smart cities

Review

Energy and Sustainable Development in Smart Cities: An Overview

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Abstract: Smart cities are an innovative concept for managing metropolitan areas to increase their residents' sustainability and quality of life. This article examines the management and evolution of energy generation, various storage systems and the applications they serve, and infrastructure technology's current condition and future prospects. Additionally, the study also examines energy-related construction and transportation systems and technologies. The Smart Cities Energy Prediction Task Force predicts electrical usage using STLF, SVM, and e-learning machines. To keep a system working well throughout the year, fossil fuels must be utilised as a backup energy source. Technologies can only benefit if integrated into the city's infrastructure. By 2050, it is anticipated that the global population will surpass 10 billion, with most people settling in metropolitan regions. Between 2020 and 2027, the global market for smart energy is anticipated to expand by 27.1% annually, from USD 122.2 billion in 2020 to USD 652 billion in 2026. In 2020, Europe will account for 31.8 per cent of total smart energy product sales. China's GDP is projected to grow by 33.0 per cent annually, reaching USD 176.1 billion by the conclusion of the analysis period. Consequently, smart cities are expanding and blooming worldwide, yet there are no permanent standards.

Keywords: smart cities; energy management system; digitisation; urban infrastructure; Internet of Things

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1. Introduction

Smart cities are an innovative idea for managing metropolitan areas to improve sustainability and citizens' standard of living [1]. Moreover, projects involving digitalisation and smart cities are required to add value to increase ecological and economic sustainability. However, this added value may be stated more straightforwardly by first subtracting the benefits from the efforts [2].

Smart cities must address the issue of constructing their infrastructure with cutting-edge technologies that use energy efficiently and have a minimal environmental impact. Creating "smart buildings" and a more efficient transportation system is crucial to the fight against climate change and other environmental issues. As part of a smart city's balanced energy exchange, a self-managing automated system that can convert electric power into a finished product with minimal human intervention is required [3].

A single system including various energy, heat, gas and water schemes, as well as telecommunications structures, is being developed in smart cities to balance power output and consumption, lower generation capacity, and affect other energy market participants [4]. Electrification, the process of converting society to using electricity as its principal energy source, is essential to the long-term health of the energy sector.

The core of this definition is achieving a healthy equilibrium between the supply and demand of energy [3]. Each of these regions has varying levels of readiness for electricity (a combination of pre-requisites). Determining the requirement for electrification is a system's energy consumption. Hence, electrification can be prepared for by gaining motivation and access to new electrical technologies by investing in them and having the financial resources to do so [5]. Price ratios between electricity and other energy carriers, a focus on energy conservation by the public sector, and a shift in electricity and capacity markets to allow for increased competition among generators are additional issues that must be considered [6].

Urban, national, and international growth are all dependent on the availability of energy. Moreover, this dependence hinders efforts to improve environmental quality and sustainability. As a result of increased energy consumption in an expanding economy, CO_2 emissions will spike, causing the global temperature to rise. In contrast, urbanisation and population density have made it more challenging for cities to control their energy use and environmental impact [7]. More than a billion Chinese people will reside in urban areas the year that emissions will spike. Future urban environments are anticipated to be dominated by carbon emissions from transportation systems, which are anticipated to undergo a radical shift in demand and energy use. Transportation and operational modes will impact the energy usage and carbon emissions of cities. In order to achieve low-carbon transportation, it is vital to give clear guidelines and sufficient legislation. According to the International Energy Agency, transportation-related carbon emissions will account for more than half of worldwide energy use by 2030 [8].

A amount of 70% of global CO_2 emissions and two-thirds of global energy use can be attributed to metropolitan regions. All governments have promised to collaborate on resolving global energy, climate, and environmental problems. After signing the first global climate pact in 2015, the EU, the US, and China pledged to lower their emissions over the following decades. We can reduce CO_2 emissions and enhance the environment using smart city energy systems [9]. Smart cities of the next generation must have an energy source that is both carbon-efficient and energy-efficient. Several forms of energy are included in a single system, including a wide variety of sources, such as electricity generation and conversion, energy distribution and storage, and transportation.

This enables greater flexibility in the usage of renewable energy, as well as substantial gains in energy use efficiency and cost savings. Rapid urbanisation necessitates an innovative strategy, and a smart city precisely provides this model. This vehicle is sustainable because it combines environmental sustainability and low-carbon environmental protection with flexible mobility and efficient recycling [10]. More than 52 per cent of the world's population currently resides in urban areas, and this proportion is projected to increase to 72 per cent by 2040. Numerous government and non-profit organisations are promoting smart city initiatives to assist communities in reducing their energy consumption to cope with population growth [11].

Due to the complexity of the power administration system, multiple types of information must be transmitted in virtual environments, including distribution systems and households/buildings. As an illustration, smoothing the power peak requires knowledge of power patterns and consumer-accepted standards. Smart cities must implement cutting-edge technologies such as Internet of Things (IoT) communication networks to meet these requirements, which track and transmit data to utility centres, where it is used to implement complex rules for smart city power administration [12]. Figure 1 highlights some of the smart city features and technologies.

This paper begins with a review of the current state of research and the future of smart cities, especially in energy. As part of our investigation into smart cities, we look at the management and evolution of energy generation, various storage systems and the applications they serve, and infrastructure technology's current state and future possibilities. The research also looks at energy-related systems and technologies used in construction and transportation.

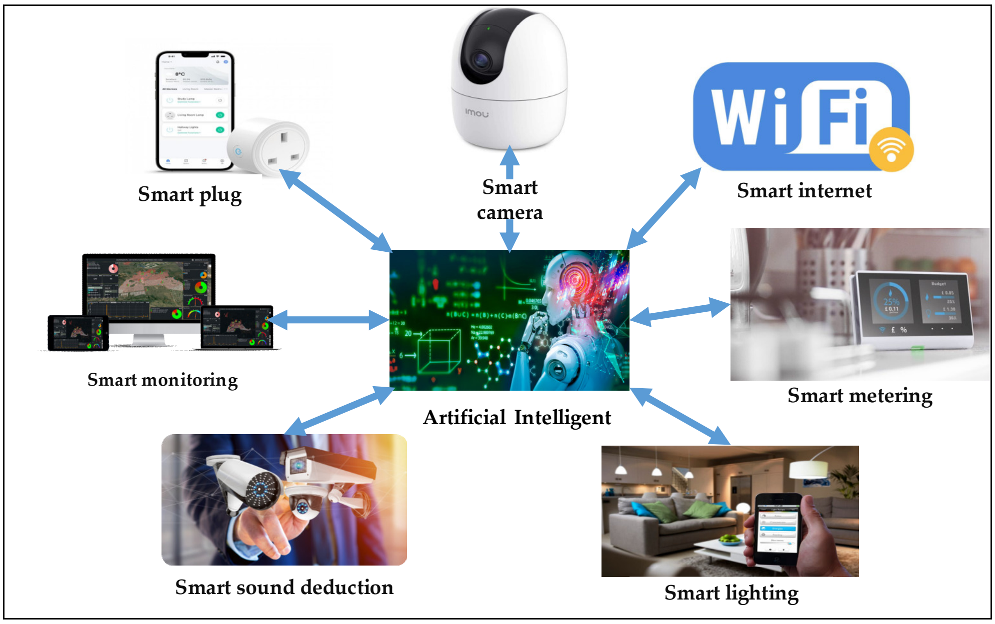

Figure 1. Features and technologies used in the smart cities.

