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Energy management solutions in the Internet of Things applications: Technical analysis and new research directions

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Abstract

By advancement of Internet of Things (IoT) technology in smart life such as smart city, smart home, smart healthcare and smart transportation, interconnections between smart things are growing that complicate evaluation of efficiency factors on the intelligent systems. Energy consumption as one of the most challenging issues is increasing with the growing IoT devices and existing interconnections between cloud data centers, mobile applications and human activities. Managing energy efficiency and power consumption is one of the important issues in green IoT-enabled technologies. This paper presents an overview on the energy management solutions in the IoT based on Systematic Literature Review (SLR). The main goal of this SLR-based overview is to recognize significant research trends in the field of energy management and power consumption techniques which need additional consideration to highlight more efficient and effective methods in IoT. Also, a taxonomy is proposed to categorize the existing research studies on energy management solutions. A statistical and technical analysis of reviewed existing papers are provided, and evaluation factors and attributes are discussed. We observed that variety of published research papers in smart home have highest percentage to evaluate energy management in the IoT. Also, deep learning and clustering methods are must popular techniques that were applied to evaluate the energy management in IoT case studies. Finally, new challenges and forthcoming issues of the energy management and efficient power consumption methods are presented.

Keywords: Internet of Things; Energy management; Smart devices; Green energy computing; Power generation

1. Introduction

Today, Internet of Things (IoT) systems are used for connecting a various collection of smart devices, cloud data centers, fog nodes and mobile applications in many smart environments (Al-Turjman and Baali, 2019; Ahmad, 2020). Also, IoT applications provide an upper boundary of cloud-edge services for improving people's daily lives by supporting cost-efficient and energy saving solutions on various communication strategies such as device to device, device to application, and device to cloud (Souri, 2019; Yan, 2020). Energy-efficient solutions in some case studies of IoT environments such as smart cities, smart transportations, smart home-care, and smart grids focus on energy saving management and improvement of power

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consumption in the IoT ethics (Zahmatkesh and Al-Turjman, 2020; Naranjo, 2019).

In the recent years, many research studies applied intelligent techniques, Machine Learning (ML) methods (Qadri, 2020; Deng, 2019), formal methods (Souri and Norouzi, 2019) and meta-heuristic algorithms (Chen et al., 2019; Chen, 2019) to examine the development of energy efficiency management for cloud-edge computing in the IoT environments. Also, there exists the challenge of continually providing optimal Quality of Service (QoS) by guarantying the Service level Agreements (SLAs) in energy consumption solutions (Safara, 2020). Based on increasing human usages to smart devices and IoT applications on smart phones, energy management concept is an important issue for decreasing cost of energy consumption in IoT environments (Safara, 2020; Jesudurai and Senthilkumar, 2019). According to existing review and survey studies (Bedi, 2018; Shrouf et al., 2014; Roselli, 2015; Reka and Dragicevic, 2018; Khajenasiri, 2017; Abdullah, 2016), there are some limitations on the presented discussions on energy efficient overview as follows: (1) Providing energy efficient solutions on just single case study of IoT environment such as healthcare monitoring or industrial equipment; (2) There is no an overview on the energy management solutions in IoT environments; (3) Ignoring methodological taxonomies for categorizing energy efficient solutions based on technical aspects and approaches; (4) Omitting technical analysis on energy efficiency features and opportunities in IoT environments.

To overcome the above mentioned gaps, this paper provides a systematic review towards technical evaluation, challenges and opportunities of the relevant research studies on energy management solutions in IoT environments. Then, an empirical exploration is presented potential efforts for evaluating technical aspects of each relevant study. Finally, this review provides a wide opening perspective on the development and progression of energy management techniques in IoT environments.

The important contributions of this review are presented as follows:

- Providing a relevant collection for existing energy management research studies in IoT environments based on Systematic Literature Review (SLR).
- Presenting evaluation analysis on technical aspects of each research study based on primary research questions.
- Discussing new challenges, open issues and research directions on the energy management techniques in IoT environments.

This paper is organized as follows: Section 2 provides a research selection methodology according to the SLR for presenting energy management approaches in IoT environment. Section 3 illustrates a technical taxonomy for existing energy management solutions and techniques and a technical analysis and summery for existing research studies according to the proposed technical taxonomy. Section 4 presents a discussion according to existing research studies in energy management solutions. Section 5 presents open issues and new challenges on the energy efficiency techniques on the IoT. Finally, the conclusion is illustrated in Section 6.

