Optimizing the Smart Cites: Energy Management Approaches, Technologies, Data Analytic and Security challenges

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As urbanization intensifies, cities are progressively transitioning into "smart cities," harnessing advanced technologies and data analytics to optimize infrastructure, enhance citizen services, and promote sustainable resource management. However, this evolution is accompanied by challenges, including cybersecurity, data privacy, and coordination between multiple stakeholders. This review paper examines current approaches to energy management in smart cities, exploring the pivotal roles of Internet of Things (IoT) technologies, data analytics, and security frameworks within smart energy systems. The study also provides a comparative analysis of 5G, Wi-Fi, Bluetooth, and Zigbee technologies, focusing on their potential applications in smart city environments. In addition, the discussion on the integration of distributed energy sources, the integration of electric vehicles and their two-way communication, the types of energy storage systems and their tabular comparison with an emphasis on the sustainable use of energy and the reduction of environmental impacts are other goals of the authors in this research. This paper explores the application of smart technologies in resource management, focusing on waste handling, street lighting, building heating, ventilation, and air conditioning (HVAC) systems, and water consumption. Traditional methods for these aspects often lack efficiency and sustainability. The paper proposes solutions utilizing Artificial Intelligence (AI), IoT, and sensor networks to create intelligent systems. Conclusively, this work offers a comprehensive perspective on overcoming the operational and security challenges essential to realizing sustainable, efficient, and safe smart cities.

Keywords: *Smart Cities, Energy Management, Artificial Intelligence, Internet of Things, Cybersecurity.*

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1. Introduction

In response to the growing urbanization of our planet, cities worldwide are exploring innovative solutions to manage resources, improve infrastructure, and enhance the lives of residents. This trend has led to the rise of "smart cities," urban areas that leverage technology and data to optimize operations and services [1, 2]. Improving the quality of life, increasing sustainability and reducing costs are among the benefits of smart cities. While smart cities improve the lives of citizens, there are also challenges. These challenges include privacy, data security, and equal access to technology. The volume of data and information collected in a smart city requires special care for citizens' privacy. Also, protecting sensitive information from cyber-attacks and unauthorized access is a major challenge. The purpose of smart city development is to integrate information and communication technology (ICT) and numerous gadgets linked to the IoT infrastructure in order to improve urban services and procedures while also connecting inhabitants [3, 4]. Intelligent city technology allows municipal officials to communicate effectively with urban neighborhoods and structures, allowing them to respond quickly to the city's and people's demands. A new era has occurred in the subject of civilization with the advent of Smart City, which utilizes the integration of cutting-edge information and ICT and AI to enhance the lives and productivity of its inhabitants [5]. Smart cities can accomplish efficient energy management with the implementation of IoT technology, which allows for continuous monitoring and dependable communication [6]. Figure. 1, shows the future, challenges, and sources of the smart cities.

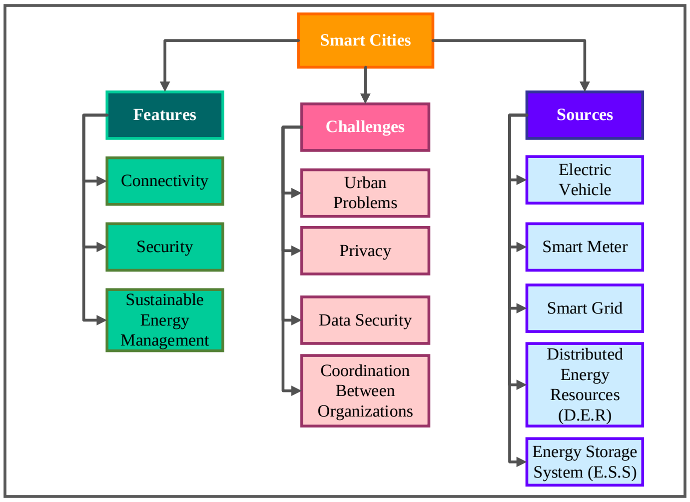

Fig.1. Future, challenges, and sources of the smart cities

In [7], a multi-layer smart city energy management approach for multiple home energy cooperation is presented. In another research, the authors have focused on energy management systems in sustainable smart cities based on the internet of energy [8]. Reference [9], analyzes how to manage energy in smart cities. The authors do this by grouping them into five key areas: how energy is produced, stored, delivered, used in buildings, and used for transportation. In [10], the authors have presented an overview of intelligent energy management. Also, in this research, examining the challenges in energy consumption management and the need for technological advances to overcome these challenges has been one of the main goals of the authors. In reference [11], the authors comprehensively review related works on smart cities equipped with the IoT in addition, demand-side management techniques for home energy management systems for smart cities are studied in [12]. An intelligent system for energy management in smart cities based on big data and ontology is proposed in [13]. Also, reference [14], is focused on smart buildings' energy management and monitoring system based on AI in smart cities. In [15], the authors have investigated 5G technology for intelligent energy management and smart buildings. Challenges of energy systems for future smart cities are reviewed in [16]. Also, a new energy management approach combining multi-carrier energy hubs for smart cities is proposed in [17]. Reference [18], deals with the study related to data analysis for smart cities. Another study studies cyber security challenges in smart cities [19]. In this regard, the reference [20], studies the future challenges for the cyber security of smart cities. Reference [21], provides a comprehensive coverage of IoT in smart cities. In addition, an algorithm based on AI for predicting electricity consumption in smart cities using blockchain technology has been investigated in reference [22]. Also, data management and security challenges in smart cities have been one of the goals of the authors in [23]. A contemporary survey on the integration of multi-source information for sustainable smart cities, which includes emerging trends and sustainable challenges, has been reviewed in reference [24]. The optimal operation model based on smart city predictive control in the presence of various flexible resources such as battery storage systems and combined cooling heat and power has been analyzed in reference [25]. Forecasting electricity consumption for sustainable smart cities using Machine Learning (ML) algorithms has been investigated by [26]. In another valuable study, the authors investigate the challenges of rapid urban population growth and how to use information and communication technologies to strengthen the development of smart cities and sustainable societies [27]. Sup lab Kanti Podder et al. analyze the impact of IoT applications on human resource analysis and sustainable business practices in smart cities [28]. A robust and stable route planning scheme for public transportation in smart cities based on multi-objective optimization is proposed in reference [29]. In another valuable study, the effects of government policies and incentives on the purchase of electric vehicles for smart mobility in smart cities have been investigated [30]. Also, the coordination of energy management systems in smart cities with electric vehicles has been reviewed in reference [31].

The paper identifies a significant research gap in the current literature on energy management systems in smart cities. While many studies have explored the integration of IoT, AI, and other technologies to enhance smart city functionalities, more comprehensive solutions are needed that simultaneously address the challenges of distributed energy resources integration, effective data analytics, and cybersecurity concerns. Specifically, current approaches often fail to integrate diverse energy sources, optimal operation of energy storage systems, and provide robust frameworks for secure communication within the energy infrastructure. This paper proposes an innovative framework that combines AI-based predictive analytics, IoT-based sensor networks, and enhanced cybersecurity protocols to address the identified gaps. The contributions include:

- A comprehensive cybersecurity framework is introduced, which includes secure communication protocols, anomaly detection systems, and robust encryption measures to safeguard the energy infrastructure.
- Advanced data analytics tools are proposed, focusing on fault detection, energy prediction, and efficiency improvements, utilizing big data and ML models to analyze energy patterns.
- This Paper presents innovative contributions across several domains of smart city infrastructure, focusing on advancements in waste handling, street lighting, HVAC systems, and water consumption management.
- This research contributes to the advancement of smart and sustainable cities by exploring the potential of diverse battery storage technologies. Through a comparative analysis, we identify the strengths and weaknesses of each system, thereby facilitating the selection of optimal solutions for specific urban contexts. Our findings pave the way for the integration of innovative energy storage systems into future city infrastructure.

These contributions address the research gaps by presenting an integrated model that optimizes energy consumption, ensures data security, and maximizes operational efficiency. This comprehensive approach covers technological and practical challenges, making it valuable for advancing smart cities' sustainable development.

Organization of this paper as follow:
Section 2 discusses data analytics. Section 3 examines the Security Concerns of the Internet of Energy for a sustainable smart city. Also, in section 4, the authors examine Characteristics and layers in architecture for smart cities to accommodate changing urban needs. Section 5 analyzes smart energy sources and technologies. Section 6 analyzes some applications of emerging technologies in the development of sustainable cities and communities. Finally, section 7 is devoted to conclusions.