The purpose of this study is to present an overview report on sustainable energy development in smart cities. Since a sustainable city employs information and communication technologies (ICTs) and other means to improve the quality of life of its residents, the efficiency of urban operations and services, and its level of competitiveness while also addressing the economic, social, environmental, and cultural needs of its current and future populations, this study improves the standard of living of its citizens while simultaneously bolstering the local economy by employing cutting-edge technologies and analytical techniques. Due to the complexity and significance of the energy networks in smart cities, energy management is one of the most difficult challenges these areas face. As a result, this study provides adequate information on energy management in smart cities. In addition to environmental issues, the emergence of "smart cities" is a part of the broader concept of sustainable pro-ecological development that employs cutting-edge information technologies. The expansion of "smart cities" has the potential to enhance people's lives and provide them happiness. This study can benefit the government, the environment, and the local population by improving the efficacy of energy and development in smart cities.

2. Research Background

Energy history involves both natural and cultural (human) temporal developments. Energy is more than just a trade medium. Only via the energy prism can one observe the world from the inside out, both figuratively and literally. Everything that has occurred, is occurring, or will occur is caused by energy and may be measured in terms of energy. This encompasses the birth of stars, planets spinning, global water, atmospheric and biological cycles, and human civilisation's evolution, industrialisation, and modernisation [13].

All physical systems in the natural world include a certain amount of energy. The structure of all matter and fields is energetic or active, whether it is photon waves speeding through space or electrons zipping around an atom's nucleus or through a conductor, or atoms and molecules interacting, vibrating, or moving randomly in thermal motion [14]. Energy is a system's capacity to change another system by performing work (causing a directed dis-location) or by creating heat (inducing a chaotic displacement/motion of the system's microstructure) [15]. As detailed in one encyclopaedia's "Physics of Energy" page and elsewhere, energy is not only "the building block" and fundamental feature of matter and space but also a fundamental property of existence. From the largest sub-nano structures in an atom's nucleus to electromagnetic radiation, energy is both the cause and effect of formation and transformation throughout the universe [16].

It is believed that 30 per cent of the world's population resided in urban regions in 1950. By 2050, however, most of the world's population will reside in urban areas. By 2050, it is anticipated that over 70% of the world's population will reside in urban regions, with over 90% of the expansion occurring in Asia and Africa. In response to various demographic (including population ageing and migration), technological (including green lifestyle), and environmental, social, and economic challenges, cities worldwide have been actively transforming their urban environments over the past few decades [17]. The need to adapt cities to these processes and challenges has resulted in the emergence of several concepts and urban development strategies based on them; these can be thought of as a gradual transformation of cities into smart/intelligent cities, leading to more efficient urban planning and management and, ultimately, guaranteeing the high quality of life of the inhabitants through the introduction of cutting-edge technologies, the amelioration of environmental conditions, and the provision of public services [18].

A smart city is an urban region that uses electronic data gathering sensors in infrastructure, buildings, cars, institutions, and devices (IoT, Internet of Things) to provide real-time information about the city's key operating systems. These include energy distribution, transportation, water purification, waste management, security, and communications [19]. Integrating sensor data into ICT platforms enables city administrators and decision-makers to remotely connect and command municipal systems to improve efficiency and resilience and to remotely connect with and communicate with stakeholders (citizens, companies, institutions, and civic organisations) [20]. Officials in a smart city can promote sustainable urban development and a more competitive and attractive business and creative environment by, for instance, encouraging innovative business models in both the private and public sectors and fostering greater collaboration among various economic actors [21].

Several authors have placed greater emphasis on the objectives of the smart city than on the concept itself. Several authors mention the potential for smart cities to improve energy efficiency and environmental sustainability in their definitions. As an intriguing aside, ref. [22] expands on the topic of smart city security enhancements. According to [23], smart cities can attract talent and entrepreneurialism by offering more competitive and attractive business environments. Following an introduction to the evolution of the notion of "smart cities", the subsequent sections present an exhaustive dissection of the numerous factors that contribute to a city's potential and the actual manifestation of intelligence [24].

Several authors have attempted to differentiate "smart cities" from comparable ideas such as "information cities" or "digital", "knowledge", and "smart" cities. It is difficult to provide a universal definition of a "smart city" because most such programmes have evolved from bottom-up experiences relating to specific needs [25]. While there is no universally accepted definition of a "smart city," most agree that they involve the use of technology to improve the quality of life for residents [26], with information and communication technologies (ICTs) playing a central role due to the concept's evolution from an "information city [27]".

This section presents an overview of energy and sustainable development in smart cities. Several databases, such as Google Scholar, ScienceDirect, ResearchGate, and IEEE Xplore, were queried during the identification phase of this review. Initial qualification criteria included "smart city", "electricity", "energy", "sustainable energy", "sustainable development in smart city", "energy in smart city", "sustainable power", and "smart home".

These initial selection criteria serve as the beginning point for the search approach, which may be summed up as follows: (i) searched for the predetermined keyword strings in multiple databases; (ii) selected only papers published in English in scientific peer-reviewed journals and conference proceedings in the last 15 years (2007–2022); (iii) favoured technical papers over surveys or other review articles; (iv) reviewed a sufficiently descriptive overview of smart cities, energy, and sustainable developments; and (v) conducted a thorough analysis of smart cities, energy, and sustainable developments prior to including it in the overarching overview. The overview was divided into three key sections based on the search criteria: energy, smart cities, and sustainable development. According to Figure 2, 96 articles were selected between 2007 and 2022.