2. Research finding approach

A systematic review of the literature energy management solutions on IoT applications was conducted. The presented review focused on identifying potential benefits and techniques of energy harvesting, energy consumption, energy efficiency, and green energy computing for smart environment such as smart city, smart home, smart transportations and smart grid in IoT secured applications. A research finding method was executed over existing scientific electronic databases including ACM, Springer, Elsevier, Wiley and IEEE. The main targeted keywords "*Energy management*" *and "Internet of Things*" *or "IoT*", along with their possible variations and synonyms, were used for executing this finding method.

In first phase, the research finding method for existing research studies was applied with selection of studies based on matching main title, abstract and keywords. In initial screening, we found a total of 2151 papers according to SLR. In second phase, followed by selection of paper by full-text reading of the filtered studies, 30 research studies were chosen as main domain of technical analysis. According to Table 1, a variety of published papers per year with existing publishers are shown.

In inclusion criteria, the following basis roles were influenced on the final research studies selection:

- Selecting research studies that discussed energy management or power consumption strategies in IoT environments.
- Selecting research studies published in English.
- Selecting high potential contexts on the papers based on peer reviewed procedure.
- Choosing research studies that were published between 2013 and 2019.
- Selecting just research papers related in this field and ignoring books, thesis and report papers.

Due to the above basic roles in inclusion criteria, our systematic review analyzes and assesses the technical aspects of energy efficiency management and green power consumption solutions on IoT environments. Based on the following primary analytical questions, this paper intends to answer are:

- AQ1. What are the strategic details of improving energy efficiency in IoT environments?
- AQ2. What are the evaluations factors effect on the enhancement of energy management in IoT?

Table 1
Variety of published papers per year with existing publishers.

Publisher	Number of published paper	Year (number of papers)
IEEE	16	2013(1), 2016(1), 2017 (6), 2018(3), 2019 (5)
Springer	7	2015(1), 2016(1), 2017 (1), 2018(4)
Elsevier	7	2016(1), 2017(1), 2018 (1), 2019(4)

- AQ3. Which technical methods and algorithms were applied to enhance energy efficiency on the IoT environments?
- AQ4. Which evaluation environments and tools applied to assess energy efficiency management in the IoT environments?
- AQ5. What are open research directions and new challenges and efforts on the improvement of energy management in IoT?

3. Energy management solutions in IoT

In this section, a taxonomy is presented to illustrate technical aspects for energy management and green power computing solutions in each IoT environment. Fig. 1 illustrates our proposed taxonomy for energy management solutions in IoT extracted from the literature reviewed. There are six categories for applying energy management and power consumption solutions in Io environments that are presented in this section including smart home environment, smart grid, smart energy harvesting environment, smart cities environment, smart industry environment, and smart building. In the following each subsection, a brief description of the smart environment is presented according to energy management solutions. Then, a number of researches reported using each of the approaches are introduced one by one. For each of the studied introduced, the main idea, the applied case study, the applied algorithm, the evaluation environment, and evaluation factors are extracted and outlined in an analytical table at the end of each subsection.

3.1. Energy efficacy solutions on smart home applications

This subsection provides a discussion on the existing energy and power efficiency management for smart home environment in IoT. In this category, 7 research studies

