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Green energy harvesting strategies on edge-based urban computing in sustainable internet of things

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ABSTRACT

The development of intelligent urban computing has carried out different critical smart ecological and energy harvesting topics such as intelligent cities and societies. The main concept of the sustainable smart city is established for collecting and negotiation of the Internet of things (IoT) devices and smart applications to help and enhancement of human life. On the other hand, energy harvesting management as an important issue in sustainable urban computing has several challenges arising from the exponential growth of IoT devices, smart applications, and complex population to decrease the related factors on the energy consumption, power-saving, and environmental waste management. However, the notion of energy harvesting management for sustainable urban computing is still growing exponentially, and it should be attended to due to economic factors and governmental obstacles. This paper reviews different existing green energy harvesting strategies on the smart applications of sustainable and smart cities in edge-based intelligent urban computing. The existing energy harvesting strategies have been divided into five categories: smart home management, smart cities, smart grids, smart environmental systems, and smart transportation systems. This review aims to classify technical aspects of energy harvesting management methods in sustainable urban computing concerning applied algorithms, evaluation factors, and evaluation environments. As technical results, a general discussion is essential for the development of existing challenges and open research directions of energy harvesting and waste management for sustainable smart cities that contribute expressively to enhance the energy consumption of smart applications and human life in complex and metropolitan areas.

1. Introduction

Today, intelligent urban paradigm and smart cities need to be managed in intelligent techniques to increase comfortable civilization, mobility in smart applications, safety, and many other humans to smart things aspects. The advancement of the Internet of Things (IoT) (Terroso-Saenz, González-Vidal, Ramallo-González & Skarmeta, 2019) has enabled digitalizing intelligent urban computing and smart cities concerning the creation of a heterogynous network such as smart vehicles, smart home appliances, air quality meters, and other items embedded with sensors and actuators which enable these objects to connect and exchange data (Souri, Hussien, Hoseyninezhad & Norouzi, 2019). The concept of sustainable urban computing is referred to the interconnection of smart applications related to IoT environments (Said & Tolba, 2021), sustainable society, and human behaviors which guarantees the use of intelligent decision-making methods for interactions of smart devices and sustainable computing.

By increasing populations, environmental needs, energy consumption, mobility, safety, employment, and many other aspects, urban areas and cities need to be managed intelligently (Singh, Jeong & Park, 2020). Intelligent urban computing refers to all computational aspects related to smart cities, smart home-care, smart grid, smart transportations, smart medical systems, smart industry, manufacturing, and smart farming (Sisi & Souri, 2021). Intelligent urban computing is a process of achievement, integration, and analysis of big and heterogeneous data generated by a diversity of resources that gathered using intelligent computational environments in sustainable urban spaces to tackle major issues such as increased energy consumption and traffic congestion. On

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the other side (Konbr & Maher), The advent of the IoT has enabled digitalizing intelligent urban computing concerning the creation of networks of physical devices, such as vehicles, home appliances, water, electricity, and air quality meters, trash deposits, and other items embedded with electronics, software, sensors and actuators which enable these objects to connect and exchange data (Dong et al., Feb. 2021). IoT is the networked interconnection of smart devices, sensors, actuators, and intelligent applications that facilitates new technological innovations among things and humans' resources to enhance the quality of resource management. Such IoT devices which will be highly prevalent in urban computing will provide a valuable resource of data to support good decisions and resulting actions (Konbr, 2019). IoT devices should exchange gathered information using cleaning, filtering, and processing abbreviating data and after that is used by devices for performing their respective operations (Zhang, Cheng, Cheng & Chen, Nov. 2020).

An important limitation of IoT devices in intelligent urban computing is powered by finite battery capacity (Han et al., 2021). When IoT devices communicate with each other, a large amount of energy is consumed due to which devices operate for a limited duration only, as long as the battery lasts (Zhang et al., 2016). Then energy management in IoT devices helps available energy harvesting components. However, the intelligent urban computing classification is particularly special. The research of energy harvesting management on intelligent urban computing is still in its beginning due to the reasons such as classification scene, cost, and complexity of energy consumption management.

This paper reviews different existing green energy harvesting strategies in edge-based intelligent urban computing. Intelligent urban computing refers to all computational aspects related to smart cities, smart home-care, smart grid, smart transportations, smart medical systems, smart industry, manufacturing, and smart farming. This review aims to classify principles and technical aspects of energy harvesting methods in urban computing concerning technical aspects, applied algorithms, evaluation factors, and evaluation environments. Based on the Systematic Literature Review (SLR), we selected 33 high potential and key relevant research studies to consider in this review.

The main contributions of this paper for energy harvesting management on intelligent urban computing in sustainable IoT applications are as follows:

- Providing a technical analysis and illustration on energy harvesting management strategies for intelligent urban computing in sustainable IoT that includes 34 research studies.
- Showing a comprehensive taxonomy for energy harvesting management approaches in sustainable IoT applications.
- Examining the evaluation factors, architectures, algorithms, and features of each research study.
- Discussing innovations and open issues on the energy harvesting management models for reducing energy and power consumption in intelligent urban computing and the IoT applications.

The organization of this paper is shown as follows: Section 2 provides the related works for energy harvesting management for intelligent urban computing in sustainable IoT applications. Section 3 shows a road map on research findings and selection based on technical inclusions and exclusions. Section 4 shows a comprehensive taxonomy for energy management approaches a detailed discussion for each research study. In section 5, an analytical discussion and statistical review are presented based on summarized research studies. Section 6 presents open issues and new challenges on energy management of IoT applications. Finally, the conclusion is illustrated in Section 7.

2. Related works

Significant efforts have been presented by the researchers towards the decision-making approaches and intelligent DSS models in various domains of the IoT. But the extraction of basic features with less computational time and selection of an efficient algorithm for detection of the majority of meta-heuristic and machine learning techniques with high accuracy are still open problems for the researchers in the domain of designing and developing energy management techniques.

In recent review studies, Raoufi et al. (Raoufi & Gorji, 2021) prepared a survey on water waste management for analyzing rainwater harvesting, greywater recycling, and energy management of photovoltaic electricity generation in Iran. In other work, Moreira and other contributors (Moreira et al., 2019) described a scheme of a system for health care that gets options to make better decisions. Its goals are to fix a few problems about health services relate to family health care management and help to increase the effectiveness of decisions by data mining methods and model-driven systems. The name of this service is decision support systems "DSSs" and works on IoT systems. In this article, three different types of it are discussed which include (data--driven/ Knowledge-Driven /model-driven) DSSs. in the next section author presented important aspects of this system in the form of a table and explained them. In the conclusion section of this article, it is concluded that combinations of statistical models and data models can help to make a better decision. The constraints of this project are about of collect recent studies in special categories and speed of developments examines IoT in this article. After the introduction of IoT by experts, its features were reviewed, then the essential components of IoT were introduced, defined, and issues related to its design, accordingly listed the technology trends in this area. Due to the wide range of applications of IoT, various areas have been introduced and described with more detailed examples that directly affect human life. One of the basics of IoT, M2M was introduced and described for connecting all IoT components. IDSSs, as the next generation of DSSs, guide users through IoT. The place of these systems and then their applications in human life is examined and in the next section, the main trends of IoT from the perspective of several studies are introduced, its impact on different markets, and the creation of competitive advantages are examined. In the final section, the relationship between IoT and startups is discussed, which includes the benefits that IoT brings, through businesses can be created and the needs of human life can be met, requires the observance of the items.