2. Data analytics

Data analytics examines, sorts, and interprets large amounts of data to extract valuable information and insights [32]. Businesses use data analytics to understand customers, improve operations, and make data-driven decisions. Smart cities rely heavily on data analysis to manage their energy efficiently [10]. The ever-growing flood of information from sensors and devices necessitates a robust system for interpreting and drawing insights from this data [33]. Data analytics acts as this crucial mechanism, allowing us to sift through massive datasets and uncover hidden patterns, correlations, and unusual fluctuations. We can optimize energy consumption and significantly reduce waste by leveraging these insights [34]. We can uncover energy use patterns and pinpoint improvement areas by analyzing data from smart buildings, transportation systems, and other connected devices [35]. ML can then predict future energy needs, allowing us to optimize these systems [36]. Additionally, predictive maintenance algorithms can identify equipment on the verge of failure, minimizing downtime and boosting energy efficiency [37]. Figure.2, presents the components of data analytics. Data analytics is a game-changer for smart energy management in smart cities [38]. By crunching the vast amounts of data collected from sensors, grids, and buildings, cities can gain valuable insights into how energy is used across different sectors. This allows them to:[39]

- **Identify areas of inefficiency:** Data analytics can pinpoint buildings, neighborhoods, or even specific appliances that consume excessive energy.
- **Optimize energy consumption:** Armed with this knowledge, cities can implement targeted strategies to reduce energy waste. This could involve optimizing traffic light timing to reduce idling vehicles, adjusting heating and cooling systems in public buildings, or promoting energy-efficient appliances for residents.
- **Predict energy demand:** By analyzing historical data and weather patterns, cities can forecast future energy needs. This helps them procure energy resources more efficiently and avoid situations of strain on the grid.
- **Integrate renewable energy sources:** Data analytics can help optimize the integration of renewable energy sources like solar and wind power into the grid, making energy use more sustainable.

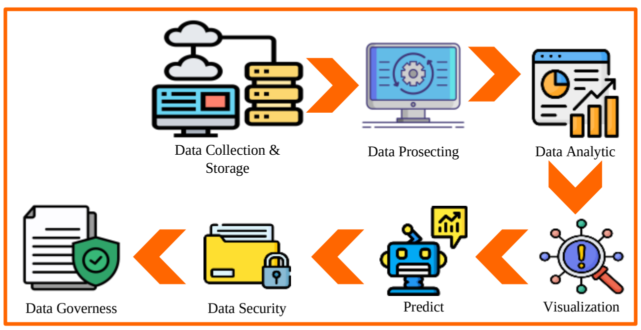

Fig.2. components of data analytic

2.1. Advanced energy consumption data collection

Advanced energy consumption data collection is a powerful tool for smart cities. It leverages advanced technologies like smart meters, IoT sensors, and data analytics platforms [40]. Overall, advanced energy consumption data collection empowers cities to make data-driven decisions that can lead to significant benefits:

- **Reduced Energy Costs:** By identifying inefficiencies, cities can save money on their overall energy bill [8].
- **Enhanced Sustainability:** Lower energy consumption translates to a reduced carbon footprint, contributing to a greener city [41].
- **Improved Infrastructure Management:** Data can help predict maintenance needs for equipment and infrastructure, leading to proactive management and fewer disruptions [42].

2.2. Data analysis and interpretation tools

Effective energy management in smart cities hinges on harnessing data. This data, encompassing energy consumption patterns, empowers informed decision-making through advanced analytics [8]. By leveraging algorithms and machine learning, these tools unlock hidden patterns within vast datasets, ultimately optimizing energy use across the city [43] .To optimize energy, use in smart cities, several data analysis and interpretation tools are employed for smart energy management:

- **Energy analytics platforms:** Energy analytics platforms are software applications that collect and analyze data on energy use. This data can come from a variety of sources, including smart meters, building management systems, and industrial control systems [44].
- **Predictive analytics tools:** Predictive analytics tools are software applications that use various techniques, including data mining, machine learning, and statistics, to analyze current and historical data and make predictions about future events. These predictions can improve decision-making across a wide range of industries, such as finance, healthcare, marketing, and retail [45, 46].
- **Energy visualization tools:** Energy visualization tools are software programs or online platforms that help you visualize your energy data in a clear and easy-to-understand way. These tools can be helpful for homeowners, businesses, and organizations alike. By visualizing your energy use, you can identify areas where you can save energy and money [47].
- **Fault detection and diagnostics (FDD) tools:** Fault detection and diagnostics (FDD) tools are software applications used to identify and diagnose problems in various systems and equipment [48]. They are commonly used in buildings to monitor and maintain heating, ventilation, and air conditioning (HVAC) systems, lighting systems, electrical systems, and more [49]. FDD tools work by collecting data from sensors installed throughout a building [50]. These sensors can measure various parameters, such as temperature, pressure, humidity, and energy consumption. The data is then fed into the FDD software, which analyzes it for abnormalities. If the FDD software detects an abnormality, it will generate an alert [51]. The alert will typically include information about the nature of the problem, its severity, and its potential impact on the building's operations. Facility managers can then use this information to diagnose and fix the problem.

3. Security Concerns in the internet of energy for a sustainable smart city

Building secure connections within a smart city's energy network (Internet of Energy) is essential for sustainable development [52, 53]. As these energy systems become increasingly interconnected and dependent on digital tools, they open themselves to cyberattacks and other security risks. This section highlights some key areas to focus on when securing the Internet of energy for a sustainable smart city, as illustrated in Figure 3 .[8].

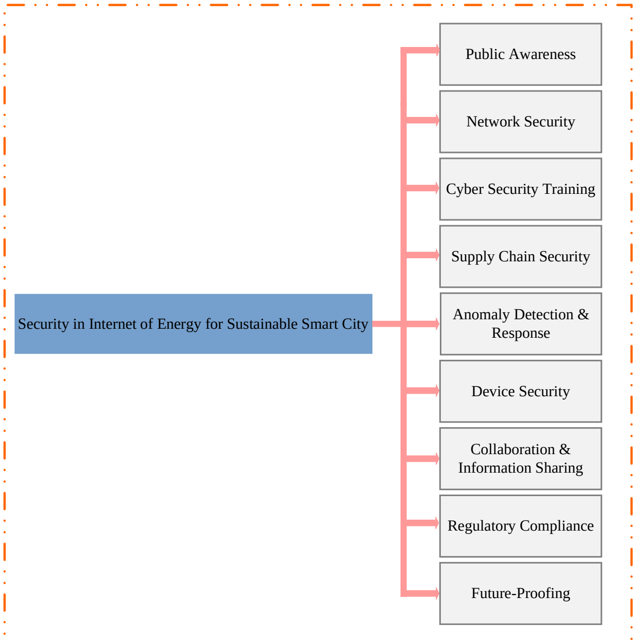

Fig.3. Critical security concerns in the internet of energy for sustainable smart cities

Figure.4, shows some ways to reduce these security risks. By addressing these security concerns, we can ensure that internet of energy helps create sustainable and secure smart cities.