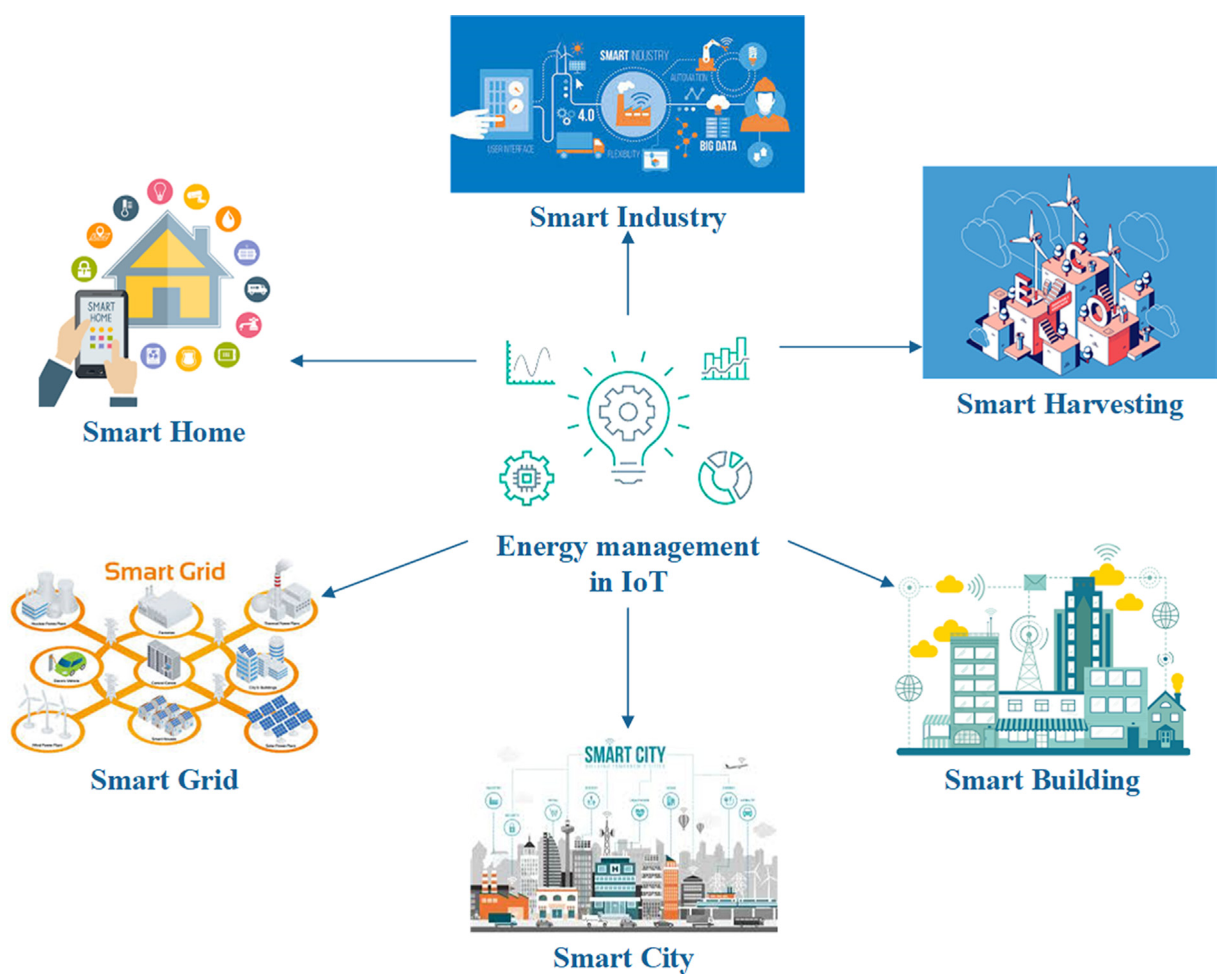

Fig. 1. The proposed taxonomy for energy management solutions in IoT environments.

are presented and discussed on technical aspects, advantages and weaknesses respectively.

Al-Oudat et al. (2019) proposed a method for energy management of electrical appliances at the peak of consumption, protection of electrical appliances against destructive currents and reducing costs that consumers have to pay. The authors developed a device that is connected with each household device to energy flow, and during 24 h it examines the performance of electrical appliances within different time ranges, calculating the amount of energy consumed by collecting data and smart processing. To perform computations in this machine, a small board is designed using EasyEDA program that consists of a micro controller, WiFi module, flow sensor, and power supply. The problem in this approach is that the consumer must not use some electrical appliances to keep the energy consumed during peak consumption. To overcome this problem, a list of electrical appliances that can be disabled at the peak of consumption is represented by the consumer, using the list and the rules provided by the Electricity Distribution Company, which includes the price list of the amount of electricity consumed at different consumption ranges, and gives the user the information to modify consumption patterns. The authors have not presented an algorithm in this paper, compared with a graph showing price - to - energy ratio and compared the impact of using the machine by not using the device.

Al-Ali (2017) designed and evaluated of an energy assessment system based on communication protocol like MQTT in IoT environment and Big Data for smart homes. The proposed energy management system (EMS) uses the analytics Intelligence Business (BI) to better energy manage. Proposed method uses benchmarking for data mining and also uses Business Intelligence tool to generate graphs, charts and reports in real time. The designed system is set up to launch new ways to manage smart energy in the context of IoT and Big Data and allows users to remotely control and monitor devices, and generate online bills through a user-friendly mobile application. Proposed method pays more attention to speed and security than previous works on energy management systems that used wireless sensor network (WSN). Many criteria such as scalability in MQTT servers, speed measurement in databases and storage have been developed to evaluate system performance.