Moreover, authors in Kaklauskas and Gudauska (2016) examines IoT in this article. After the introduction of IoT by experts, its features were reviewed, then the essential components of IoT were introduced, defined, and issues related to its design, accordingly listed the technology trends in this area. Due to the wide range of applications of IoT, various areas have been introduced and described with more detailed examples that directly affect human life. One of the basics of IoT, M2M was introduced and described for connecting all IoT components. IDSSs, as the next generation of DSSs, guide users through IoT. The place of these systems and then their applications in human life is examined and in the next section, the main trends of IoT from the perspective of several studies are introduced, its impact on different markets, and the creation of competitive advantages are examined. In the final section, the relationship between IoT and startups is discussed, which includes the benefits that IoT brings, through businesses can be created and the needs of human life can be met, requires the observance of the items. Also, Sadeghian et al. (2021) reviewed energy-saving strategies on building and public lighting systems in sustainable cities. Many electrical energy saving and power management strategies have been discussed in this literature review by comparing evaluated algorithms and QoS factors. For discussing energy-aware non-interfering monitoring systems, Gopinath, Kumar, Prakash Chandra Joshua and Srinivas (2020) proposed a comprehensive review to identify optimal techniques on energy consumption management based on electrical utilities in buildings by a single energy metering approach.

Besides, authors in Biel and Glock (2016) presented a review of existing models of decision-making to decrease costs. Today we come across important problems like lack of resources, increasing cost of energy, and producing greenhouse gases. The purpose of this article is about makes models to solve these problems with new approaches about price, systems, and rules. The author prefers two kinds of approaches first one related to the planning of production and the second one about energy efficiency. In energy-efficient lot-sizing author uses batch processing to optimize the cost of ordering and cost related to carrying with the proposed model of inventory management. Machine scheduling is another approach in this article job allocation and sequencing it assigns jobs to machines and defines the sequence of jobs assigned to the same machine. Parallel machine scheduling is a specific case of a dynamic flow shop. Integrated energy quality considerations in current models by minimizing energy refers to costs. In most situations, the energy-related cost estimation was based on price-driven demand response (DR) systems.

And finally, Chatterjee, Armentano and Cymberkno, (Dec. 2017) analyzed patients' health data to help physicians have better diagnoses and help them realize relations between some sicknesses. "IoT" and data analyses play a great role in this development in medical science. About 600,000 patients pass away from cardiovascular sickness. Keeping track of people's health information by using "IoT" systems the risk of cardiovascular sickness would decrease. A normal distant healthcare system consists of an "IoT" system to take and observe individual health information, analysis network, data storage, and a part to provide medical guidance. This paper is about gathering and storing patients' data, analyzing them, and then providing the best possible health results in the context of the cardiovascular system (Zhao, Gu, Gao & Chen, 2020).

Based on the above-mentioned studies, we conclude that there is no comprehensive survey and review study to analyze and categorize existing research studies by focusing on managing energy harvesting strategies for intelligent urban computing in the sustainable IoT environments. In the next section, a roadmap to illustrate research findings and selection is provided.

3. Research planning and methodology

In this section, we show a roadmap to search, select, and refinement of existing research studies in the field of energy harvesting management for intelligent urban computing in sustainable IoT based on the Kitchenham et al. (2009). To present a comprehensive survey on the energy harvesting management approaches and the proposed analytical review, Fig.1 shows three stages for searching, selecting, and refinement of existing research studies. In the searching level, research goals are searched in the examined research finding level (Souri, Navimipour, et al., 2018). At this level, the important keywords are searched to find appropriate case studies in electronic databases as follows (Wang, Zhong & Souri, 2021):

"Energy harvesting" OR "Energy" OR "Energy management" AND "Urban" OR "Urban computing" AND "Internet of Things" OR "IoT". Finally, at the refinement level, the final selected papers are applied, and the final research studies are collected to consider future analysis.

Fig. 2 shows a time domain of selected energy harvesting management studies for intelligent urban computing with publication year. The final result of research selection was collected from 33 research studies.

For achieving the best results of technical analysis, the following research questions (RQ) are defined to evaluate and report technical features on the energy harvesting management for intelligent urban computing in the sustainable IoT:

RQ1: Which energy harvesting management fields are analyzed for intelligent urban computing models in IoT?

RQ2: Which optimization techniques and models are presented in this literature?

RQ3: What are the evaluation factors for evaluating the energy harvesting models in IoT?

RQ4: Which tools and simulation environments have applied for evaluating intelligent urban computing in IoT?

According to the above questions, we have applied inclusion and exclusion refinement methods to get best performance on paper selection based on sensitive word finding in electronic databases.

4. Energy harvesting management for intelligent urban computing

The energy harvesting strategies are applied with optimal solutions and best on-time efforts to realize complex and large-scale intelligent urban computing by decreasing energy and power consumption in the IoT ecosystem (Coelho, Relvas & Barbosa-Póvoa, 2021). In this section, we illustrate a technical taxonomy to show the main categorization of energy harvesting strategies on intelligent urban computing platforms in the IoT ecosystem. Fig. 3 illustrates our proposed taxonomy for energy harvesting strategies extracted from the literature review. In other words, energy harvesting strategies are presented in this section, including supervised machine learning algorithms, unsupervised recommender algorithms, fuzzy logic and methods, natural-inspired and evolutionary algorithms, and deep learning. On the other hand, we have categorized intelligent urban computing platforms that are presented in this section into five general classes in terms of smart homes, smart cities, smart environmental systems, smart grids, and smart transportation systems (Wu et al., 2017).

4.1. Smart home

Smart home is one of the popular issues for energy harvesting management in IoT environments. It is classified into two parts assistive operations and management operations. Assistive operations sight in smart home is giving basic support to the users in their everyday actions in the home. Furthermore, management operations present unique features of the smart home (Safara et al., 2020). Examples of these operations are including the energy performance of the home and control of the devices and lights to minimize energy waste while pleasing the residents' demands (Feng, Liu & Feng, 2021).

According to Fig. 4, some things can be arranged automatically in a smart home: With simple remote control, all home's light bulbs can be controlled. Light intensity and brightness can be modified and can be programmed to automatically turn on or off for a definite time. In a smart home, we can turn off all the switches remotely. Some devices have timing, and the on and off choice can be established to the wanted

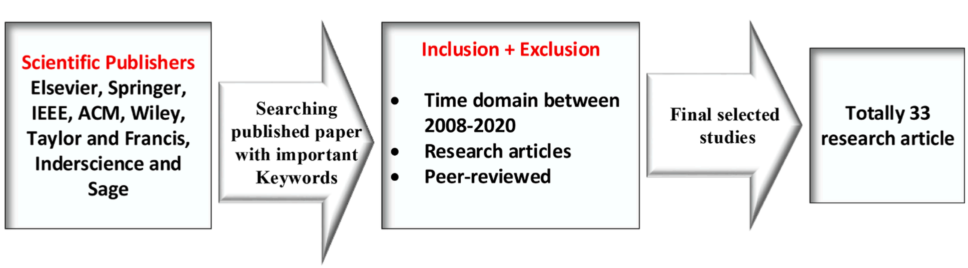

Fig. 1. Selection and refinement strategy.

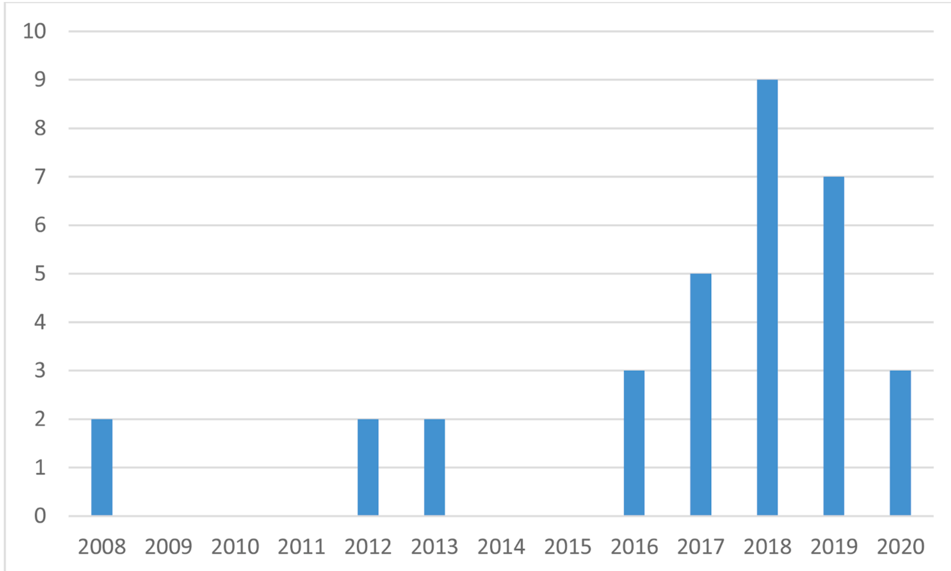

Fig. 2. Publication per year analysis for existing energy harvesting management approaches.