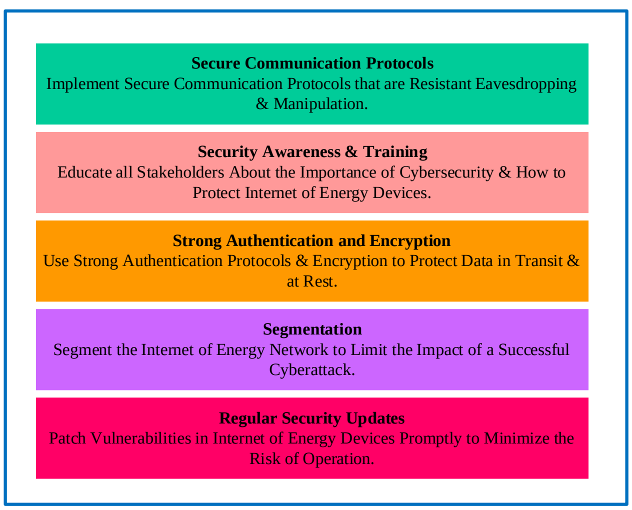

Fig.4. Some ways to reduce these security risks

- **Network Security:** This focuses on securing the communication channels within the internet of energy [52]. It involves measures like:
  - ✓ **Encryption:** Protecting data transmission from unauthorized access [54].
  - ✓ **Firewalls:** Filtering incoming and outgoing traffic to prevent malicious activity. Intrusion Detection/Prevention Systems (IDS/IPS): Monitoring networks for suspicious behavior and taking action [55].
- **Public Awareness:** Educating citizens about cyber threats and best practices is vital [56]. This includes:
  - ✓ Educating residents on safe energy consumption habits to avoid manipulation.
  - ✓ Raising awareness of potential scams targeting smart city infrastructure.
  - ✓ Encouraging responsible data sharing practices.
- **Cybersecurity Training:** Equipping personnel involved in managing the internet of energy with the necessary skills to identify and address cyber threats [57]. This includes training on [58, 59]:
  - ✓ Incident response protocols
  - ✓ Secure coding practices
  - ✓ Vulnerability assessment and penetration testing
- **Anomaly Detection & Response:** Developing systems to identify unusual activity within the internet of energy [60]:
  - ✓ Using ML to detect deviations from normal energy consumption patterns [61].
  - ✓ Implementing automated responses to isolate and contain threats [62].
  - ✓ Developing incident response plans for dealing with detected anomalies [63].
- **Device Security:** Securing individual devices within the internet of energy [64-66]:
  - ✓ Implementing strong authentication and authorization mechanisms for devices.
  - ✓ Regularly patching devices to address vulnerabilities.
  - ✓ Securely storing and managing device credentials.
- **Disaster Recovery & Authorization:** Ensuring the internet of energy can recover from disruptions and maintaining control over access [67]:
  - ✓ Implementing backups and redundancy plans for critical systems.
  - ✓ Defining clear access control policies and procedures.
  - ✓ Regularly reviewing and updating access permissions.
- **Collaboration & Information Sharing:** Encouraging cooperation between stakeholders to improve overall security [68]:
  - ✓ Sharing threat intelligence among utilities, government agencies, and cybersecurity firms.
  - ✓ Developing common security standards and protocols for the internet of energy.
  - ✓ Establishing communication channels for incident response coordination.
- **Regulatory Compliance:** Ensuring the internet of energy operates within the legal framework [69]:
  - ✓ Understanding and complying with relevant data privacy regulations.
  - ✓ Implementing security measures that meet industry standards.
- **Future-Proofing:** Building a security framework that can adapt to evolving threats [70]:
  - ✓ Staying updated on emerging cyber threats and vulnerabilities.
  - ✓ Regularly testing and evaluating the security posture of the internet of energy.
  - ✓ Investing in research and development of new security technologies.

3.1. Management strategies

Below are some management strategies for security concerns in smart cities, which can be followed to ensure the safe and reliable operation of internet of energy infrastructures.

- **Robust cybersecurity measure:** In the first stage, it is recommended that potential security weaknesses be identified and fixed. For example, robust encryption algorithms can be provided to protect data in transit [71]. Also, robust authentication algorithms can be used to limit access. In addition, users can be taught security methods.
- **Physical Security measure:** At this stage, the priority is protecting internet of energy infrastructure against events. One of the other goals is to provide measures to ensure the security of Internet energy infrastructure components throughout the supply chain [72].
- **Compliance with standards:** The first step in following the standards is to consider the grade codes set for the security of internet of energy infrastructures and then provide frameworks to develop these standards.
- **Resilience and continuity**: Considering resilient backup systems to ensure continuity of operations in case of events and rapid recovery [73].

4. Characteristics and layers in architectural for smart cities to accommodate changing urban needs

This paper acknowledges the ongoing effort to establish a clear and well-defined architectural framework for smart cities, which would be crucial for their real-world implementation. Despite the theoretical promise, there are significant hurdles to overcome before a universally applicable smart city architecture can become a practical reality. While broad architectural proposals struggle to adapt to the evolving needs of smart cities, this paper proposes a more grounded, "bottom-up" approach. This architecture, detailed in Figure.5, is comprised of four distinct layers: a detection layer (also known as the sensing layer), a transmission layer, a data management layer, and finally, an application layer.

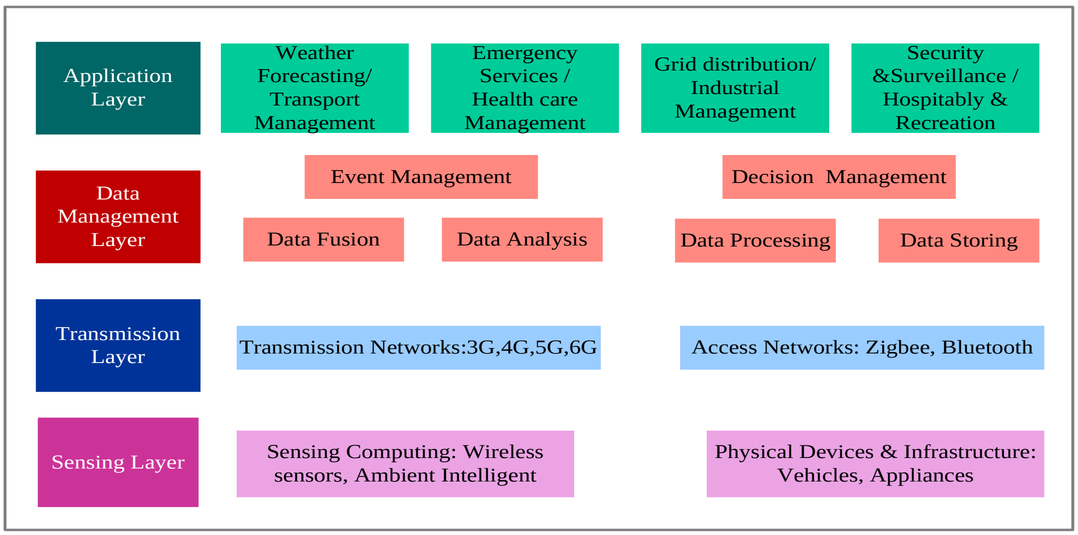

Fig.5. Four layers in architectural designs to adapt to the evolving needs of smart cities

Smart cities are revolutionizing how urban areas handle energy consumption. By integrating technology with infrastructure and residents, these cities aim to optimize energy use and create a more sustainable future. Thus, consumers can adjust energy consumption based on real-time pricing and reduce peak demand on the grid. In addition, the sensors in the equipment can detect potential failures and enable preventive maintenance and prevent energy-wasting failures. Some of the main characteristics of smart cities are as follows:

- **Smart connectivity:** One of the outstanding features of smart cities is smart connectivity. Urbanization takes advantage of these connections, including the IoT and 5G systems, to improve connectivity among various areas of the city and deliver a range of services.
- **Intelligent Traffic Management:** Smart city uses smart traffic systems to improve urban traffic management and control. This measure improves mobility and increases the efficiency of both public and personal transport.
- **Sustainable Energy Management:** Smart city uses technology to optimize energy management and transition to renewable energy sources. These measures will reduce energy consumption, reduce pollution as well as improving individuals' standard of life.
- **Smart City Security:** Smart city security technologies like smart video surveillance and emergency notification mechanisms help enhance urban security and protect citizens.
- **Electronic Urban Services: Smart** Cities provide electronic services to citizens. These include electronic payments, online registration, and access to urban information that improves the urbanization process.

5. Smart energy sources and technologies

According to US Department of Energy research, when driving an EV, it may utilize 60% of the input energy, which is double as much as a car that runs on conventional fossil fuels [74]. Electric vehicles, by helping reduce carbon emissions, are seen as a crucial part of fighting climate change. But if everyone who has a vehicle today moves to an electric option and then all people connect them to electricity until they get charged after arrival at 6 p.m., extra pressure control is very important for the current urban infrastructure. So, the smart IoT technology helps solve these problems, as well as giving consumers more insight and control over how much energy they consume. For control and monitoring purposes, electric vehicles (EVs) can be included into a variety of private areas, including field area networks (FAN), building area networks (BAN), neighborhood area networks (NAN), and home area networks (HAN) [40]. As seen in Figure.6, protocols for communications are categorized as two types of methods: wired and wireless [75]. The process of maximizing sustainability, economic benefits, and performance via the utilization of technology to improve energy generation, distribution, and use is referred to as smart energy management. Table 1 summarizes some papers' components, processes, and observations about energy management and smart cities. Efficiently controlling energy usage in urban areas poses numerous obstacles. An inherent obstacle lies in the difference between the availability of energy and the level of energy required.