Cho (2013) presented this article to introduce a mechanism to reduce the energy consumption of home appliances using the IoT. The system is built on the Android platform using Java and it's algorithm architecture consists of three parts, the first part is "heterogeneous network end device module", which is a structure that converts the protocols of different devices into identifiable protocols for other devices and the management system, the second part is "electric appliance-oriented middleware module", the middleware module is a sub-module and the most important part of the main architecture of the general system which uses software to make connections between devices that use different protocols, and the third part "activity recognition bundle" is used to classify devices usage and energy consumption by positioning sensors. This system is evaluated on home appliances in a smart home at different time intervals. This mechanism can be implemented by means of communication methods between electronic devices with internal and global Internet, such as Bluetooth, ZigBee, etc. finally the precision and recall of energy consumption for 4 activities were evaluated. It should be noted that the weakness in this study is intelligent control i.e., accurately identifying the functionality and energy consumption of all machines simultaneously, to this end, predicting user activities and using a recognition model with hybrid data such as image and location are proposed for future study.

Li (2018) proposed implementation a method for Self-learning Home Management System (SHMS) based on machine learning in IoT environment. The suggested method has features such as power alert, price clustering and price predictions, which have been implemented and developed by machine learning technology. In the proposed method, the authors used a house to simulate system design which in these house a smart plugin is used to monitor power consumption and also used data analysis to optimize power consumption according to the homeowner's habit. In this article, the authors introduce a system that can monitor the amount of electricity consumed and optimizes homes by reducing the extra load on the power supply and reduce consumption costs.

Naik and Patel (2018) have proposed an administration system for smart houses that originates from the Internet of Things. The algorithm used to perform this operation is JSON. After sending the data to the server, filters are applied through this algorithm and the obtained data is stored. The suggestion is that smartphone apps or databases connect to and manage microprocessors, sensors, and Internet-enabled devices via web servers. And the tools that make this possible are Xenserver and microcontroller board. The authors implemented the proposed system for final evaluation and tested it for several months. They compared the results of their work with other existing systems through cost and speed metrics, reliability and energy consumption, and demonstrated the efficiency of their system. As a strength of the proposed article, it should be noted that the proposed management system can check the climatic conditions of the region and adjust the room temperature automatically, but on the other hand, in this article, no plan has been proposed to ensure the security of the system.

Park et al. (2018) investigated about miscellaneous sorts of anticipated risks and factors that affecting risk perception of IoT in the field of home energy management. They also analyze variables of demographic. The perceived risks contain risks of security, privacy, financial, electromagnetic radiation (EMR), etc. The most effective factor among them is Perceived EMR. In particular the authors considered about person inclination that contain sensitivity to changes in electricity costs, environmental degradation, etc. Furthermore, two important factors are Electricity price changes and new technology adoption. Users are probably afraid of EMR although researchers identified a weakness of ICT services is threats of cybersecurity. Nevertheless, as examining relevance of Demographic variables with risk perception that received a lot of attention, more researches are desired.

Rashid (2019) proposed a smart home energy monitoring system accommodating CIOT that includes a smart plug based on Raspberry Pi that serves as the gateway which can read ongoing data from each home instrument, load the educated scheme using educating server and examine the confirmed data from the scheme and Google Colab as the educating server to be used for reserving the educating data set and making the Long Short-term Memory (LSTM) scheme based on TensorFlow. This development completes machine learning to help managing household's energy utilization, hopefully appropriate energy utilization habits can be engendered. Briefly this scheme leads machine learning to create systems for managing energy and build a more cost-effective way for users in a world where is increasingly effecting by global warming.

Table 2 describes a side by side comparison for technical and main features of energy management solutions in smart home environment. Existing case studies such as big data, activity recognition for home applications, tactile Internet and context-aware management were applied for smart home environment.

3.2. Energy harvesting methods in smart environments

Energy harvesting is one of important issues in IoT environments for managing energy saving and battery lifetime and finite battery capacity to permit mobility conditions of smart things (Garg and Garg, 2017). Due to environmental aspects such as machine to machine and human to machine interactions in IoT environment, energy harvesting features can use some power generation environments such as solar, wind and thermoelectric resources. In this category, 5 research studies are presented and discussed on technical aspects, advantages and weaknesses respectively.

