global development in the face of climate change and resource depletion. • Artificial intelligence (AI) provides new opportunities for organizing activities to meet these challenges. • Improvements are needed in the design, deployment, and production of RE to ensure sector growth and resilience. • Recent developments in AI adoption for the RE sector in the Europe Union are explored. • The study analyzes efficiency in the transformation processes of RE within the energy chain and the structure of renewable energy sources. • It also examines labour productivity in the RE sector and its correlation with investment levels, as well as the implications of AI adoption for RE and smart city research.
Gonzalez et al. (2020)	2020	Bogotá Colombia	Government and governance in intelligent cities, smart transportation	Artificial intelligence, cloud computing, big data and information and communication technologies (ICT)	• A supervised neural network can simulate a good architecture with low error when using appropriate inputs and sufficient data. • ICT connectivity is crucial for smart cities to optimize the continuous flow of data and facilitate urban development. • Smart city development should prioritize governance and government to improve citizens' quality of life.
Abbas et al. (2020)	2020	Rehab County in New Cairo city – Egypt	Narrowband-Internet-of-Things optimization for smart meters	Internet of Things	• Enhance NB-IoT spectral efficiency • Reduce signaller-centred, addressing burden during each transmission request for periodic IoT applications.

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Table 12 (*continued*).

Ref. No.	Year	Location	Type of facility	Technologies/Process utilized	Observation
Santos et al. (2019)	2019	Santander (Spain)	Air quality monitoring	Internet of Things, Sensor node, wireless networks	• Study focuses on event-based sensing approach for Smart Cities, WSN, and IoT to increase battery life and reduce computational costs. • Evaluates different measurement-based sampling techniques in a case study of Santander, Spain. • Uses periodic data on environmental pollution parameters from Santander's Smart City services for analysis. • Assesses commercial electronic devices to evaluate the contribution of different event-based techniques to IoT node battery lifetime. • Provides insights to enhance the efficiency and sustainability of smart cities through IoT and WSN.
Petritoli et al. (2019)	2019	Casaccia R.C. (Rome)	Smart lighting as basic building block	Information and Communications Technology (ICT), camera	• Investigated energy savings potential of optimizing delivery times and intensities of public street lighting • Used smart lighting techniques for management
Shah et al. (2019)	2019	New York	Smart city infrastructure	Internet of Things, Sensors	• Study focuses on smart solutions implemented in New York city for resource utilization and citizen experience improvement • Waste management, water management, air quality control, lightning, parks improvement, LinkNYC program, NYCDot.
Jiang et al. (2019)	2019	China	Medical diagnosis	Internet of Things, Medical Images, guided anchored neighborhood regression (GANR)	• Divides image patches into clusters to present all patterns of the images • Learns dictionaries for each cluster • Introduces a strategy to find the most precise anchor neighborhood projection • Guides reconstruction error of LR patch to reconstruct HR patch
Macke et al. (2018)	2018	Curitiba, in Southern Brazil	Quality of life	–	• Focuses on smart living within the context of a smart city. • Four factors for achieving success in smart living: socio-structural relations, environmental well-being, material well-being, and community integration. • Meeting these criteria would improve citizens' quality of life and create a stronger community in the city.
Arsenio et al. (2017)	2017	Águeda	Electric bicycles	Information and Communication Technologies (ICT)	• Examines secondary school students' willingness to use e-bikes for their daily travel to school. • Additional ICT-related devices such as B2B connectivity and proximity sensors are assessed for increasing the likelihood of choosing e-bikes over cars. • Identifies perceived barriers to cycling to school, including the risk of accidents and hilly streets. • Absence of cycling infrastructures and cycle lanes are also identified as significant barriers.
Reddy et al. (2016)	2016	Gujarat, India	Transportation planning	Multi-level parking	• Proposed smart transportation applications in GIFT City improve transport outcomes. • Outcomes include transport safety, productivity, reliability, informed travel choices, environmental performance, and network operation resilience. • GIFT City's transport master plan is user-centered, addressing the needs of all users. • Enables all GIFT City users to enjoy a world-class lifestyle in this vibrant global city.

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Table 12 (*continued*).

Ref. No.	Year	Location	Type of facility	Technologies/Process utilized	Observation
Yu et al. (2016)	2016	Ahmedabad, India	Slum upgrading programs and Disaster resilience	Survey	• Describes participants' current mitigating strategies, perceived needs, and preferences for infrastructural upgrades • Interviews and focus groups used for data collection • Interviews allow portrayal of multiple views while subject to individual bias, recall bias, and poor articulation • Focus groups used to examine emergence of new concepts or themes in group setting.

reduce their energy usage during periods of high demand. This can help to reduce the strain on the grid and prevent blackouts. The implementation of demand response programs is a future direction for smart energy management in smart cities.