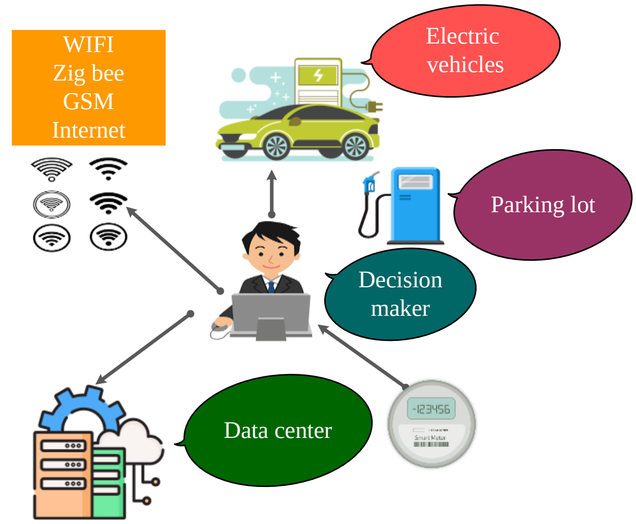

Figure.6. Both wired and wireless categories of various communication protocol

Table1. Some later papers contain components, processes, and observations about energy management and smart cities.

Ref	Year	Component	Process	Observations
[76]	2024	smart city pilot policy	Discussion of a quasi-natural study with regard to digital oversight	In contrast to cities without a resource foundation, governance's function in developing the handling of natural resources doesn't seem as obvious
[77]	2024	smart cities and energy efficiency	effect of smart city on energy efficiency	provides a framework to making decisions to assist SCP growth and increased regional energy performance
[78]	2023	use of cutting-edge energy management strategies in smart cities is discussed	An organized survey of the literature	Discusses how cutting-edge energy management strategies are being applied in smart cities. Suggested possible next steps for the Homes Energy Management Systems (HEMSs) research
[79]	2023	combining technological advances with local natural resources in smart cities	Explores essential components related to the integration of green areas and intelligent technology in smart city settings	Provide guidance on the management of natural resources and the advancement of sustainable growth in smart cities to politicians, developers, and academics
[80]	2024	Power management of lighting loads	In order to regulate electrical power and energy demand in environmentally friendly buildings, this research offers a method for regulating lighting loads in combination with solar energy	Suggests a method for controlling the energy usage of LED lighting demands together with interconnected photovoltaic systems
[81]	2017	IoT Software Design for Smart City Energy Management and Modelling	Provides a software framework for the IoT that allows for energy management and the modeling of fresh control rules in a municipal area	The platform fills a gap in modern applications by providing a system to manage energy for a municipal area

[14]	2023	Energy oversight and evaluation system for smart buildings in smart cities	The AI Method for Tracking Networks in Smart Buildings (AIMS-SB) was utilized to control energy usage as well as generate and regenerate the energy needed for a smart building	By reaching balanced consumption, the suggested approach seeks to increase the tracking systems' distribution of energy productivity
[82]	2024	Smart Cities Net Zero Planning	Advances smart urbanization techniques as well as offers insightful information to researchers, elected officials, and developers	Introduce an innovative viewpoint on smart city design that incorporates analysis of the visual effects, financial effectiveness, impact on the environment, and green energy solutions
[10]	2023	Progress in technology leading to intelligent energy management	An introduction to smart energy management, outlining the difficulties cities confront in controlling their energy use and the necessity for technology developments to help them manage these difficulties	Helps to further advance the creation of smart cities and offers insightful information to academics, business people, and legislators who are striving for a better tomorrow
[83]	2024	Micro grid technology and smart flexible management of energy in smart cities	Micro grid management of electricity in smart cities depends on involvement in energy storage systems and demand response programs	Suggested a framework for energy management and oversight with the goal of regulating the MGs' V/F ratio in smart cities

As urban areas expand, their energy requirements rise, resulting in an inequality between energy supply and demand. This issue is commonly tackled by augmenting energy generation, which might result in more carbon pollution and damage to the atmosphere. Moreover, the infrastructure of energy in urban areas frequently suffers from obsolescence and inefficiency, resulting in substantial energy loss during the process of transmission and distribution. The absence of actual time energy management and monitoring technologies worsens this inefficiency, making it difficult to discover and rectify energy inadequacies. Additionally, cities face challenges such as uncertain energy prices and insufficient investment for energy construction can impede the deployment of novel energy technology. In order to address such difficulties, smart cities require technical innovations. Advances in technology have made major advances in solving the issues of managing energy smartly in smart cities in the past decade. Here are some significant technological developments in energy management in smart cities. Smart grids and smart cities are interconnected concepts that work together to create more sustainable, efficient, and resilient urban environments. By leveraging advanced technologies and data-driven approaches, smart grids can play a crucial role in enabling the development of smart cities that meet the needs of a growing population while minimizing their environmental impact. The smart grid idea was established to equip the electrical system with the features and services required for a smooth transition to efficiency and incorporating renewable energy sources [84]. Figure.7, shows some characteristics of a smart grid.

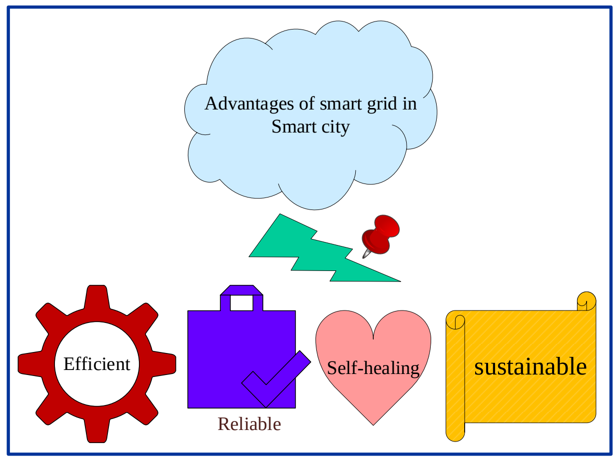

Fig.7. Some characteristics of a smart grid

5.1. Electric Vehicles

An energy management approach in smart cities with electric vehicle is to regulate power flow in order to reduce emissions, increase fuel economy, guarantee drivability, and preserve the energy storage state of charge and lifespan by carefully enforcing boundaries [85]. An overview of the main goals of EMS is displayed for electric vehicle in Figure. 8. Also, Figure. 9, shows the classification of electric vehicles. An electric vehicle battery should be considered a place for energy storage. Electric vehicles are more than just vehicles. They are a suitable source for providing the energy we need. This is possible with two-way chargers that cover several items:

- Vehicles to grid (V2G): This capability allows electric vehicles to feed their stored energy into the grid as distributed storage units. By draining energy during periods of peak demand, this capability can help reduce pressure on the grid and prevent widespread outages. Electric vehicle owners can earn money by selling excess energy to the grid [86].

- Vehicles to home (V2H): This feature allows electric cars to discharge their stored energy as virtual storage to power homes. V2H can reduce dependence on the upstream grid and provide homeowners with more energy independence. By using the stored energy, homeowners can lower their electricity bills [87].
- Vehicles to load (V2L): V2L can enable the use of equipment in locations without a reliable power source. In general, using this capability, electric vehicles can be used as mobile energy sources for various applications such as construction sites, emergency situations, camping [88].

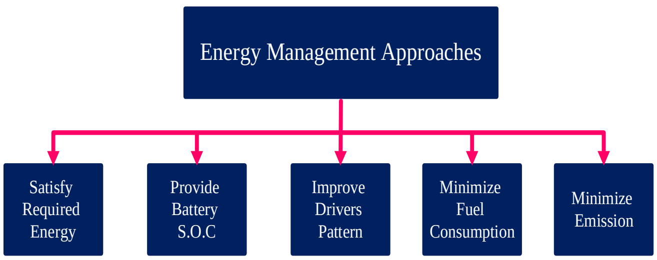

Figure.8. Main goals of energy management system for eclectic vehicle

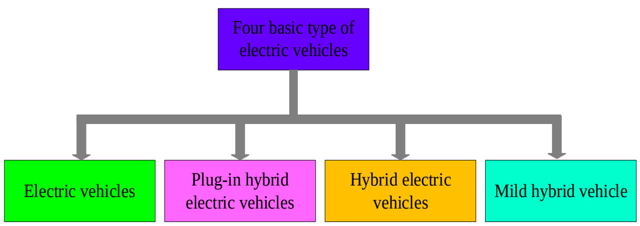

Figure.9. Classification of electric vehicles

5.2. Smart Meters

Another smart energy source in smart cities is smart meters (SM). These devices are designed to communicate directly between the electric or gas boiler and the power provider. Figure 10, shows the system architecture as well as every piece of hardware and software for the intended SM. Customers can use the system to calculate the cost of the planned bill, which helps them control their consumption habits. Accurately measuring and recording each customer's power usage is crucial for power systems in the smart-city because of accurate billing purposes, energy justice, sustainable and renewable energy generation and reducing energy consumption. A key metering technology for the upgrading of conventional grids and the creation of smart cities is Advanced Metering Infrastructure (AMI) [89]. This real-time connection means that consumers can see exactly their amount of energy and cost. And consumers can make informed decisions about what to use and how to behave more affordably. At the same time, applications can provide accurate billing based on real-time energy consumption and accurately control and balance supply and demand.