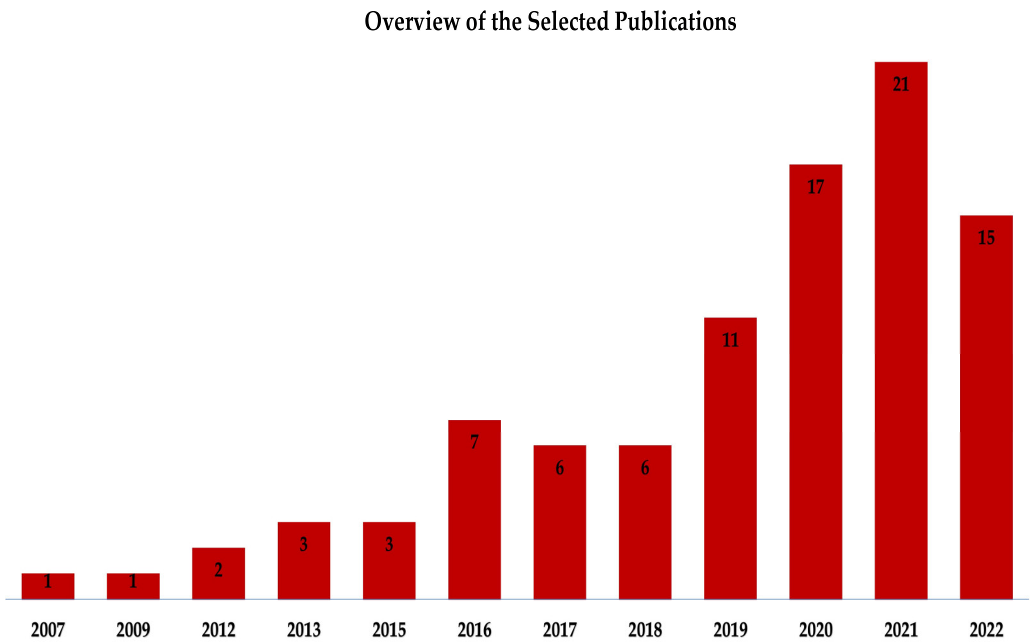

Figure 2. Selected articles based on publication year (from 2007 to 2022).

3. Overview of Energy Management in Smart Cities

Energy generating systems are designed to convert primary energy sources, such as heat, electricity, and cold, into secondary/alternative energy forms. Common forms of renewable energy production include wind turbines, hydroelectric dams, and multigenerational power plants. Renewable energy takes precedence over fossil fuels in a typical intelligent energy system. In order to keep a system working well throughout the year, fossil fuels must be used as an additional energy source [28].

Monitoring and logging are two of the many roles management systems use to promote a good interaction between house inhabitants and the management scheme. Various alerts related to predetermined risks should be used to validate home security through the management system. Homeowners may operate household equipment according to their preferences through SHEMS, mobile phones, or manually [29].

According to Ref. [30], numerous research has concluded that the Internet of Things (IoT) offers substantial advantages over other communication networks. The Internet of Things is gaining popularity due to its usability and compatibility with various communication protocols [31].

Hence, new digital household equipment exacerbates power grid quality issues, such as excessive harmonic contents, imbalanced loads, and erratic short-circuit currents. In contrast, power grid authorities do not tax homeowners based on the impact of their buildings on power quality. Consequently, all suggested energy management systems concentrate on the financial benefits of lowering electricity usage or even exporting electricity to utility networks [6].

Building energy management systems (BEMS) are being applied in residential, industrial, administrative, and commercial structures. Similarly, integrating intermittent renewable energy sources with the suitable energy storage system installed in the building is a crucial need for dependable and effective BEMS [30]. It is vital to minimise energy use from non-renewable sources and reduce energy demand via energy-saving, ecologically friendly technology. In this regard, electrochromic devices (ECDs), which can manage energy flow during the day and produce artificial illumination at night, might decrease the need for separate lighting and cooling systems [32].

Hence, the status of a particular zone inside a structure is determined by employing sensors. Depending on the architecture and how sensors are integrated into the building, a zone might be a single room, an individual floor, or the whole structure. In addition, sensors are used to monitor interior comfort by utilising occupancy, CO_2, temperature, and humidity measurements. However, sensors may also detect situations such as fire, floods, or intrusion [33].

Even though steps have been taken to reduce energy waste in buildings by employing various management techniques based on occupancy information, to reach intelligent buildings by giving more accurate occupancy models that represent their energy consumption, this issue is still not yet fully resolved. Therefore, researchers [34] conducted a complete analysis of the techniques for collecting and using occupancy-related factors that impacted the overall energy consumption of buildings and proposed a road map for solving these issues, where the suggested road plan focuses on developing ICT and construction industry prospects [35].

According to researchers [36], smart plug technology will be extensively utilised to monitor and regulate energy usage in all places with smart appliances. Moreover, constant effort is expended to develop and incorporate emerging communication protocols and functionalities into smart plug-in applications in a range of Energy Ecosystem situations. An assessment design and implementation of smart plugs already on the market were also presented in the study. In addition, the overall development of sensors paired with computational algorithms may contribute to addressing a wide range of the technical obstacles involved with this energy system's integration issue [37]. The researchers assessed the various smart energy management strategies and currently available applications [35].

Numerous authors and organisations have defined and implemented the "smart city" concept, which is relatively novel [21]. Smart cities are designed to solve or alleviate the effects of fast urbanisation and population expansion, including energy supply, waste management, and transportation, by maximising efficiency and resource utilisation. The literature classifies smart city intervention areas in various ways. A problem with these classifications is that they only consider the smart grid when classifying energy, leaving out crucial factors such as transportation and infrastructure [38].

The energy requirements of a city are both complex and numerous. Consequently, modern cities should leverage the synergies between these energy solutions to enhance their existing systems and implement new ones in a coordinated and optimal manner. Unpredictable supply and demand, the need for more energy-efficient transportation, and several other factors are energy issues that must be addressed collectively rather than individually [4].

3.1. Energy Storage

Using batteries to convert chemical energy into electrical energy is a well-established technology with numerous applications. Electrochemical cells that can be utilised to construct batteries include lead–acid (Pb–acid), sodium–sulphur, sodium–nickel chloride, and lithium-ion batteries [39]. Cost, environmental problems, a short lifespan, and voltage and current restrictions are the most significant disadvantages of this technology. As battery prices continue to plummet in the coming years, this trend is anticipated to continue [10,16,40,41].

Superconducting magnetic energy storage (SMES) [15,42,43], super-capacitors, and flywheels are the best options if you need a quick response and a considerable amount of energy to be released in a short amount of time. Superconducting coils generate magnetic fields with an alternating polarity that store electrical energy. High currents charge and discharge double-layer capacitors [15,43,44]. This technique is not primarily used for energy storage but to improve grid stability and power quality. Mechanical rotatory devices are utilised to store energy derived from motion. Despite having long life cycles, they are more expensive than batteries and can only provide energy for brief periods [39,45].

Many countries generate and distribute power using hydroelectric storage (hydro-pump) [32]. The water pumped from one reservoir to another is used to generate electricity later. Large unit sizes and climatic and topographical limits make it difficult to use these systems in small-scale applications [46]. Fuel cells, boilers, and turbines can all use hydrogen as an energy source. All that is left is pure water vapour when oxygen is used to burn it. In order to create clean, carbon-free fuel, it is necessary to use pre-combustion CO_2-capture processes to synthesise other molecules, such as water or fossil fuels [9]. Compressed air can be used for large-scale energy storage.