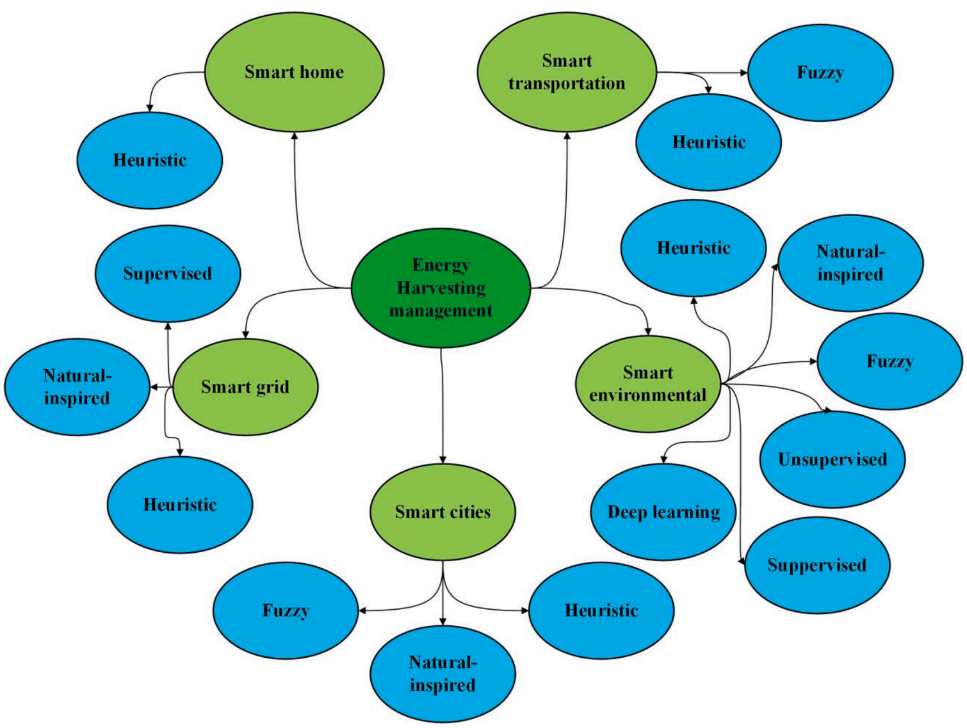

Fig. 3. The proposed taxonomy for energy harvesting strategies.

time. Home security cameras are one of the most primary and important parts of a smart home. Using the advanced sensors any activities in the house can be monitored. With intelligent entrance applications, it can be arranged who can access your home and also doors entrance works digitally. The temperature can be set automatically using an automated thermostat system established in a smart home (Fan et al., 2021). Finally, smart lighting, and smart door lock systems are new challenging environments to enhance energy efficiency and minimizing power consumption in the smart home environments.

There are 4 research studies in this subsection that show the categorization of existing energy harvesting approaches for smart home in IoT applications.

Authors in this research (Ali et al., 2017) expressed a smart monitoring system on patient/home health. This research is implemented through an IoT system. Sensor nodes can gather data such as body temperature, heart rate, galvanic skin response, environmental data, and contextual data and send information wirelessly to system gates with low power utilization. To supply energy to the sensor nodes, radio and solar frequency energy generation schemes have been used. It is also sketched to generate energy from radio frequency, multiband antenna, and rectifier circuits. The voltage obtained and the existent level were adequate for the configuration of the sensor nodes and this is evidenced by the test of a room sensor when supplying energy with a photovoltaic (PV) solar cell.

Yun, Ustun, Nadeau and Chandrakasan (2016) suggested the application of thermoelectric strength collecting for implanted, battery-free

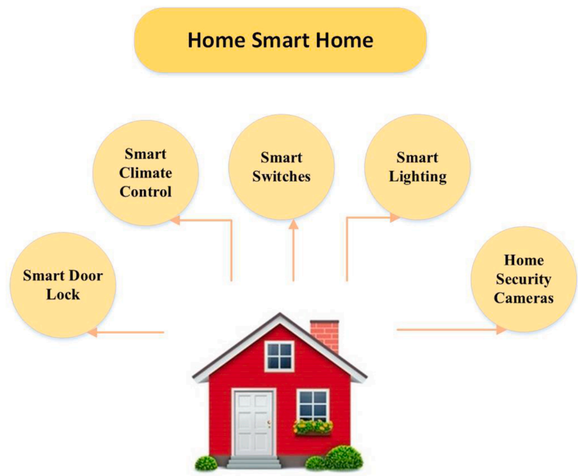

Fig. 4. Smart home for intelligent urban computing IoT application.

sensor points in intelligent dwellings. Especially, one similar implementation is battery-free tension feeling in vacuity isolated plates for constructions. The plates significantly enhance warming and chilling power utilization, and the temperature distinction evolved throughout them would be employed to force a cordless detector to check their strain grade. Firstly, they generated a prototype for the accessible strength utilizing documented climate information. Subsequently, they evaluated the thermoelectric generator's substantial electrical strength by integrating the producer with a vacuity isolated plate and placing it within a window for examination. Eventually, the authors established the possibility of employing the determined thermal slope to drive a sensor node. They illustrated that thermoelectric potency gathering might empower a novel category of implanted, no-maintenance, battery-free sensors for intelligent dwellings.

Kim et al. (2018) proposed ground tiles are provided which can be used at various places in the house and can produce sufficient power to relay the data wireless communication to the electronic device when a user stands on it. In form of power extraction, the octahedral–tetragonal step border is the best output region that has an immediate benefit concerning balanced power generation. Writers also built a device that utilizes a portable foot change as a person robotic piezoelectric transducer. A wireless transmission scanner network and the transmitter change device of the main electrical appliance effectively regulates the feedback impedance received from the steps of a person. The results have shown that the conveniently configurable tiles provide the promise of a smart home for people, with future uses for those that are mentally disabled.

Zungeru et al. (2019) have suggested a stable smart home switch mechanism that incorporates dwelling electrical network access, energy generation and processing for complex electric modules and circuits, and wireless connectivity for clever sockets and ports. This article introduces the concept and development of communications networks and ego-energy storage safe smart home fluorescent signals. The research described in this study presents a device architecture that makes the building's electrical energy extremely safe. The suggested scheme even gathers and energy stored for any operational digital devices to use an energy buffer solar modules. The authors suggested smart home focused on energy management services that use Zigbee wireless interaction to reduce the usage of basal energy. The developed safe smart home used automated technology and controls, and Message Queuing Telemetry Transport (MQTT) for simplicity of power use operation. The research results produced from intensive concept tests indicate an increase in the safety and energy conservation of the structure.

4.2. Smart cities

Smart cities are one of the strongest and most complicated scenarios for a smart environment which includes various fields including the lighting, energy, public health, building, house and education according to Fig. 5. There are 11 research studies in this subsection that show the categorization of existing energy harvesting approaches for smart cities in IoT applications.

Mora et al. (2019) suggested a design that can complete the action of processing for applications with a large amount of data. To solve this problem, they have used cloud computing and mobile computing methods with the IoT model. The main target for this design was to be able to process a lot of information from pictures and videos. The advantage is that the needed data is accessible for all the 3 layers and each layer can perform its tasks independently without the need to communicate with other layers. Bringing the number of layers to n and expanding this design to more applications is one of the author's plans.