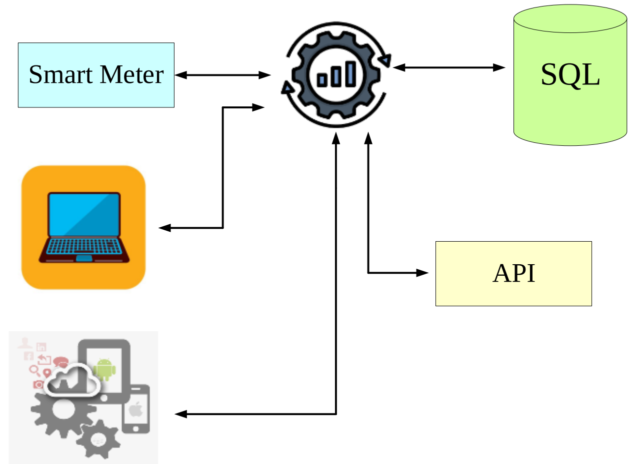

Fig.10. The system architecture, hardware, and software for the intended SM

5.3. Distributed energy resources

Smart cities can leverage various cutting-edge solutions, as detailed in Table 2, which outlines the key features of the explored technologies [90-94]. Solar panels, also known as photovoltaic (PV) panels, are a popular choice for small-scale electricity generation [9]. These panels use semiconducting materials to directly convert sunlight into electricity [95, 96]. The falling cost of PV panels in recent years, driven by competitive market forces, has significantly contributed to their growing popularity [97]. Thermal collectors (TCs) absorb sunlight to heat water or other fluids [98]. They are available for both small-scale applications like heating water and large-scale applications like generating electricity in concentrated solar power (CSP) plants. Solar TC can be integrated into building designs, providing a sustainable and efficient way to heat homes and businesses. This reduces reliance on fossil fuels and lowers energy consumption [99]. Solar CSP is ideal for large-scale power generation, providing a reliable and dispatchable source of renewable energy. It can be used to store excess energy as heat, ensuring a steady supply even during periods of low solar radiation. Photovoltaic-thermal (PV/T) collectors combine solar electricity generation with heat collection, but they are less common. Solar PV/T offers a highly efficient way to utilize solar energy, maximizing its potential [100]. It's particularly suitable for applications requiring both electricity and heat, such as residential and commercial buildings. In addition, the use of renewable energy is the most effective step that can be taken towards a sustainable city. Wind energy is a scalable energy source that is suitable for both onshore and offshore installations. It can supply a significant portion of the city's electricity needs, reduce dependence on fossil fuels, and improve air quality [73]. Large wind turbines are a well-established technology that generates clean and affordable electricity. However, smaller turbines are more expensive and require backup power sources, like batteries or connection to the grid, due to the inconsistency of wind. Biomass is a renewable and carbon-neutral energy source that can be used for heating, electricity generation, and transportation fuels. It helps reduce reliance on fossil fuels and promotes sustainable waste management [101]. Biomass has become a topic of increasing importance in recent years [102]: it is a versatile energy source that can be used directly via combustion to produce heat or indirectly after converting it to a gaseous or liquid biofuel capable of providing heat or electricity at competitive prices. However, farming biomass crops needs to be done responsibly in order to be sustainable. Indeed, new European directives cap the first-generation biofuels, made with sugars and vegetable oils found in arable crops, while favoring the second-generation biomass compound of woody crops, agricultural residues, and waste. Poly-gen improves energy efficiency by capturing and utilizing waste heat, reducing energy consumption and emissions. It's suitable for a variety of applications, including residential, commercial, and industrial sectors [103]. Earth's core continuously generates heat that flows outward (geothermal energy) [104]. This heat can be harnessed directly for warming buildings and spaces (thermal production) at lower to moderate temperatures. At higher temperatures, it can be used in co-generation plants to produce both electricity and heat. Geothermal electricity can be very cost-effective in locations with suitable underground conditions; however, these ideal geological features are not widespread. Geothermal energy is a reliable and sustainable source of energy, particularly in areas with high geothermal activity. It can provide a baseload supply of electricity and heat, reducing reliance on fossil fuels and improving energy security [105]. By combining these advanced solutions, smart cities can create a sustainable and flexible energy infrastructure that reduces reliance on fossil fuels and emission, improves air quality, and lowers energy costs [105]. This not only benefits the environment but also enhances the quality of life for residents and businesses.

Table.2. Comparison of most common distributed energy sources

Generator	Thermal	Electric	Dispatchable	Efficiency
Solar PV	✓	✗	✗	<30%
Solar TC	✗	✓	✗	<60%
Solar CSP	✓	✓	✓	<60%
Solar PV/T	✓	✓	✗	<60%
Wind power	✗	✓	✗	<60%
Poly-gen	✓	✓	✓	>60%
Biomass	✓	✓	✓	<60%
Geothermal	✓	✓	✓	>60%

5.4. Energy Storage Systems

The term energy storage systems refer to a large range of systems that fall into five categories: mechanical, electrochemical (or battery), thermal, electrical, and hydrogen storage technologies. Classifications of energy storage systems are shown in Figure. 11. In smart cities, storage systems regulate energy use by facilitating the integration of renewable energy sources and allocating load demand based on requirements [106]. Cities experience varying energy demands throughout the day. Storage systems can strategically discharge power during peak hours, reducing the burden on traditional power plants and potentially lowering overall energy costs [107]. This can sometimes be suggested by demand response aggregators [108]. It is worth mentioning that storage systems have various vital applications in smart cities. For example, they can be integrated into microgrids as a backup and enhance energy flexibility. In addition, as mentioned, storage systems can store excess energy produced by wind turbines and solar cells and supply the energy needed by electric vehicle charging stations. However, this equipment has some key challenges in smart city development. For example, large-scale batteries can create fire and explosion hazards if not properly designed, installed, and maintained. Also, extracting raw materials such as lithium and cobalt can cause pollution and habitat destruction, while battery recycling still needs to be fully developed. The suitability and affordability of storage systems can vary significantly depending on specific urban conditions, regulations, and infrastructure availability. Table.3, provides a general overview. In addition, Table.4, compares the advantages and disadvantages of each storage system.