Compressed air and energy are normally housed in a subterranean cavern or chamber [47–49]. This energy storage system (ESS), such as hydro storage, is often confined by terrain. In light of the wide range of ESS characteristics, not all ESSs are well-suited for every application. Bulk storage (1–8 h) for load balancing or spinning reserve; DG storage (0.5–4 h) to integrate dispersed renewable sources, reduce peak demand, and delay transmission; and end-use power quality storage (1–30 s) are all examples of the latter [48].

Fluid or another substance is utilised to store thermal energy in a reservoir. In smart cities, these ESSs are utilised most frequently for water tanks that can meet the thermal demand of both residential and commercial buildings. Recent applications of molten salt tanks for high-temperature thermal storage include utility-scale concentrated solar power plants [31].

3.2. Models and Applications of Energy Storage Systems (ESSs)

Numerous applications exist for energy storage systems (ESSs). Methods and sizes of data storage can also vary greatly. Small- to medium-sized research projects usually utilise battery-based solutions for integrating renewable energy sources. Alternative ESS solutions focusing on power quality are being researched [35–37]. Ref. [34] illustrates an isolated microgrid power system with flywheel storage. This section addresses the utilisation of super-capacitor banks to regulate the load frequency of electrical power systems.

Intriguing alternatives combine many storage technologies to circumvent the limitations of singular storage systems. Ref. [37] highlights the power electronics and control demands of an electric vehicle (EV) hybrid flywheel–battery system. Plug-in electric vehicles (PEVs) are another use of ESSs that has been the subject of much research. The majority of research in this field is on the charging and discharging of fleets of electric vehicles. Then, a comparison between centralised and decentralised decision-making was made [34].

Various objectives can be attained utilising intelligent charging methods. Intelligent charging methods can be used to achieve a variety of goals. Microgrid economic viability has been evaluated using used electric vehicle batteries as stationary energy storage [27,45,50,51]. However, in contrast to earlier studies that examined important variables such as battery degradation in only a superficial manner, another study proposed charging procedures to extend the useful life of batteries [40]. Many researchers focus on finding the most effective ways to manage and utilise heat in buildings. Electricity price signals govern ESSs. Numerous control techniques are compared with a thermal water storage predictive control system. Solar thermal storage and cogeneration systems are widely utilised in residential and commercial contexts [41].

As energy use and environmental impact awareness have expanded, EMS has evolved. In addition to ensuring building comfort, an EMS provides building operators with decision assistance to optimise building configuration (both physical and digital) and energy-efficient building operation. Additionally, an EMS may provide energy usage predictions [41].

According to researchers [33], BMS mandates control techniques for building actuators such as ventilation, heating, lighting, and other electrical systems. These techniques define acceptable temperature ranges, CO_2 limitations, and other parameters associated with occupant comfort, and they guarantee that the condition of the building does not deviate from these ranges and limits by signalling actuators as required [50,52]. Moreover, due to the capability of conditioning and regulating domestic energy usage, Smart Energy Control Systems (SECS) have become more prevalent in the smart homes scenario [53]. Smart Energy Control Systems (SECS) have become more prevalent in intelligent homes due to their ability to condition and control domestic energy usage, decreasing energy losses and needless electricity consumption [54]. In Table 1, the importance of energy in smart cities is presented by giving an overview of the importance and the purpose of energy storage and energy management in smart cities.

Table 1. Overview of smart cities energy.

Aspect	Summary	References
Energy management	Since a smart city is a centre that efficiently manages its resources to provide its citizens with a high standard of life while remaining ecologically conscious, due to the complexity and significance of the energy networks in big urban centres, energy management is one of the most difficult challenges these areas face. Consequently, smart city efficiency relies greatly on intelligent residential energy management. Energy management encompasses demand-side management, peak load reduction, and carbon emission reduction. Risk management, efficiency, and sustainability are integral components of any energy management strategy in smart cities.	[10,12,44,45,50,55–60]
Energy Storage	Since smart cities' energy consumption uses cutting-edge technologies, global cities cannot run without a smart grid and some energy storage device. The Americas and Europe are anticipated to experience the largest impact from energy storage in smart cities, followed by Asia and the Pacific. Several energy storage methods are discussed, and the one with the greatest potential for widespread adoption is described here, with an in-depth examination of energy storage's technological, economic, and consumer implications. Future European cities are highlighted, although the concept is applicable globally. Now widely available are direct-to-consumer energy storage solutions, such as electric vehicle (EV) charging stations, single-family houses, and neighbourhoods with energy storage systems (ESS). As a result, the community gains autonomy and improved energy management. Digital technology in the form of advanced metering infrastructure (AMI), distribution grid management, high-voltage transmission systems, and demand response is used to produce intelligent and integrated power transmission and distribution. The term "smart energy" refers to the production of electricity, heat, and transportation fuels from renewable sources and the consumption of energy more efficiently through improved design, high-efficiency technology, and conservation.	[14,15,17,39,43–45,48,49,51,61,62]

4. Techniques for Predicting Electrical Consumption in Smart Cities

Since the 17th century, numerous industries, including energy forecasting, have utilised statistical tools such as set theory. Popular techniques include grouping, support vector machines (SVMs) [63], and e-learning machines (ELMs) [64]. STLFs are predictions based on short-term load frameworks. In two significant ways, researchers have enhanced SVM prediction algorithms [47].

In the first stage, an input model is chosen using a feature selection approach. The hyper-parameters of the SVM were optimised utilising an optimal particulate solution, and operator connections were reduced [13]. This research method demonstrates more precision using cutting-edge data from two distinct databases for load prediction [64]. Next, [18,58] employed ELM evolution to predict energy in a subsequent STLF study.

The synthetic bee colony method is used with ELM to forecast the next 1–24 h; ELM assists the synthetic bee colony method in determining the ideal input variables [65,66]. The researchers uncovered novel, cutting-edge information regarding ISO New York and Latin American electricity suppliers [67].

Ashraf et al. applied deep learning to computer vision, the Internet of Things, cybersecurity, and health. In their model outputs, energy forecasting techniques such as STLF and LSTM [68] prioritise apartment complexes. To enhance forecasting, they concentrated primarily on lowering the variability in the behaviour of electricity demand [69].

According to further research, an integrated deep learning and LSTM optimisation method for residential structures were determined to have the optimum target function for power prediction utilising hidden layers [70]. Their technology examines the STLF forecasts of building and real estate data [65]. These discoveries render conventional prediction models ineffective. According to [71], implementing a load prediction technique for different kernel transfers reduced the error rate.