Li, Chen, Tang and Luo (2019) have provided an algorithm that shares the resource between communication and radio jointly. The Authors proposed a time average rate of maximizing the computation which improving the performance of the system. The proposed algorithm dynamically deciding to transmit power, local frequencies of CPUs, task loading on the edge, and better bandwidth. By the foundation of WET, Energy harvesting devices could save the RF signals into themselves as temporary batteries and release their energy to devices they needed power in their low battery situation. The main idea is to harvesting Signals such as radio frequencies with the Wireless Energy Transfer technique as Energy and releases them in needle states that help UEs to use their best system computational capacity and rate without considering the energy sources needed for UE.

Xiao and Krunz (2018) proposed a new dynamic network slicing architecture for large-scale energy-harvesting fog computing networks. This article works at fog computing systems, in which cloud data centers can be expanded by a great number of fog nodes located in a broad geographical zone. To supply computational services for locals every node has to gather the energy from the nearby environment. Here the idea of dynamic network slicing is suggested by the authors. In this theory geographical orchestrator organizes workload repartition among local fog nodes, making sections of energy and computational resources to backing a special kind of service with specified quality of service assurances. Resources that are devoted to each section can be dynamically controlled matching service requirements and energy accessibility. Authors define the performance of their offered idea through the 3GPP and also evaluate its substructure by using the true BS location data of a factual locale system with beyond 200 BSs placed in Dublin city. Authors' scalar outcomes demonstrate that their substructure remarkably progresses the workload proceeding qualification of fog computing.

Fig. 5. Smart cities for intelligent urban computing IoT applications.

Tentzeris and Kawahara (2008) discussed innovative scavenging techniques for autonomous ICT applications. They highlighted the disadvantages of commonly used power resources of sensor nodes such as batteries and investigated for better power sources and alternatives like paper material, RF signals, and energy harvesting technology. The team created a three-dimensional inkjet-printed RFID cubic antenna for the real-time locating and oriented-less energy scavenging behavior of the sensor nodes and documented frequencies returned from the antenna. Afterward, they developed a wireless sensor transmitter prototype for the sake of scavengers' integrability and measured the module's radiation diagram by using Satimo's Stargate 64 Antenna Chamber system. They chose different locations, mostly in Tokyo, like train stations, laboratories, city streets, and outdoor areas to test their systems' performance and estimate their frequencies for energy harvesting. The experiment results demonstrate the difference between broadcasting devices' frequencies and their radiation level, as well as the maximum amount of energy harvested from the daily life of a worker in Tokyo documented in charts.

Guo et al. (2016) suggested synchronized data and energy transmission from intermediate nodes, the architecture of way-switching and energy-splitting operating modes, and also the related optimization techniques. The author reveals the implications of community harvested energy from transmitting nodes belonging to several radio networks. The authors discuss the efficiency transfers in mass processing, particularly by the use of cooperation between nodes while ensuring the quality of service. The results show two essential experimental inquiries: how to efficiently plan information and energy transfer from a typical transmitter node, and how much power could be extracted via atmospheric signals to transfer.

Cui, Yoon and Youn (2018) suggested creating an Omnidirectional Biomechanical Energy Harvesting Block (OBEH) which is capable of generating electricity from human walking. Human walking is an amount mechanical source of electricity that is lost every day. With the progress of the IoT, the smart city era is due soon. After all, wireless sensors use chemical batteries, and that causes some problems with wireless sensors and related applications. For the smart city vision to be effectively realized, a self-generating power grid should be implemented as a countermeasure to reduce the reliance on batteries, finally, WSNs can work more sustainably. A formal architecture process for the OBEH sidewalk block is provided here; it consists of three essential components, in particular, first about track human's footstep, second about creating a model about output result, and third about reliability and optimization of the OBEH sidewalk block. This research recognizes two types of intrinsic randomness, namely first variations in material properties and second size and direction of footsteps. The Reliability-aware Designing problem was utilized to enhance the output energy produced by an annular piezoelectric layer attached to the middle of the structural layer while achieving a target reliability of 99.87%.

Alzahrani and Ejaz (2018) presented a support organization tactic for cognitive IoT networks with RF power gathering in 5G networks. This framework is to maximize the output convincing the quality of service and reduce the control energy on each IoT sign. The results show that this proposed framework, the greedy algorithm is so close to the simplex technique. For future projects, this group will be looking towards the zone of stocks management based on NOMA for IoT.

Wijnants et al. (2012) suggested the concept of a combined public network system that would, to a large extent, integrate elements of any of these issues by combining a Wi-Fi access system with the features of the Wireless Sensor Network (WSN). The multidisciplinary design of the suggested device produces the end to end approach which organizational chains extends from information identification at the specific levels of IoT device to the distribution of end-user product and perceived information protection through the Wi-Fi access network shown in the group. The suggested structure can be considered environmentally conscious because it requires multiple steps to reduce the energy usage of the elements of the WSN protected. The WSN system engages extensively in environmental issues through a green decentralized justification architecture and a virtualization sensor, which are cooperatively designed to minimize the general network energy usage. The WSN design incorporates the collection of real-time observations related to atmospheric characteristics of real-world artifacts, while the city-scale Wi-Fi connection point content aggregation provides universal access to the internet for users and, as such, incorporates universal user-side data usage and automated content distribution.

Liu, Xiong, Fan and Zhong (2017) presented a method to develop energy usage by decreasing urgent energy that is utilized to forward information between sink nodes and sensor nodes (SN). They overcame related limitations by reshaping energy beams and alteration in time. To promote the system, they created a problem and made it solvable by benefiting the semidefinite relaxation method (SDR). This approach also can detect the lowest extent of energy being expended. They asserted that system efficiency can be significantly impressed by increasing the energy usage in presence of scent data; however, by enhancement in data quantity, this result fades. In the future, they intend to analyze the role of other criteria on the system's operation.

Chatzopoulos, Gujar, Faltings and Hui (2018) provided privacy and optimal crowding costs by using smart contracts in blockchain. The authors have proposed a model in which cyber physical nodes send data collection requests to an internet system platform, which enforces them and delivers the cost-effective auction to the appropriate cells to interest the machine units in those cells. To perform tasks through honest bidding. Extensive experimental results showed that the proposed privacy-preserving auction outperforms state-of-the-art proposals regarding cost by ten times for high numbers of mobile users and tasks. The authors provided that the optimal incentive-compatible cost bid employed which determines the selection of mobile users who will handle each crowdsensing task outperforms peak propositions when adopted for the parameter under consideration by an order of magnitude for a high number of mobile users and Tasks.

d'Orazio et al. (2017) presented some cloud-based methods to optimize smart cities due to a concern of smart cities being heavily populated in the future. In the case of information diversity, a graph database sounds suitable for the project. They boost graph data by questioning, analyzing, and inducing them. Furthermore, they struggle to determine the stability of data and they establish limitations for better client service. Achieving those intentions leads to encounter special conflicts which require using new languages.

4.3. Smart grid

The software provides smart grid devices to be both multi-function and remotely flexible. This is what is enabling the smart grid to transition from a traditional inactive centralized form for energy production and sharing to a dynamic, bi-directional, de-centralized model for energy generation, warehouse, and brokering towards the edge and closer to the user. As we transfer to the smart grid, we need to realize that the physical principles are less important and it is the software and the form of that software that requires to be handled.

Based on Fig. 6, the compound of renewable energy and energy optimization are important factors of sustainable energy harvesting and mitigating smart grids. IoT technologies offer several applications in the energy-aware smart grid area such as smart metering, smart charging, piezoelectric-based energy harvesting, and power-electric flow management. IoT can be applied for increasing energy performance, improving the share of renewable energy, and diminishing environmental influences of energy usage in smart grids. There are 6 research studies in this subsection that show the categorization of existing energy harvesting approaches for smart grids in IoT applications.