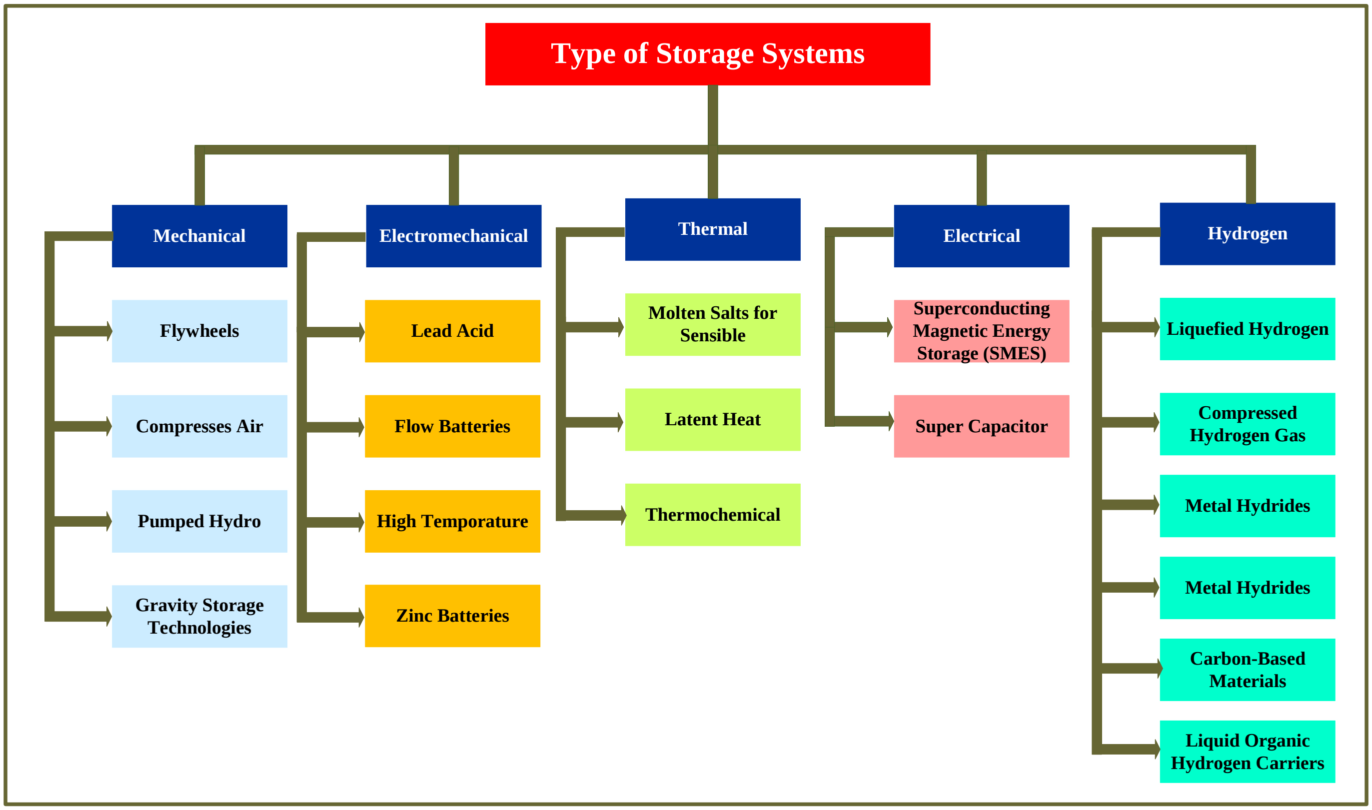

Figure.11. Classifications of Energy Storage Systems

Table.3. Comparison of applications and economic efficiency of energy storage systems for use in smart cities

Storage type	Suitability for urban environments	Economical
Mechanical	Generally suitable	It is affordable
Electromechanical	Highly suitable for urban, especially battery model	It is very economical, especially the type of battery
Thermal	More suitable for integration in buildings	Can be cost-effective for long-duration storage
Electric	Highly suitable for urban	Can be cost-effective for short-duration storage
Hydrogen	Provided that proper infrastructure is provided, it can be suitable for urban use	Can be cost-effective for long-duration storage

Table.4. Comparing the advantages and disadvantages of energy storage systems for utilizing in smart cities

Storage type	Advantages	Disadvantages
Mechanical	High density & Long during storage	Significant infrastructure & Environmental impact
Electromechanical	Fast & High efficiency	Limited capacity for long during
Thermal	High density & Long during storage	Requires careful thermal management & Potential safety concerns
Electric	Very fast response & High-power density	High self-discharge rate
Hydrogen	Clean production	Required specialized infrastructure & Safety concerns

5.5. ML techniques for home energy management systems

Energy consumption is a growing concern, and smart homes offer a unique opportunity to address it. Here's why investigating ML for smart home energy management is crucial:

- **Unveiling Hidden Patterns:** Traditional methods struggle to identify complex patterns in energy usage data. ML algorithms can sift through vast amounts of data from sensors (temperature, appliance use) and resident habits to uncover hidden trends [109].
- **Predictive Power:** ML models can learn from historical data to predict future energy consumption. This allows for proactive

measures like pre-cooling a house before peak hours or scheduling appliances for off-peak periods [110].

- **Personalized Optimization:** Every household has unique energy usage patterns. ML can personalize recommendations based on resident behavior, weather, and appliance usage. This targeted approach can significantly improve efficiency [111].
- **Automated Energy Management:** ML models can automate energy-saving decisions. For instance, adjusting thermostats, dimming lights, or optimizing pool pump schedules based on real-time data and predictions.
- **Cost Savings and Sustainability:** By optimizing energy use, smart homes with ML-powered management can lead to significant cost savings for homeowners. It also contributes to a more sustainable future by reducing overall energy consumption.

In conclusion, investigating ML for smart home energy management holds immense potential. It can lead to smarter homes that use energy efficiently, save residents money, and contribute to a greener future.

AI encompasses the idea of machines performing tasks in a more innovative way [112]. This field aims to create intelligent systems that can learn and adapt, mimicking human behaviors and decision-making processes. ML, a subset of AI, focuses on designing systems that can learn from experience, using data as their source of knowledge [113]. In general, ML can be divided into three categories [114, 115]:

- Reinforcement learning (RL)
- Supervised Learning (SL)
- Unsupervised Learning (UL)

RL is emerging as a promising approach for optimizing energy consumption in smart homes [116, 117]. It offers several advantages over traditional methods, making it well-suited for the complex and dynamic nature of home energy management systems. In Figure.12, the classes of home energy management systems that are able to effectively use RL techniques are classified. Below are some things related to proving the usefulness of RL for home energy management systems:

- HVAC control: RL can optimize the operation of heating, ventilation, and air conditioning systems to minimize energy use while maintaining comfortable temperatures [118].
- Appliance scheduling: RL can schedule appliances like washing machines and dishwashers to run during off-peak hours when electricity prices are lower [119].
- Demand response: RL can help homes participate in demand response programs by adjusting their energy consumption in response to real-time electricity prices [120].
- Integration with renewable energy: RL can be used to manage home energy storage systems and integrate renewable energy sources like solar panels into the overall energy management strategy.

Fig.12. Classes of home energy management systems that are able to effectively use RL

RL offers promising benefits for home energy management systems, but several challenges and considerations must be addressed. These challenges and concerns are therefore explored in Figure.13.

Fig.13. Challenges and considerations for RL

6. Some applications of emerging technologies in the development of sustainable cities and communities

6.1. Waste Handling

The waste collection process is an essential issue for municipal service providers [121]. The traditional method of collecting waste is a complicated and time-consuming process that requires a lot of human resources and is incompatible with today's technologies. Irregular waste collection management, including domestic, industrial, and environmental waste, is one of the leading causes of many human problems. Mismanagement in waste collection causes the contamination of various diseases and will adversely affect the health of living organisms. To overcome these problems, an intelligent waste management system helps to maintain a clean environment by automatically managing waste collection without human interaction. Intelligent waste management can be used in cities with high waste generation, but there is no effort to control it. This idea is mainly compatible with smart cities. Intelligent waste management prevents excessive collection of domestically produced waste. Smart buildings may help improve waste handling by implementing intelligent waste collection systems. This may incorporate services such as electronic garbage sorting, systems for recycling, and immediate time waste tracing. Smart buildings may increase their total efficiency by streamlining the handling of waste. AI is poised to transform waste management. AI offers innovative solutions, from identifying waste types and optimizing collection routes to detecting illegal dumping and analyzing waste composition [122]. This comprehensive approach addresses critical challenges, improving efficiency, sustainability, and overall waste management practices. Figure.14, presented the fundamental concepts of AI in waste management.