Another paper developed a smart resource management deep learning model to help dispersed households and businesses. According to [10], the DLA-PM power management architecture is described. This forecasting tool may help customers and power distributors work together more effectively. For example, cloud-based server data monitoring, device-based real-time energy management, standardisation technology improvement, the development of a new framework for energy forecasting, and faster and more precise learning are all conceivable outcomes [26].

In recent works, the neural wavelet connections CNN [57], LSTM [70], and STLF [66] have been used to form set structures. Sequential algorithms such as RNN [72] and LSTM have been the subject of extensive, in-depth studies on energy prediction. There has been no notable change in sequence learning models, even at the network edges. A resource-constrained energy forecasting model can assist in addressing this issue. CNN and LSTM structures utilise neural wavelet connections [73]. In energy prediction, interest in RNNs and LSTMs, two prevalent sequential approaches, has increased [57], [74]. Except for a few small modifications, sequence learning models have stayed substantially unchanged. This issue can be addressed using a resource-restricted energy forecasting model. Table 2 shows the list of different techniques used in smart cities for energy forecasting. These techniques help in predicting the consumption of energy to be used by smart cities in the near future.

Table 2. Techniques used in smart cities' energy forecast.

S/N	Forecast Methods	Reference
1.	Short-term load forecasting (STLF)	[65,66,68]
2.	Medium-term load forecasting (MTLF)	[57,70]
3.	Long-term load forecasting (LTLF)	[53,68,70]
4.	Long short-term memory (LSTM)	[41,57,66,68,70,73]
5.	Convolutional neural network (CNN)	[41,57,66,68,70,73]
6.	Discrete wavelet transform (DWT)	[73]
7.	Recurrent neural network (RNN)	[72,74]

It is possible to distribute electricity reliably to many customers, each with specific requirements. This can be achieved by integrating a distributed power management system with the grid's intelligence. Current methods of supplying electricity to customers do not inform them of their use, environmental impact, or any other variables that may result in excessive electricity use. In contrast, an intelligent grid can precisely track and distribute electricity consumption [75].

Grids are notoriously inefficient due to insufficient energy conservation and overuse. A lack of data on residential and commercial electricity use makes it impossible to determine when there is an abnormal demand for electricity. Intermediary cloud analysis is performed on customer requests prior to their transmission to intelligent networks [61].

Before delivering queries to the intelligent grid, cloud servers save and scan them for irregularities and observe an abnormality if the demand at home or business fluctuates significantly. Residence-1 in the smart city is provided with Y kW of power. All industries and businesses will continue to gain from this cycle as long as cloud servers offer exceptional results [18]. There are two common denominators: vector minimum-maximum and scalar mean (max value). On a scale from 0 to 300, the normalised data for housing parameters runs from 2.8 to 3.8. This can significantly modify the training approach for normalised data model parameters that fall between one and one. Short-term demand forecasts need a reduction in the original data set size. Various approaches improve the forecasting performance of both databases using the original data formats [59].

5. Sustainable Development and Energy Management System in Smart Cities

City residents' needs come first in a climate- and people-conscious city. Sustainable development focuses on the city's overall progress, equity, and preservation in contrast to smart cities. Green areas and eco-friendly practices are incorporated into the urban environment to reduce pollution and carbon intensity and protect natural resources [3,13]. Using ICTs and other cutting-edge techniques, a city can improve its citizens' quality of life, operational efficiency, and competitiveness while also satisfying the needs of current and future generations. Cities must become more intelligent and environmentally sustainable to cut CO_2 emissions. The primary advantages are enhancements in renewable energy, waste management, and traffic conditions. Numerous smart city concepts centre on efficient grid and watershed management systems [62].

A human safety and energy monitoring system can be created using water level monitoring devices. Programmes and activities that save resources when referenced are considered sustainable. The five pillars of sustainable development include ecological preservation, social growth, cultural preservation, and economic development [45]. These comprise intelligent streets, intelligent lighting, intelligent parking spaces, and intelligent traffic lights. People can navigate with greater ease, and transfers are completed faster. Users can lower their carbon footprint and increase their social capital by utilising these ecologically friendly devices [76]. In addition to enhancing public service, infrastructure, and sustainability, smart cities seek to provide people with a more advanced social environment [63]. These concerns and the rebirth of cities as economic engines of national and global significance have evolved due to urbanisation and global economic upheaval [77]. Towns must actively seek investment opportunities in this new era to remain competitive, expand their tourist appeal, and improve the quality of life for their residents. Cities can achieve economic growth and social and environmental sustainability by using ICT [78]. The most significant advantages include improved garbage management, traffic patterns, and increased energy efficiency and storage. In order to reduce pollution and enhance air quality, a city's sustainable strategy must include ecologically friendly practices, parks, and supporting technologies. Sustainable cities are becoming increasingly important in the fight against global warming [2,55].

Some examples are traffic flow management and universal health care. The energy industry must be modernised for ICT to be incorporated into the grid to build a smart city [78,79]. It is possible to analyse small-scale intelligent community solutions, such as apartment building clusters, to boost energy independence and reduce CO_2 emissions using a web-based platform [50]. Smart cities may positively impact the quality of life and the efficiency of municipal operations. Rethinking existing regions and building new ones from scratch to make cities more ecologically friendly and efficient, as well as developing transportation, energy, and government services that will allow city people to sustain themselves, are major challenges for city planners around the world. Information technology has the potential to greatly enhance smart cities. There are various advantages to using existing infrastructure, including lessening the need for a new building, cutting

CO_2 emissions, and creating new options for citizens, such as e-government services and actual transportation norms [22,80]. All people and the earth shall be able to live in peace and harmony as a consequence of the Sustainable Development Goals (SDGs). We can all work toward a wealthy and environmentally sustainable future, even in the current state of affairs, by following the Sustainable Development Goals. The significance of global issues such as poverty, environmental degradation, the truth, and freedom of expression is growing [26]. Recent technological advancements have expedited the growth of smart cities. Near-real-time analysis can be accomplished with mobile and high-speed wired networks that link basic sensors and equipment. Mobile and ubiquitous computing, cloud computing, middleware, and agent developments all facilitate the integration and utilisation of digital systems in the physical environment [62].

5.1. Efficient Use of Energy in Smart Cities

In smart cities, new and existing structures are more energy-efficient and effective. Power generation from different sources and dispersed power generation are optimised through an analysis of energy consumption [17]. Effective energy management necessitates precise metering. Managing energy in these metropolitan areas is one of the most difficult issues because of its complexity and importance. In order to better fulfil corporate social responsibility and reduce greenhouse gas emissions, it is possible to keep track of operating costs and accurately prepare budgets by looking at utility bills. It is a goal to reduce reliance on unstable supply chains. The approach outlined below makes it possible to discuss energy use and, in turn, economic development for a sustainable smart city [15,55].