Al Ahmad and Allataifeh (2018) provided by creating a smart city using piezoelectric energy harvesting. Piezoelectric materials convert mechanical force (vibration energy) into electrical energy. Piezoelectric contains the non-conductive material titanium lead zirconate (PZT),

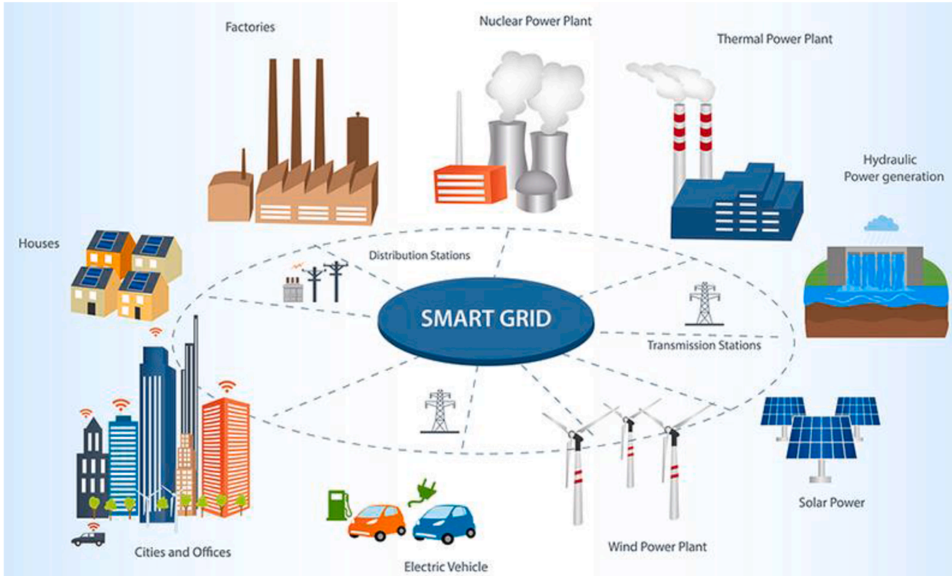

Fig. 6. Smart grid for intelligent urban computing IoT applications.

which is located between two metal plates and is attached to a base. The cost of piezoelectric production is relatively high, but compared to other methods of generating electricity, they do not cause any environmental pollution. In this paper, a piezoelectric vibration oscillator generates a sine wave with the required frequency and voltage to eliminate the switch bias. This system increases energy efficiency and is a renewable system that has no energy loss. The system has been used in several low-consumption applications, such as agriculture, body network medical applications, and wireless sensor networks.

Tan, Gunduz and Poor (2013) provided a model as an outlook that aims to optimize energy usage while preserving client security and secrecy. The point is to determine each individual's essential amount of energy and the energy which has been dissipated in absence of supplier interposition. They introduced a rank for each of the parameters such as energy dissipation and safety of data, thus they were able to estimate the energy effectivity and client security. They also realized that preserving the additional energy by an acquiring apparatus not only optimizes energy usage but secures the client's secrecy as well. The advantage of this work is that they have noticed a unit called EH that can prepare discrete amounts of energy at every moment in an i.i.d (independent and identically distributed), and they also have studied a battery with limited storage space which can be recharged. Such batteries effectively prepare energy by saving supplementary energy to use in the future, they can even improve seclusion by concealing the sign of each electrical equipment amount of use from the producers.

Magno and Boyle (2017) examined different aspects and sources to yield energy for habiliment gadgets from the human body, result in proposing a fresh procedure that improved previous technology by enhancing the generated power also boosting the durability of battery by trying varied transducers. The authors assessed their work while devices were located on a human also with piezoelectric generators and DC-DC converters. The invented scheme is currently impractical but it is promised to be functional by offering a new process in prospect.

Ozger, Cetinkaya and Akan (2018) presented IoT empowered method to extend the internet of things utility in Smart Grid. In this structure nodes are IoT cordless widgets and system generators sections are connected to the internet. Cognitive Radio helped this construction to solve the raucous states of a band, increased band performance by using incompatible channels, and overcame spectrum shortage. EH or energy scavenging process provided advantages in various domains, resolved the supply limitation difficulty, and improved the life duration of the cordless widget. So authors suggested a new networking model called energy harvesting cognitive system for IoT empowered which a combination is of energy harvesting and cognitive methods. The future work will be focused on the consideration of stability in energy usage and EH features to support battery-less function.

Prawiro and Murti (2018) introduced an intelligent charging and wireless energy transfer system that, by adding a dongle to the devices, eliminates the possibility of recharging the device without creating restrictions such as the possibility of using the device, movement, and multiplicity of charged devices. This system uses device to device communication to identify devices with this capability and within the allowable range and prioritizes based on the amount of remaining charge. Using the resonant coupling circuit, the energy transfer operation is performed. The simulation results show the probable time to connect to the charging system between 10 and 20 s. Also, in exchange for the use of quality amplifiers, the performance increases dramatically, and this increase in performance is independent of user mobility. The advantages of this system and the possibility of using it in outdoor and indoor environments, maintaining the ability to move while charging and applying priorities based on the remaining charge of the device, and providing a premium version to users to have a higher priority for charging, combining with existing systems for better results and development The proposed system for other mobile devices, such as electric vehicles, is a future consideration.

Zhao et al. (2017) proposed a power storing and energy supplying system using radiofrequency. To make this system function, a wide antenna, which gathers energy, is installed on the recipient device. Here the goal is to increase efficient energy and fulfill the power usage. To fulfill this goal a programming difficulty rises, which combines the power consumption part and the subcarrier. Experimental results show that this new power depletion system makes an extension in the rate of energy reserved and supplied, especially when the number of users is higher than Device to device communication

4.4. Smart environmental systems

Air condition and water pollution are the important factors that state concrete challenges in the environment. Proper monitoring is required so that the world can deliver sustainable extension, by keeping a healthy community. In recent years, environment monitoring has converted into a smart environment monitoring system, with the approaches in the IoT and the improvement of advanced sensors. The smart environment is described as a new technology that presents several types of equipment and solutions for numerous environmental problems refer as water health and quality, air quality and pollution, resource waste management, and other environmental indicators. According to Fig. 7, IoT platform provides sensors and smart devices to gather and connect with other intelligent systems such as smartphones and smart applications by 5G or Wi-Fi technologies to send large volumes of data to the network and can enable us to have a better knowledge of our surroundings and obtain proper solutions for today's environmental difficulties (Weng et al., 2021).

In this subsection, four research studies have investigated to show the categorization of existing energy harvesting strategies for edge-based urban computing in IoT environments.

Jiyun, Hongxing, Zhicheng and Xiaodong (2018)s proposed a study on the inline vertical cross-flow generator for the harvesting of future hydroelectric power within water inventory channels for the production of electricity to water measurement devices. Exclusively, computational analyses were conducted on the block structure forms of the water generator device to establish the ideal structure. The observational findings showed that the computational approach used in this study is reliable enough to estimate the efficiency of this micro-water generator.

Ha and Phung (2019) provided a loT-enabled dependable control design for gathering solar energy in smart buildings' microgrid management. The proposed method is based on using loT and cloud computing, and optimization and control algorithms. The proposed method implements the hardware, a microgrid on the roof of a 12-floor building using a power velocity tracking system and a power velocity array renewable energy sources, as a testbed. Experimental results have proven the effectiveness of the proposed design and achieved the desired resilience and reliability. These developed loT-enabled dependable control systems due to their ability in well-timed self-recovery and omnipresent computing, are energy sustainable and fully tolerant.

Acarer, Uyulan and Karadeniz (2020) studied radial inflow turbines to show the abilities of Radial Wind Turbines (RWT) and also to present them as an alternative source of urban energy. For this purpose, they used machine learning algorithms such as Artificial Neural Networks (ANN) combined with Computational Fluid Dynamics (CFD) simulations to simulate the complex 3D flowfield of the turbines. For simulation, ANSYS is used and for the implementation of ANNs, the Simulink tool in Matlab is used. The results show that using RWTs for energy will result in increased safety for animals and humans, and also lowers noise compared to other turbines, with more durable and recyclable materials. Furthermore, a better Power Coefficient (Cp) is achieved compared to other turbines.