Use of Artificial Intelligence and Machine Learning: Another future direction for smart energy management is the use of artificial intelligence (AI) and machine learning (ML) to optimize energy usage. These technologies can analyze vast amounts of data and provide insights into energy consumption patterns, allowing cities to make data-driven decisions and improve energy efficiency.

Community Energy Programs: Community energy programs involve local communities in the planning and implementation of energy management initiatives. By engaging citizens and promoting community involvement, cities can improve energy efficiency and foster a sense of shared responsibility for sustainability.

Public–Private Partnerships: Finally, public–private partnerships are a key future direction for smart energy management in smart cities. By partnering with private companies, cities can access the expertise and funding needed to implement innovative energy management technologies, while also leveraging the strengths of the public sector to promote sustainability and social equity.

Overall, the future of smart energy management in smart cities looks promising, with the potential to reduce energy consumption, lower costs, and improve sustainability. By implementing these future directions and continuing to innovate, cities can create more liveable, efficient, and sustainable urban environments.

11. Potential research areas and emerging technologies in the field

As the field of smart energy management in smart cities continues to evolve, there are several potential research areas and emerging technologies that are discussed in this section. Here are some examples:

Block chain for Energy Transactions: Block chain technology has the potential to revolutionize the way energy transactions are conducted in smart cities. By providing a secure, transparent, and decentralized platform for energy transactions, block chain can enable peer-to-peer energy trading, reduce costs, and increase energy efficiency.

Edge Computing for Smart Grids: Edge computing involves processing data at the edge of the network, rather than in a centralized data center. This can improve the speed and efficiency of data processing for smart grids, enabling real-time monitoring and control of energy consumption.

Internet of Things (IoT) for Energy Management: The IoT involves connecting physical devices to the internet, enabling them to collect and exchange data. In the context of smart energy management, the IoT can be used to monitor and control energy usage in real-time, optimizing energy consumption and reducing waste.

Big Data Analytics for Energy Efficiency: Big data analytics can be used to analyze vast amounts of data and identify patterns and trends in energy consumption. This can enable cities to make data-driven decisions about energy management, reducing costs and improving efficiency.

Energy Harvesting Technologies: Energy harvesting technologies involve capturing and storing energy from natural sources, such as solar, wind, or thermal energy. These technologies can provide a reliable source of energy for smart cities, reducing reliance on fossil fuels and promoting sustainability.

Machine Learning for Energy Forecasting: Machine learning algorithms can be used to forecast energy consumption patterns, enabling cities to better manage energy resources and plan for future energy needs.

Distributed Energy Resources (DERs): DERs involve small-scale energy sources, such as solar panels or wind turbines that can be connected to the grid and used to supplement or replace traditional energy sources. By incorporating DERs into smart grids, cities can improve grid reliability and resilience.

There are many exciting research areas and emerging technologies in the field of smart energy management in smart cities. By exploring these technologies, researchers can contribute to the ongoing development of smart cities and help to create more sustainable, efficient, and liveable urban environments.

12. Conclusion

In conclusion, this review paper has discussed the significant advancements in smart energy management technologies in smart cities. We categorized the technological advancements into various applications such as smart grids, smart buildings, smart transportation, and smart cities. We also discussed the benefits of these advancements, such as increased efficiency, reduced costs, and better sustainability. Moreover, we provided case studies of cities that have successfully implemented smart energy management technologies and discussed the challenges faced during implementation and how they were overcome. Finally, we highlighted potential research areas and emerging technologies, such as blockchain, edge computing, IoT, big data analytics, energy harvesting technologies, machine learning, and distributed energy resources (DERs). In conclusion, the review paper emphasizes the importance of technological advancements in smart energy management in smart cities, which can significantly improve the energy efficiency of cities and contribute to a more sustainable future. To continue the development of smart cities, future research and development should focus on addressing the challenges of implementation, developing innovative technologies, and fostering collaboration between industry, academia, and governments.

CRediT authorship contribution statement

Pitchai Pandiyan: Performed the experiments, Analyzed and interpreted the data, Wrote the paper. **Subramanian Saravanan:** Analyzed and interpreted the data, Materials. **Kothandaraman Usha:** Conceived and designed the experiments. **Raju Kannadasan:** Analysis tools or data. **Mohammed H. Alsharif:** Performed the experiments. **Mun-Kyeom Kim:** Conceived and designed the experiments, Contributed reagents.

Declaration of competing interest

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Data availability

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