5.2. Renewable Energy Sources in Society (RESS)

An urban construction group is accessible as an alternative. Using an Internet of Things platform from top to bottom, members of this small, intelligent community can work together to increase their energy-generating ability. The city's CO_2 emissions should be reduced. According to our proposed approach to energy management systems, RESS-equipped buildings can be coordinated to lessen their dependence on the primary distribution network [67]. By utilising renewable energy, greenhouse gas emissions can be reduced or eliminated. According to current global studies, wind and solar are the most cost-effective energy sources. Our objective is to develop a novel technique for evaluating the optimal RESS capabilities based on the building's usage patterns, seasonal fluctuations, energy costs, and carbon emission taxes [68].

A single transformer may provide electricity to a cluster of structures with a smart interface. The primary objective of any effort to improve energy efficiency is to eliminate waste. Increasing energy efficiency has numerous advantages, including reducing greenhouse gas emissions, energy import requirements, and household and economic expenditures. Urban buildings should rely less and less on primary distribution systems to reduce their energy consumption and dependence on secondary distribution networks [60].

For construction of energy management systems to be more effective, it is necessary to describe energy consumption and output patterns in detail. By implementing an energy management strategy, both energy output and consumption can be decreased. This method reduces the energy consumption of a building while increasing its productivity. Regarding energy management, neither production nor efficiency is compromised to eliminate waste and boost efficiency [18]. Due to energy use, generation patterns, and other unknowns and relationships, optimising models that aim to minimise or maximise energy consumption presents issues. It is necessary to differentiate between residential and promotional properties to attract more investors in metropolitan areas [55]. It is essential to consider weather conditions, work schedules, and the building's energy footprint in densely populated metropolitan areas, particularly for commercial and industrial operations. Numerous studies indicate that the size and form of urban building clusters can be affected by organising them as microgrids or small-scale power networks. Common methods for determining the optimal magnitude of RES include minimising total energy expenditures and maximising the quantity of energy produced through RES and SBI [69].

Construction costs and operating cash flow are compared using a PCGF (Project Cost Growth Factor). Its final goal is to demonstrate the program's financial return and evaluate the process's efficiency and efficacy. The first new economic indicator to be given is the growth factor for a cost estimate. Economic data suggest that the component does not only focus on expenses or earnings [77,80]

Home area network (HAN) nodes can access power in various building areas. When conducting energy flow activities, the building controller adheres to the requirements of the cooperative system. Several considerations must be considered when deciding how to use the energy stored in solar panels and batteries, including the type of construction, varied power requirements, electricity pricing, and the controller itself [32]. In order to increase microgrid performance, there should be a consideration of the use of the best building size and operation plan for distributed energy buildings that must all be connected by the same power transformer [81]. Because they are based on a particular type of structure and a single pattern of energy usage, cooperative systems are ineffective. In order to maximise the energy independence of urban structures, it is required to create the ideal approach to cluster size and energy planning and operations utilising a comprehensive set of realistic assumptions [50,52]. Building-to-building communication must be considered in the communication requirements of a cooperative plan. Home IoT infrastructure is constructed using a central home controller (CHC) and smart metres throughout the building [82]. CHC manages RER and SBI data for buildings. HSS receives or transmits data from or to smart metres in many building locations. Utilising metres, creating a standard set for the local area network (HAN) is feasible [69–71].

6. Results

This in-depth analysis of the existing literature discovered several new trends in the smart city (Figure 3). In order to create a city that is both liveable and efficient, smart city sustainability emphasises the importance of a city's infrastructure and power. On the other hand, this article emphasises the significance of utilising ICT to effectively integrate resources to improve the city's interconnectedness, intelligence, and overall quality of life. Since technology development is essential in developing smart cities, the article discussed using different technologies for the sustainability of smart cities, especially electricity. Research into the role of smart cities in attaining long-term development is urgently needed [13].

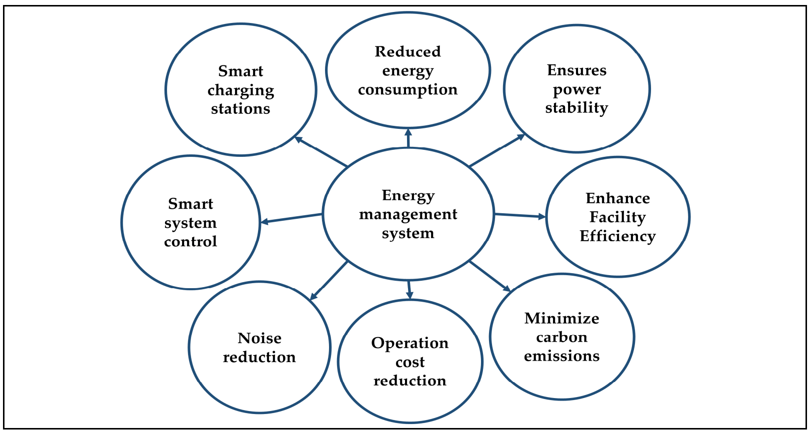

Figure 3. Energy-management-system-based renewable energy in smart cities.

According to Behzadfar [82], increases in energy consumption and the capacity of the world to provide for them all indicate a future of rapid urbanisation. Smart city construction is one option among many, but it may be advantageous. The ICT infrastructure of the smart city has improved the residents' quality of life and health. It expands physical services while maintaining economic expansion. In addition, it has accelerated government, political, and participatory processes to prevent and manage natural and artificial disasters and ensure legal compliance [83].

Ullah [36] reported that rapid urbanisation paves the way for developing "smart cities". Future intelligent cities must be environmentally conscious. The social, economic, and environmental sustainability of Australian cities is determined by costly and quantifiable means. This study evaluates the "smartness" of Australia's six most populous cities to determine their sustainability. It illustrates the key variables and subfactors that influence smart cities' economic and environmental viability. Governance, retrofitting, land use and environment, socioeconomics, and the environment are identified factors. Governance is the most important factor for Australian urban regions, followed by land use, environmental management, and retrofitting. This shows that the government helps realise smart cities. This article highlights the sustainability practices of smart cities in Australia, which can be replicated in developing nations [84].

According to the study [7], smart city ideas and strategies are as diverse as cities. Some smart urban development strategies focus more on technology than social factors. Smart urban planning promotes social and technological advancements and integrates existing infrastructures while considering population growth and new needs. The objective of smart urban design is to enhance governance, public participation, and the use of land, resources, and money. Current ICT development can reduce or eliminate the need for top-down decision making, increase evaluation data sources, and inspire innovative urban planning. The public must be educated on how innovative strategies can enhance the lives of individuals. Plans for smart cities should be prioritised. By catering to the next generation, these costly projects can enhance the quality of life in historic districts and college campuses. Due to the increasing number of highly educated inhabitants, internet users, mobile phone users, information and communication technology (ICT) trainers and trainees, and e-government users, there is a tremendous possibility to evolve into a smart community.