Bozorgchenani, Disabato, Tarchi and Roveri (2020) introduced an efficient method to increase a fog computing network's lifetime using solar panels. Since fog nodes usually use the battery as an energy source, a way to efficiently manage their energy can increase their lifetime. They used an Energy-Efficient Computation Offloading (EECO) algorithm for categorizing the nodes based on their cost and energy and then assigning them their offloading priority. This method consists of offloading the computation to edge servers and smart energy management to forecast the energy used and needed by the nodes. The authors showed that their method has increased the network lifetime by 20% compared to the fog networks with solar panels and 100% compared to the fog networks that don't use a solar panel.

Sharma, Haque and Jaffery (2019) presented an approach for the finite vigor layout difficulty by using the power collected from the sun to recharge the WSN's battery. This method uses the ZIGBEE network which also lets the energy collecting property even in old WSNs versions. The simulations have been done by using the NetSim simulator. The simulation results show that the presented method mounts the whole parameters. Sketching a method that also works with the physical address and routing substrates (layer 2 and 3 application layer). Enhancement of algorithms to decrease the energy used for the proposed method. Suggesting a more pragmatic framework for nimble farming supervision which uses IoT based vigor.

4.5. Smart transportation systems

Smart transportation is one of the most essential components of a Smart City design. It is an arrangement of technology that efficiently handles existing as well as new transportation systems, improving operational effectiveness, gaining protection, and reducing the transport demands of people at a low and efficient charge. It additionally gives a unique strategy in implementing various forms of transport, improved support, and more qualified traffic control solutions (Zhang et al., 2021).

According to Fig. 8, IoT in transportation is not only for traveling from one place to a different place, but it also makes it safer, greener, and more comfortable. For instance, a smart car performs work concurrently such as navigation, communication, entertainment, efficient, safer travel. IoT helps travelers to persist seamlessly connected to every means of travel. The vehicle is connected with a description of wireless types to the internet such as Bluetooth, Wi-Fi, 3G, 4G, smart traffic system, and even to other vehicles (Mi et al., 2021). Sensors built inside or outside a vehicle recommend lane departure and continuously observe objects at all sides to evade the crash. IoT elements of transportation spread beyond the car to interact other, allowing automate real-time decision to optimize travel (Souri & Norouzi, 2015).

In this subsection, we have analyzed eight studies to investigate the categorization of existing energy harvesting management techniques for smart transportation systems in IoT environments.

Pan et al. (2019) presented the plan, modeling, in-lab, and scope - experiment results of a compressed ball-twine-based electromagnetic power harvester with a mechanical movement corrector (MMR) system

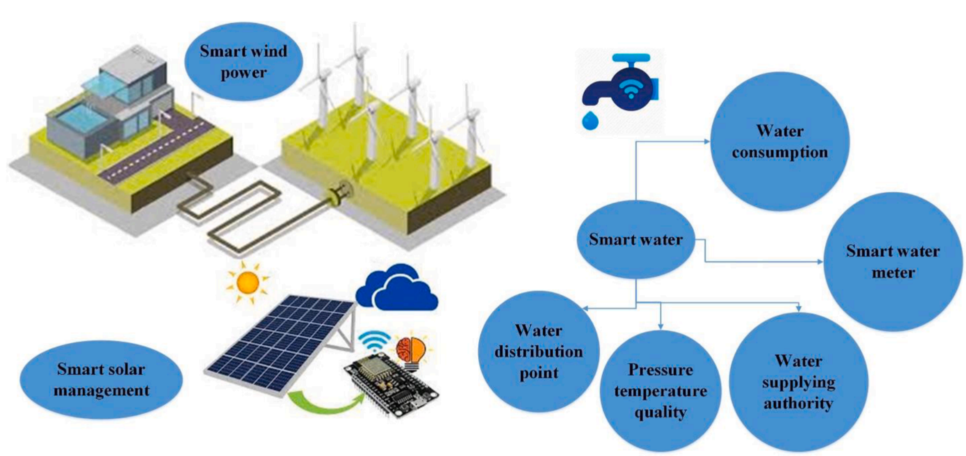

Fig. 7. Smart environmental systems intelligent urban computing in IoT application.

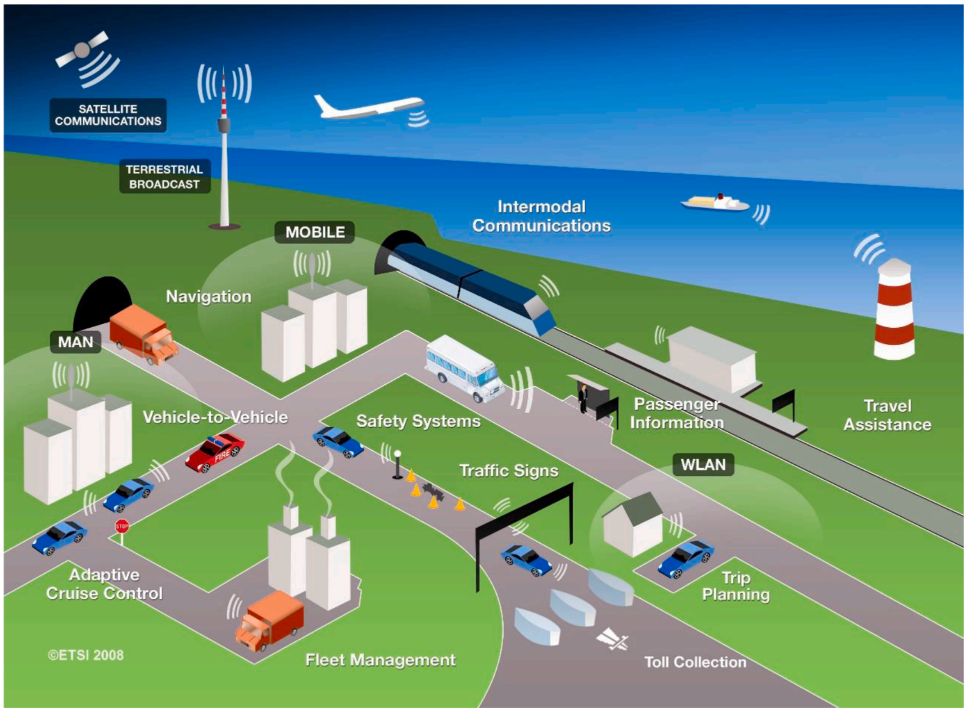

Fig. 8. Smart transportation for intelligent urban computing in IoT applications.

for clever railroad forwarding. A universal pattern thinking the train-rail-harvester interplay was expanded to break down the kinetic specification of the coupled device and foretell the power harvesting implementation of the harvesters at various train rates. Both in-lab and field experiments were done to test the power harvesting efficiency of the harvesters and execute the pattern. Ground experiment conclusions showed that the mean energy of 1.12W and 2.24W were attended. It is shown that the proposed ball twist-based power harvester operates as a stable more inert in equal with pre-compacted buffers and a tunable moderator keyed by a foreign resistive bar of the producer when the one-way clutch is in occupation.

Xu et al. (2019) provided a new transportation detection system that used the kinetic energy harvester method (KEH) in delicate transportation mode detection. This detection scheme is based on attention-based Long Short Term Memory (LSTM). The evaluation is done by using 38.6 h collected dataset and the categorization framework is compared with K-Nearest Neighbor (KNN), Naive Bayes (NB), and Support Vector Machine (SVM) machine learning algorithms. The evaluation results show that the proposed KEH-based method has high detection accuracy of over 97% and less power usage that excels the recent transportation mode detection systems. The weak point of this approach is the size of the proposed prototype is comparably bigger than common mobile devices.