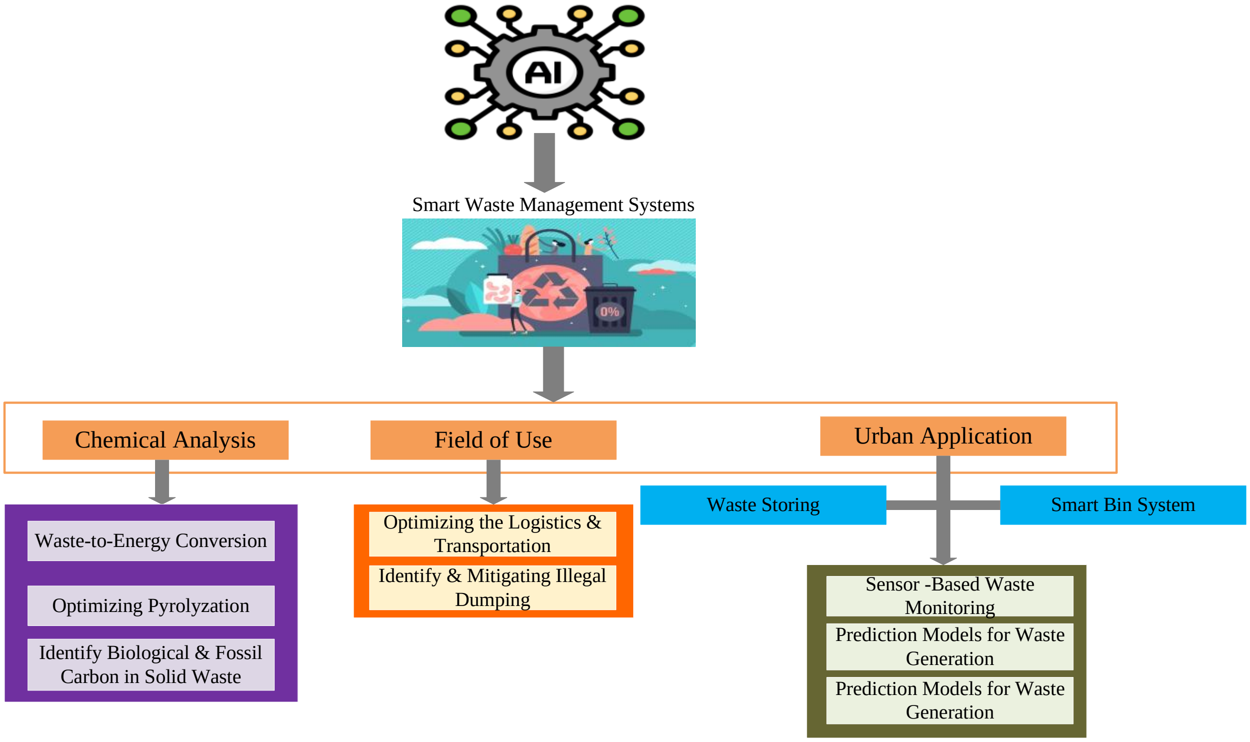

Fig.14. key concepts of AI in waste management

6.2. Smart Street Lightening

A smart street lighting system based on Artificial Neural Networks is suggested in [123]. The application may be used in conjunction with the whole street lighting observation and regulating system. Reference [124], describes a cost-effective, smart, and interactive street road lighting scheme built on an IoT platform. It comprises of IoT based effective electrical pole containing an LED light driver. A smart street light is a public lighting device that uses new technologies such as CCTV cameras, light-sensitive photocells, remote control sensors, and IoT-related equipment to provide street lighting [125]. The connection of smart street lights connected to the network with a data center that exchanges information in real-time forms the smart lighting system. The smart lighting system is known as an important step while creating smart cities. Furthermore, to providing local lighting based on the input parameters, the launch of the smart lighting system increases the satisfaction of citizens in the field of security and safety and causes maximum savings in this sector. Considering this, the smart street lighting network infrastructure is in the public area. It can be used as the backbone of the internet of everything, for example, for applications such as city traffic control, vehicle movement monitoring, measuring the weather and the level of pollution, etc. This system automatically adjusts the light intensity based on the time of sunset and sunrise, the schedule of the operator or expert system, human presence, traffic, field of view, or weather conditions, resulting in significant energy savings and reducing maintenance costs. In the implementation of these plans, a "gateway device" was used with the ability to control several lights up to a certain kilometer radius [126]. The explained Plan consist of gateway, Data center and central panel for controlling energy management in street lightning shown in Figure.15. The street lighting management system is a system that has the ability to control and monitor a certain set of street lights through the Internet platform. Controlling, reducing, or increasing the desired power and turning off and on the lights is done by a specific platform on the Internet. Monitoring and supervising the correct operation of the lights according to the location, installing and checking the electrical parameters of the lights and power lines, as well as warnings related to it are done by this system. The benefits of this Plan are as follows:

1. Reducing energy consumption by up to 40%.
2. Reducing maintenance processes
3. Possibility of remote energy management, control, and monitoring.

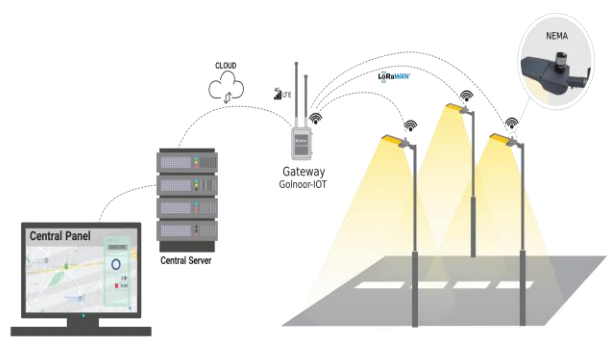

Fig.15. The Plan consist of the gateway, Datacenter and central panel for controlling energy management in street lightning

6.3. Smart Cities & HVAC Systems

According to the World Economic Forum, buildings account for 40% of worldwide energy usage and contribute 33% of greenhouse gas emissions. Buildings are crucial in transitioning towards a more environmentally friendly future with fewer carbon emissions. They are present in our living, resting, and working spaces, and they play a significant role in world energy consumption, accounting for approximately one-third of global greenhouse gas emissions. Intelligent HVAC systems can significantly decrease carbon emissions and energy usage [127]. Moreover, these procedures are essential for cutting costs and establishing an effective system by alleviating the burden on staff. The world is changing due to the widespread use of technology like IoT, and its application in IoT plays a crucial role in attaining improved energy efficiency. One method to achieve this is by ensuring the accurate implementation of preventive maintenance. By implementing IoT sensors, HVAC contractors can shift from reactive maintenance to a more proactive and condition-based approach to preventative maintenance [128]. The sensors gather live data from HVAC systems and transmit it to a cloud-based platform for vendors to retrieve and evaluate. Technicians can remotely diagnose problems by examining readings when issues are noticed, such as a decrease in efficiency, high power usage, or excessive vibration. IoT-enabled HVAC systems can enhance energy management by granting access to up-to-date data and tracking usage patterns. Sensors are highly crucial in HVAC systems. For instance, strategically positioned thermal sensors can precisely identify temperature variations in all parts of a structure. A region with less congestion can have a more rapid temperature decrease compared to areas with a higher volume of people passing through. Intelligent HVAC systems can analyze this data to alter temperatures and automatically decrease energy usage.

Conversely, occupancy sensors can activate or deactivate cooling and heating systems based on the presence or absence of people. Occupancy sensors ma y identify presence by monitoring movement and gathering this data. The collected data can be utilized to perform real-time temperature adjustments, resulting in energy consumption savings. Smart HVAC systems are characterized by their great level of customization, setting them apart from traditional legacy HVAC systems. Consumers can remotely regulate the temperature, fan speed, heating, and humidity in their homes and workspaces, allowing them to manage energy use. Figure.16, shows a more detailed view of the interior environment of the smart home and how it is connected to the external environment.

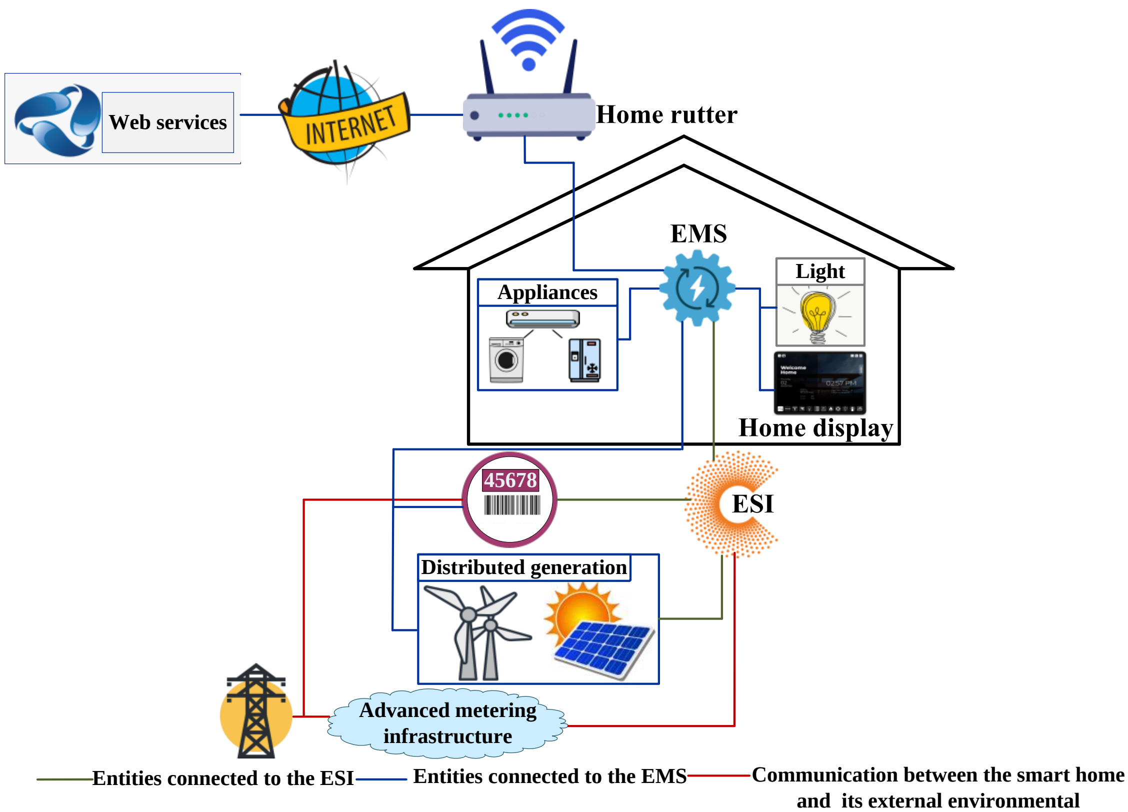

Fig. 16. More detailed view of the interior environment of the smart home and how it is connected to the external environment.