According to Ref. [84], by 2050, 70% of the world's population will be in urban regions. Developing environmentally friendly and ecologically sustainable urban areas is motivated by reducing CO_2 emissions. Energy efficiency and storage, waste management, and traffic movement have been the greatest improvements. Smart cities use advanced power grids and water management systems to ensure the safety and dependability of the city's water supply; the city checks its energy consumption and potable water quality. As a result of the accelerated development of smart cities, municipalities will be able to monitor their citizens more effectively using CCTV cameras with facial recognition.

According to Ref. [85], security becomes an increasing concern as the Internet of Things (IoT) and sensor technology become more prevalent. In order to utilise these sensors, a complex and expensive infrastructure is required. Energy consumption and efficiency are crucial factors for any structure. Intelligent technologies such as traffic lights and pedestrian light panels can monitor traffic's environmental impact and infrastructure deterioration. By 2050, the world's population is projected to reach approximately 10 billion, with the majority residing in cities.

According to Ref. [84], smart cities must provide an alternative to the single-occupant fossil-fuelled automobile. Smart cities need a holistic approach to integrating automation, transportation, and other technologies with socioeconomic requirements. According to experts, sixty per cent of the total energy consumption will occur in future cities. The Internet of Things (IoT) requires the creation of smart homes, factories, and workplaces. Autonomous vehicles necessitate intelligent roadways. Figure 4 below shows an illustration of the energy consumption in smart cities.

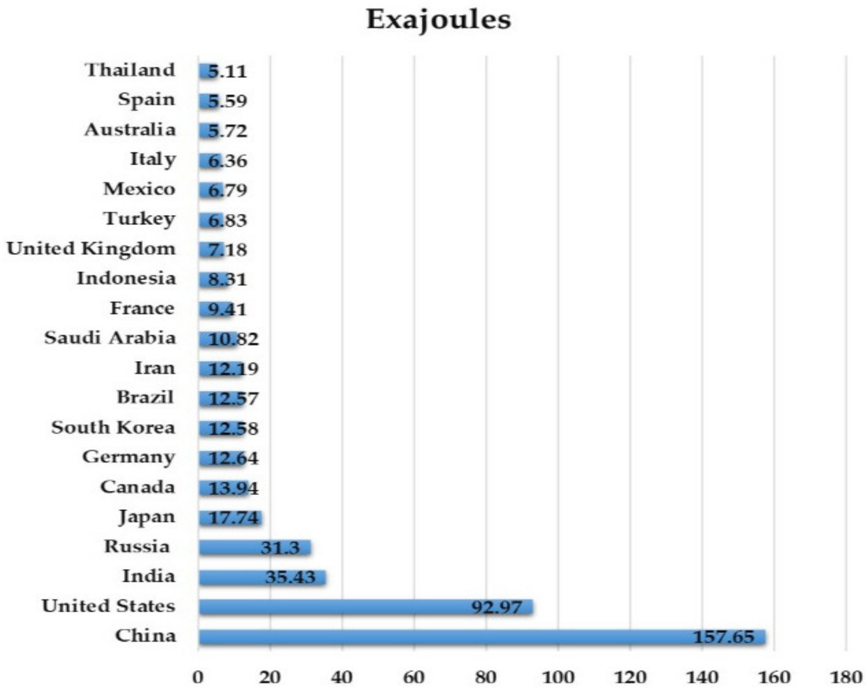

Figure 4. Energy consumption.

Covered airports within the city could be used for international flights. Smart cities are becoming more efficient, innovative, inclusive, and resilient through data and technology. Innovative technologies such as Digital Twin, AI, big data, and IoT (Internet of Things) are essential for creating a civic platform for new types of cities with sustainable livelihoods and agile prosperity. The Sustainable Development Goals (SDGs), which are centred on the function of smart cities, reflect our current worldview. The Global Smart Cities market, valued at USD 741.6 billion in 2020, is anticipated to expand at a CAGR of 22.5% [86].

Using digital technologies such as big data or artificial intelligence, intelligent and adaptive traffic light management systems that can respond to changing traffic flows and specific conditions, which could significantly reduce congestion, can be developed and implemented [87]. The Smart City Technology and Smart Energy (Applications) Market is expected to reach USD 602.7 billion in China by 2026, with a CAGR of 27.6 per cent. Europe and Asia-Pacific are among the regions with the highest adoption rates of smart cities. The US smart city market is anticipated to be valued at USD 233.9 billion by the end of this year. Europe will account for 31.8 per cent of global smart energy segment sales by 2020 [88].

China is anticipated to experience a compound annual growth rate of 33.0 per cent during the analysis period. Smart city solutions are increasingly adopted due to the need to reduce energy consumption and the growing environmental waste problem [47]. To combat the effects of the pandemic, these industries are turning to cutting-edge technologies such as artificial intelligence (AI) and the Internet of Things (IoT). Smart Utilities' Infrastructure Monitoring and Management service is expected to be one of the fastest-growing services in the industry. Deployment and Integration providers will take the largest share of the market for Smart Transportation Services [89].

APAC is adopting smart city technologies due to government attempts to improve digital infrastructure. Solid-state technologies and closely related disciplines are required for a proactive approach to problem solving. Active methods' intellectual prowess is mostly dependent on technological advancements. Passive and active methods are intertwined with inefficient energy use in cities. The smart grid is one way to reduce energy consumption actively [4].

The smart grid indirectly connects to "passive" smart city solutions, which can respond "statically". Smart buildings need new energy and capacity supplier criteria to maintain a continuous power supply. Less than one per cent of the Russian population currently possesses smart home technology. Distributed energy generation at specific locations utilising absorption refrigeration and micro-CHP would boost the overall efficiency of the metropolitan system. As much as possible, the night-time energy consumption should be increased to equalise the daily power supply profile [60].

Using electric vehicles is the most obvious solution. When the digital technologies of infrastructure companies are combined on a single intelligent platform for information accounting, analysis, and processing, there is a massive shared effect. Reduced electricity prices are a crucial factor in the development of smart cities. Government energy pricing regulations should manage the price of natural gas and the gas-to-electricity ratio. The variable load schedules of residences must be considered to limit production cost fluctuations. Smart city energy systems and electrification plans must consider several technical and budgetary factors [45].