Lee et al. (2008) proposed the Mob Eyes resolve for controlling civil monitoring in VSNs. They believed that Mob Eyes is a useful software that was precisely made controlling civil monitoring and elicit difficult mobility to spread information among close medium and to make a chip list to question monitoring information. It uses analytic patterns for Mob Eyes formality, assessments of efficiency as a practice of transport mobility, results of simultaneous utilization of numerous harvesting factors, valuation of net aerobic, and efficiency reliability of Mob Eyes in an encouraging civil exploring use. Matlab's software was used to assess the model. After analyzing data, they concluded that Mob Eyes could be shaped to get the most appropriate exchange between privacy /totality and aerial.

Gkoumas, De Gaudenzi and Petrini (2012) proposed a new method in energy harvesting subject which is generating required power for outdoors advertising structure by vibrant of wind in haul roads. The author's goal was to make advertising structures in haulage roads independent of power networks via using piezoelectric material in its structure. They evaluated the effectiveness of the proposed idea and mentioned that they just evaluated some of the sections of this idea and more sections need to be investigated. For future works, they raised the subject of generating required power for billboards in a traffic jam by the vibrant wind.

Gao et al. (2021) have presented an energy strategy prototype based on electromagnetic vibrations to provide the power of rail-side equipment. The authors considered three sections to explain their project. Their system consists of sensors and an energy collector which work stably in every weather condition it's one of the best features in their project. Accordingly, this system can be used for urban rail transit and tunnel railway. Authors tested their system in two models of wheels: the first model is rounded wheels and the second model is out of round (OOR) wheels. The experimental tests show that the author's methods are suitable for analyzing rail vibrations with OOR wheels. The provided methods are nature friendly and they decrease costs.

Boyle et al. studied divergent details about batteries activity in varied platforms by tracking them with data mule agent alongside Wireless Sensor Networks (WSN) appraising at issued aspects such as power lifespan and its durability, human robustness vulnerability to radio frequencies, connection mechanism, and sender fountainhead. The authors proffered a fresh scheme to enhance the mentioned aspects. However, it was merely theoretical owing to solitary retention appliance.

Pirisi, Mussetta, Grimaccia and Zich (2013) have presented How they can achieve the energy harvesting technology by using "piezoelectric and permanent-magnet" for energy generate energy from the speed of cars on the Speed-bump. They used some meta-heuristic algorithms in this paper. To produce this energy authors applied frequency engine, with relevant software for evaluation metrics. That it's should be used from meta-heuristic algorithms in the MatLab framework. All experiment result shows that generator converts only 85% of mechanical energy into the electrical that which equal 700W. The researcher concludes that this technology, in addition to optimizing energy, reduces "9" tons of greenhouse emissions.

Lan et al. (2016) presented a model to recognize the type of citizen's commutation which can be helpful in many areas such as measuring the CO2 produced by people. As most motion analyzer equipment are exposed to run out of charge repeatedly and that may lead to client frustration, the indicated model is based on Kinetic Energy Harvesting (KEH) which not only produces energy by locomotion but also estimates the commutation type whether the individual is on feet or using a conveyance (90/84% exact). They also can distinguish the type of conveyance in 85% of cases. These assessments take place by type and intensity of the voltage which has been produced via the equipment.

5. Discussion

This section provides a comprehensive and statistical report on existing energy harvesting management for intelligent urban computing in IoT. According to the defined questions in Section 3, we apply technical reports to respond to these questions as follows:

RQ1: Which energy harvesting management fields are analyzed for intelligent urban computing models in IoT?

Fig. 9 illustrates the percentage of existing approaches of energy harvesting for intelligent urban computing models in IoT. As observed smart cities monopolize the maximum percentage by 11 research studies. Smart transportation systems have 8; smart grid has 6 and smart home and smart environmental systems both have 4 research studies. Smart cities have more significant impacts on the energy harvesting management for intelligent urban computing in IoT. On the other hand, smart home and smart environmental systems both have 4 research studies totally, which means these approaches are still two open issues that could be solved in the future. Finally, developed metropolitan cities are investigating to research and implement smart solutions for smart cities environments to decrease energy and power consumption based on the IoT devices.

RQ2: Which optimization techniques and models are presented in this literature?

Based on Fig. 10, the heuristic-based method is used more than the other methods. According to the proposed taxonomy, the authors applied heuristic algorithms for evaluating energy harvesting management of smart cities, smart home, and smart transportation systems. For smart transportation studies, fuzzy methods were provided to examine energy management based on fuzzy logic models. In smart cities case studies, authors have evaluated the existing energy-aware approaches using fuzzy methods, heuristic, and natural-inspired algorithms. For smart grid management strategies, authors have applied heuristic algorithms, supervised machine learning methods, and natural-inspired techniques. Finally, a variety of applied optimization techniques are collected for smart environmental management. Authors used fuzzy methods, heuristic algorithms, unsupervised and supervised machine learning methods, deep learning, and natural-inspired algorithms. Also, researchers have implemented energy harvesting strategies for smart grid, smart environment systems, smart cities and smart transportation systems as a real data and benchmarks.

RQ3: What are the evaluation factors for evaluating the energy harvesting models in IoT?

Based on Fig. 11, the selected research studies were analyzed and assessed by main evaluation factors including energy consumption, throughput, response time, accuracy, precision, recall, F-score, and error rate. Eventually, response time, energy and power consumption, and accuracy factors have been evaluated in experimental results of the existing studies. Also, throughput had the minimum attention than the other factors. In general, we mentioned eight important factors, but other important factors could be evaluated, such as security, time complexity, and trust issues, performance efficiency, etc.

RQ4: Which tools and simulation environments have applied for evaluating intelligent urban computing in IoT?

Based on Fig. 12, we observed that eclipse environments with java language and MATLAB have been applied to the implementation and simulation of existing energy harvesting strategies in the intelligent urban computing.

6. New research directions and challenges

Based on the above technical reports and results, there are some innovations and research directions in the energy harvesting strategies that have not been analyzed comprehensively to cover the way for upcoming studies. We explain some open issues briefly as follows:

- Fault prediction has some open issues such as finding a deep relationship between energy consumption factor and fault points. Applying deep learning and federated learning approaches can be useful to support minimum failures in the smart industry and IoT (Lv, Qiao & Song, 2020).

  In the smart industry, historical-based prediction is an open issue to achieve the optimal accuracy of the estimation. Also, to prove the correctness of industrial maintenance, formal estimation models are considered as new open issues.

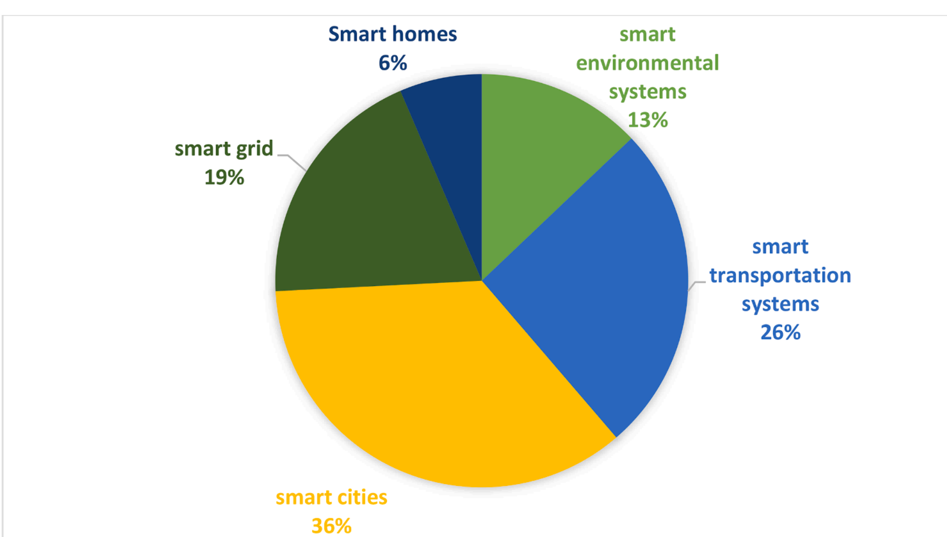

Fig. 9. Variety of energy harvesting management in the IoT.