Moreover, integrating intelligent HVAC technology with ML enables the system to acquire knowledge and adjust to user preferences. Smart cities must prioritize their citizens' well-being, actively address environmental concerns, and demonstrate their role in societal progress [129]. Outdated systems pose risks while building a more ecologically suitable structure will require sophisticated technology and enduring civilization.

Undoubtedly, smart HVAC systems enhance the sustainability of our operations by optimizing energy use. The implementation of HVAC automation is a crucial initial measure in the process of making buildings more environmentally friendly.

Nevertheless, the utilization of technology and automation necessitates a substantial degree of testing. Like any intelligent device, smart HVAC systems also have their potential risks. Any device or system linked to the cloud or internet is susceptible to being compromised by hackers. Hence, it is crucial to prioritize cyber-security measures and conduct routine assessments on all interconnected devices to protect valuable data and provide optimal protection. Therefore, ensuring the safety and security of individuals who utilize technological breakthroughs is imperative.

6.4. Reducing Water Consumption

Water usage may be greatly decreased with smart home equipment, promoting a sustainable future. Utilizing soil moisture sensors, intelligent irrigation systems adjust watering schedules in response to plant needs and meteorological circumstances. By using only, the quantity of water required for cleaning, smart toilets with automated washing and drying systems save water use. Water circulation detectors are used by intelligent devices to regulate the use of water and lower water utilization. Sensors that detect movement are used by smart faucets to control water flow and turn off the faucet instantly when it is not in demand [130]. Smart bathrooms monitor shower activity and set a consumption cap. Before significant harm is done, smart sensors for leaks notify householders. Sprinkler controllers with intelligence may identify leaks and stop water wastage. Water quality is optimized, and use is tracked by smart metering systems [131]. Optics are another tool used by smart swimming systems to reduce water waste. A sophisticated smart water management system now integrates IoT gateways to optimize water resource utilization, quality control, and equipment maintenance. The IoT gateway serves as a central communication hub, facilitating seamless interaction between a network of sensors and equipment's. Meanwhile, a diverse sensor

network is a complete set of IoT devices, such as monitors and sensors. In addition, the wireless connection includes Wi-Fi, Bluetooth, Zigbee and etc, to communicate with sensors and retrieve real-time data about parameters such as water quality, flow rate, pressure level, and environmental conditions [132, 133].

5G, Zigbee, Wi-Fi, and Bluetooth are critical technologies for developing sustainable and smart cities. Each technology has unique strengths and weaknesses, making it suitable for different applications. By understanding the capabilities of each technology, city planners and developers can design smart cities that are more efficient, sustainable, and livable. In Table 5, we have compared the features of these 3 technologies so that users can choose their technology type wisely [40, 134-136]. For example, according to the table, we saw that Zigbee technology is suitable for water monitoring and smart street lighting. Finally, data aggregation integrates data gateways across existing sources and provides users with a coherent view of water system performance. System integration and control include cloud-based analysis, real-time monitoring, and automatic control. In the first case, the collected data is given to cloud-based platforms for better analysis. In the second case, the IoT gateway enables an immediate response to anomalies or emergency situations by monitoring the parameters of the water system. Then, in the third case, the gate can initiate automatic actions such as adjusting water flow rates or triggering alarms based on pre-defined rules and thresholds by integrating with cloud-based control systems.

Table.5. Comparison of Wi-Fi, Bluetooth and Zigbee technologies for use in smart cities

Specifications	Wi-Fi	Bluetooth	Zigbee	5G
Application in sustainable & smart cities	Public Wi-Fi for IoT; Surveillance; Remote monitoring	Wearable tech; Indoor localization;	Smart metering; Environmental monitoring & IoT networks	V2G; V2L; V2H; Ultra-Reliable low-latency applications
Range	100 to 200 m	10 to 100m	10-300m	About 20 km
Data range	54 Mbps -1 Gbps	2 Mbps -50 Mbps	Up to 250Kbps	1 Gbps-10 Gbps
Energy consumption	High consumption	Normal consumption	Very low consumption	High consumption
Network topology	Point 2 multipoint	Point 2 point; Piconet	Mesh and star	Cellular
Scalability	Limited by access point	Up to7 devices in piconet	It covers up to 65,000 devices	It covers up to millions of devices
Economical	×	✓	✓	×
Latency	More than Bluetooth	Very low	Almost equal to Wi-Fi	Very low
Security	High	is high but weaker compared to Wi-Fi	Normal and weaker than (Wi-Fi) and (Bluetooth)	Very high
Efficiency	Very low	High	Very high	Low
Typical use cases	Video streaming & Public internet grid	Indoor navigation; street & health tracking	Street lighting; Water monitoring & Gas sensors	Electric vehicles; Real time surveillance

6.5. Elevators & Escalator

Elevators and escalators are essential elements of high-rise buildings, retail establishments, and public spaces, facilitating the swift and efficient movement of occupants between different levels [137]. Smart elevators utilize sophisticated algorithms and sensors to improve elevator utilization, cutting down on energy use and time spent waiting. Building management systems (BMS) and occupant detection systems can be added to elevators to increase total productivity [138, 139]. Energy efficiency is a crucial factor when selecting various brands. Therefore, makers of escalators, moving walkways, and elevator components aim to incorporate the most effective systems for conserving energy. Among the conventional mechanisms for energy management of escalators, the following can be mentioned [140]:

- **System On/Off:** This system has a radar that, when detecting the presence of a passenger around the defined area and also on the escalator, gives the escalator a normal movement command. When the passenger is not on the escalator, and after a certain time has passed, the radar gives the command to turn off the escalator [141].
- **Movement speed management system:** In this system, when the passenger is not on the escalator, the system uses less engine power, so the speed of the escalator decreases. At the time of detecting the presence of a passenger, the mentioned system will gradually increase the speed of the escalator until it finally reaches the rated speed.
- **Combined system:** In combined systems, two modes of ON/OFF and escalator movement speed management

systems are used. When the passenger is not present, the speed is reduced first, and after a certain period of time, if a passenger has not used the escalator, the escalator will turn off, and it will start moving again when the passenger reappears within the recognizable range of the escalator.

7. Conclusions

In conclusion, this research has shed light on the vital role of energy management in achieving Smart Sustainable Cities, which leverage technology for a better quality of life, resource efficiency, and economic strength, all while ensuring a sustainable future. Our exploration has shown that smart grids, building management systems, and the integration of renewable energy sources – facilitated by data analytics – are key tools for optimizing energy use and reducing consumption within smart cities. The environmental benefits are clear, with reduced emissions leading to a more sustainable urban environment. Moreover, these advancements translate to cost-effectiveness, as cities save money through efficient energy use. This study has further delved into the complexities of data analytics and security concerns within the internet of energy, a crucial component of smart city energy management. By acknowledging these challenges, we pave the way for future research that can address them and ensure the secure and efficient utilization of data in smart energy systems. In addition to this focus on data, our review of various smart energy sources, technologies, and their applications within smart cities provides a valuable foundation for further exploration and development in this critical field. Ultimately, this research underscores the importance of energy management as a pillar of smart sustainable cities, promoting a future where technological innovation fosters a thriving urban environment that is both sustainable and cost-effective.

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