7. Discussion and Conclusions

According to Ref. [83], the energy of a system influences how much work it can perform. In addition to potential and kinetic energy, there are also chemical and thermal forms of energy. Solar power, fossil fuels, gas, electricity, and batteries are just a handful of the numerous energy generation possibilities accessible [55]. Energy cannot be generated or destroyed but can be transformed into several forms. Clean energy, green energy, sustainable energy, renewable energy, and smart energy are among terms that have evolved in recent years as alternatives to the more familiar "conventional" energy. These new concepts in the energy sector are motivated by the possibility that the global supply of usable energy will be depleted. Green energy, often known as clean energy, refers to power sources with low or no negative environmental impact [14]. Green energy is derived from renewable sources such as the sun and wind. Both sustainable energy and renewable energy may be supplied at a faster rate than they are consumed, making them excellent for long-term use. There are several subtle differences between renewable and sustainable energy sources. Sustainable energy is derived from non-human sources, whereas humans create renewable energy. Biogas is a form of sustainable energy generated by the cultivation, utilisation, and decomposition of organic matter [17]. This notion is related to zero-energy systems and zero-energy structures, which consume no net external energy because their energy consumption and production are equal. What precisely is intelligent energy? Smart energy spans a broader spectrum of concepts than conventional and renewable energy. Smart could be considered a model for the "Internet of Energy." This strategy incorporates the concepts of smart power generation, smart power grids, smart storage, and smart consumption. That said, smart energy is any conventional energy that is backed by contemporary information and communication technologies [62].

The intelligent energy system combines the generation, delivery, and use of renewable energy in an intelligent manner. Therefore, intelligent energy consists of three distinct components that must be combined into a single system by careful design and effective communication [22]. Smart infrastructure, smart grid, smart metres, and proper use of information and communication technology enable efficient distribution in a smart energy system, which may incorporate low-carbon-generating sources such as photovoltaic, solar thermal, biogas, and wind energy (ICT) [90]. At the core of a smart energy system is an information architecture that collects and distributes data on energy consumption and rates charged by various service providers. Intelligent home appliances, such as dishwashers and water heaters, can be run with optimal energy efficiency when the necessary ICT is used to regulate their activities. ICT is beneficial for HVAC and heating, ventilation, and air conditioning (HVAC) transactions (HVAC) [49]. With the assistance of information and communication technology, energy may be derived from various sources, including solar panel systems, wind turbine systems, and others. Optimisation of consumption is the third fundamental feature of a smart energy system. Utilising efficient energy storage, intelligent metering, and effective energy management may be crucial to optimising energy usage in a smart energy system [91].

The smart energy grid, often known as a smart grid, is the system's central nervous system. A smart grid is defined formally as the effective integration of the actions and behaviours of all connected users, including (1) consumers, (2) generators, and (3) users who are both consumers and generators. Smart grids offer minimal loss levels, a higher-quality supply, system and user safety, supply security, and system fault tolerance [69]. Using smart grid technologies, various renewable and non-renewable energy sources, such as solar and wind power, can be coupled with more traditional thermal energy obtained from fossil fuels. Future smart grids will be extraordinarily sophisticated compared to those of today [61]. Perhaps one day, every user will generate their own solar, biofuel, or wind energy. A smart grid will supply electricity at the precise voltage and frequency necessary for all of these power sources, ensuring that they operate in perfect harmony [15]. There is great support for the demand response management of energy consumption; dispatch of power generation for solar and wind; point-of-sale transaction services for plug-in electric vehicles (PEVs) that are not tied to a physical location; and enhanced customer interactions. The smart grid relies heavily on intelligent energy metering [59]. During predefined time intervals, the smart metre records and transmits the quantity of electricity consumed to the utility provider for analysis and billing purposes. This enables reliable usage reading without the need for human involvement. Intelligent batteries, such as those made from lithium-ion or fuel cells, can store and distribute energy efficiently and survive for an extended period [76].

Section 3 provides an overview of smart cities' future. Smart cities will have advanced technologies for monitoring citizens and planning, designing, and constructing their transportation networks and infrastructure. Future generations may live in a world with smart grids, buildings, and electronics. Using the smart grid is one proactive step toward lowering energy consumption. Its overall efficiency is about 90%, and its electric efficiency is 55% [22]. There is a tremendous multiplier impact when infrastructure businesses merge their digital technologies on a single intelligent platform for information accounting, analysis, and processing. Smart buildings will need new criteria from energy and capacity suppliers, such as installing additional production and grid capacity to provide a constant power supply. This research seeks to pinpoint remedies for future smart cities. Utopian ideals like these are characterised by advanced social and economic systems, concern for the environment, and a constantly growing body of knowledge [47].

Section 4 provides an overview of energy generating systems built to transform primary energy sources such as heat, electricity, and cold into secondary/alternative energy. Fossil fuels must be employed as a supplementary energy source to keep a system running smoothly all year round. Storing energy in a mechanical rotatory device is more expensive than a battery and only works for short bursts of time. Using pre-combustion CO_2-capture techniques to synthesise other molecules such as water or fossil fuels is required to manufacture clean, carbon-free fuel. Most commonly, these ESSs are used in smart cities to store water for heating and cooling purposes in homes and businesses [92]. Moreover, Smart Energy Control Systems (SECS) have grown more commonplace in the smart homes scenario because of their ability to condition and regulate residential energy usage. The Smart Cities Energy Prediction Task Force uses STLF, SVM, and e-learning machines to predict electrical consumption [93]. Long-term and medium-term load forecasting are shown in Table 2 as the basis for the smart cities' energy forecasting methods. Smart cities can reliably supply electricity to diverse needs by combining the grid's intelligence with a distributed power management system. Both the vector minimum-maximum and the scalar mean have a common factor [94].

Section 5 gives the overview in contrast to smart cities. Sustainable development concerns of cities, including growth, equity, and preservation, were presented. In order to construct a smart city, it is necessary to modernise the energy sector and integrate ICT into the grid. New and existing buildings in smart cities use less energy and do more. Due to its complexity and significance, efficient energy management is one of the most challenging problems [95]. The methods presented in this overview open up possibilities for dialogue on smart city energy use and, by extension, economic growth. One of the many benefits of improving energy efficiency is a lower output of greenhouse gases. How to best use solar panels and batteries depends on factors such as the specific setup, the specific power needs, the specifics of the electrical market, and the controller itself [95].

Furthermore, different techniques are used in smart city electricity to address the future power. Innovative technologies, great living standards, and environmental friendliness are all part of the package. The energy sector's stability and readiness to enter a new stage of electrification, in which electricity penetrates practically all domestic, industrial, and transportation systems and processes, thus drastically increasing their controllability and making them "greener," are important factors in its development. Even though this study found that one of the primary goals of smart city efforts is to enhance the quality of life for citizens, no description was provided for exactly what this entails or how much it will cost the environment and society as a whole. This means that future attempts to define a "smart city" should address the cause-and-effect link between bettering one's quality of life and implementing cutting-edge technology.

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