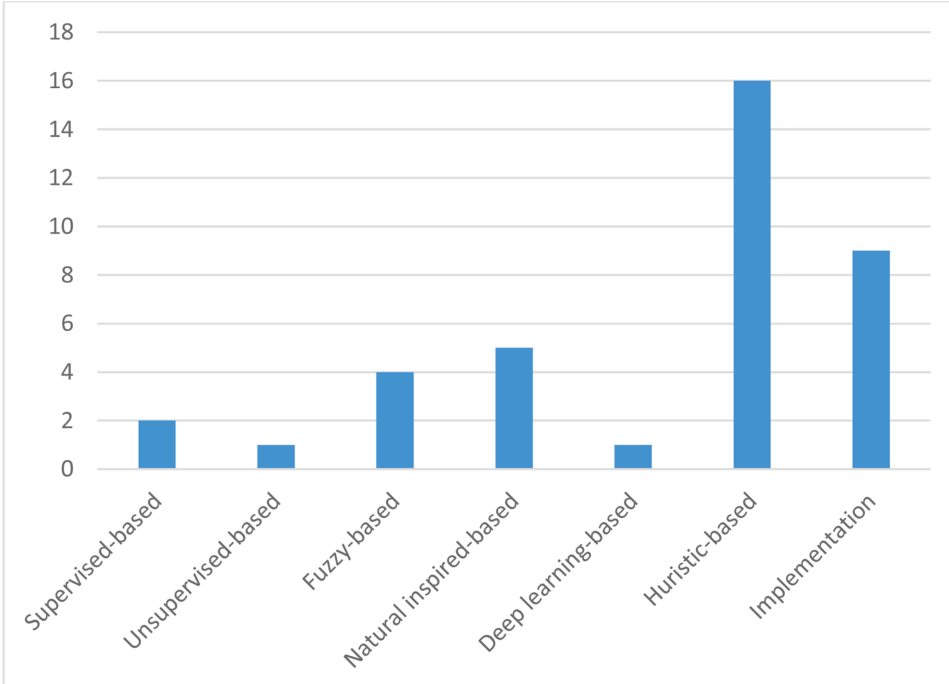

Fig. 10. Percentage of energy harvesting strategies for based on new innovations and algorithms.

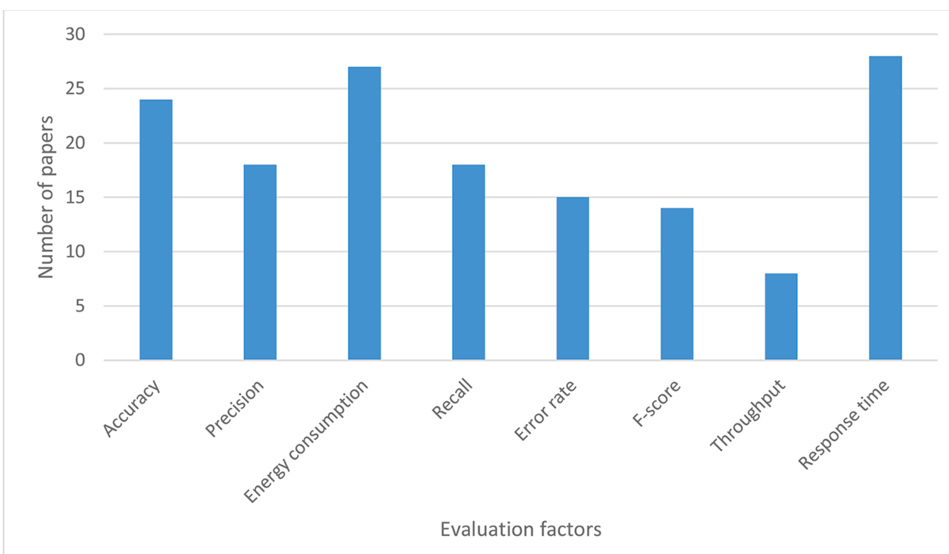

Fig. 11. Comparison of evaluation factors in the energy harvesting management approaches.

Time management in test cases and defect clustering are the main open issues in the energy-aware industrial IoT. Also, to achieve optimal quality testing, meta-heuristic testing methods can more consider for evaluating test cases in industrial equipment.

Energy-based healthcare architecture has some open issues such as secured data-centric clustering, data filtering clustering, and extracting dependency matrix for evolutionary aspects in energy management approaches in sustainable smart city.

Wireless sensor body area network is one of important issues to apply energy harvesting strategies for managing power consumption of sensor life and saving energy in mobile conditions. Also, safety and security can be evaluated for these topics based on energy consumption as a multi-objective scenario.

- Conceptual formal methods (Safarkhanlou, Souri, Norouzi & Sardroud, 2015) as one important evaluation techniques can be applied to check correctness and validation of energy management procedure for smart home applications. Some of critical points of this issue are reachability of on/off electricity status, deadlock-free position for renewing energy harvesting based on solar panels and proving fairness condition for locking doors and parking shelf doors (Souri, Rahmani, Navimipour & Rezaei, 2019).
- Big data analysis is a new challenge for managing energy consumption in industrial equipment and manufacturing environments (Lv et al., 2021). Some new evolutionary algorithms such as deep learning and machine learning can enhance accuracy of decreasing energy consumption for industrial environments (Lv, Qiao, Li & Song, 2020).

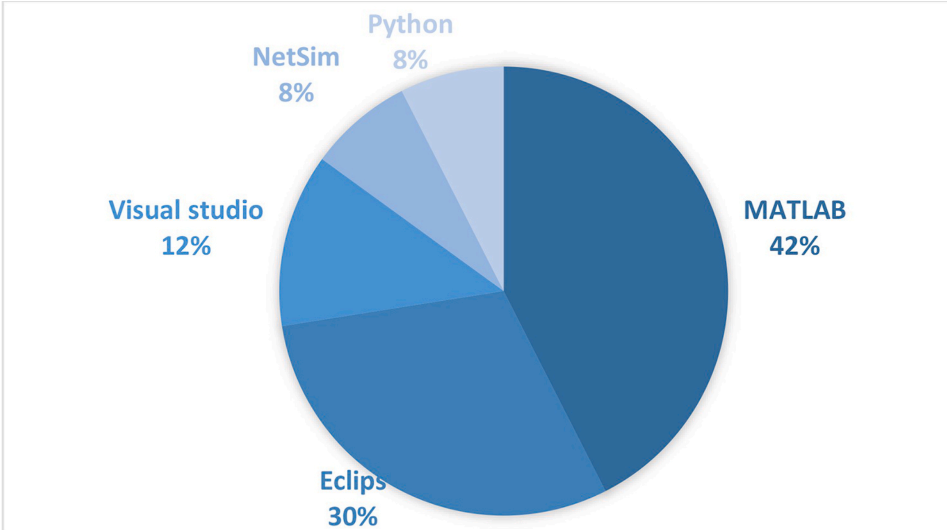

Fig. 12. Comparison of simulation and implementation environments for this literature.

7. Conclusion

The use of the energy harvesting strategies for managing power saving and energy consumption in the intelligent urban computing has an important impact to increase the performance, efficient management, and accuracy of the smart applications. This paper presented a technical review on the energy harvesting management strategies for intelligent urban computing in the sustainable IoT from 2008 to 2020 that 33 research papers were selected for the technical analysis. We observed most existing papers in this field were published in 2019. IEEE publication with 55% has the highest published papers. Springer and Elsevier have the number of papers with 25% and 14%. We classified 33 selected research studies in 5 classes in the categorization of energy management strategies that smart transportation systems has more significant impacts in energy harvesting management of IoT applications. On the other hand, smart grids and smart home have 6 research studies totally, which means these approaches are still two open issues that could be solved in the future. There are many challenges should be analyzed and discussed in the energy harvesting strategies for intelligent urban computing using deep learning, federated learning and evolutionary algorithms.

Declaration of Competing Interest

All authors declare that there is no conflict of interest between each position of author in list, writing and main contributions of the paper.

All authors have approved the manuscript and agree with its submission.

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