Ashraf (2019) presented a method high accessibility and low delay in harvesting IoT sensing devices based on integrated energy management and data rate. Given the energy constraints on nodes and to avoid touch communications delays, the main idea is to integrate data rate control and energy management to obtain IoT devices energy until the nodes are always alive. Author used three models: A-Model linear, B-Model nonlinear, C-Model and MATLAB simulator software to demonstrate the effectiveness of integrated data rate control and energy management. the advantage is that The data queue is set based on the number of nodes and the energy queue is based on the capacity of the data queue, so controlling the energy queue ensures a secure connection to keep the nodes connected.

Carreon-Bautista et al. (2016) have proposed a low and independent power management unit (PMU) that is capable of tracking maximum power point tracking for renewable resource. These include solar, geothermal, and biomass. In this system the output voltage is regulated by a digital system using the dc - dc converter of the measured units. It operates in a fully self-governing system, charging / adjusting with minimum power consumption and allowing the operation of low voltages by the start block. Maximum power extraction is done through a purely digital mppt model. The system was fabricated using a 180 nm CMOS process and maximum end - to - end efficiency was measured at 57% with 1.75 mW of input power.

Ju et al. (2018) have suggested a new power management framework for kinetic energy based on human motions in IoT environment. This framework includes offline improving algorithm, online connected sink selection and a module controlling power of transmission to maximize power of generated energy by human. The main idea is to calculate consumed energy by a human, with help of IoT wearable systems. Each movement of a human has a different frequency, so it is difficult to design a model to reach to a better daily kinetic power, this paper uses a new way to improve used kinetic power by comparing the resonant frequency to normal motion frequency. Authors have used a wireless transceiver to get data and send them for other calculations. A VDGR (Velocity Damped Resonant Generator) model used to convert human energy to digital frequency. The advantage is that with comparing other methods, the suggested method can create more kinetic power. The suggested kinetic harvester algorithm that have been used, reaches better results than others in power of understand human behaviors.

Mondal and Paily (2017) presented an architecture of self-powered IoT nodes for managing solar energy on a small scale based on power transformers in order to get higher end-to-end output. The main idea is to process the energy used only once before it reaches the Orbit, regardless of the environment, unlike traditional architecture, which processes the energy of harvest twice. Author uses 0.18-μm CMOS technology to simulate and design an energy system and used MOSFET models for Post-layout simulations. The advantage is that the performance of the architecture presented in the system has increased significantly compared to traditional architecture, and also the simulation of the circuit shows that it performs better in different lighting conditions.

Tsenempis (2019) presented a model support green recyclable energy in order to provide energy for IoT systems, so, the renewable sort of energy will be gradually replaced with the conventional. They may render the system a sufficient amount of energy and also save it for future demands. It can utilize green energies like solar fuel beside non-renewable energies. They also provided a scheme to organize the usage and optimize the consuming fuel. Moreover, they optimized battery usage by developing the rank of battery charging and preserving it. Future works, includes promoting the indicated method in terms of energy saving,

Table 2
A side by side comparison for technical aspects of energy management in smart home.

Reference	Case study	Infrastructure	Applied algorithm	Evaluation factors	Applied tool	Evaluation method
Naeem Al-Oudat 2019	Energy Management at Home	IoT Devices	–	Price-Energy	–	Design
A.R. Al-Ali	Smart Home Energy Management System (EMS)	IoT Device	–	Security, energy	–	Implementation
Wei-Ting Cho 20 May 2013	Smart House	Iot device Android	Hybrid	Accuracy Energy Consumption Power consumption	–	Implementation
Weixian Li	Smart Home SHMS	IoT Device	–	electricity costs, energy consumption	smart plugin (Z-Wave UK Plug-in) (Z-Wave Vera Edge Plug-in)	Implementation, Simulation
Kevin Naik et al. 2018	IoT based smart home management system,	IoT devices,	JavaScript Object Notation (JSON),	Reliability, Cost, Speed, energy efficiency,	Xenserver, MIT App Inventor, microcontroller board,	Implementation,
Chankook Park 2018	Smart Home	home energy management services	multiple linear regression	Energy Security Cost		Data mining
Rozeha A. Rashid 2019	Smart Monitoring	Smart Energy Monitoring	Machine learning	Cost/ energy		Data mining

power control and increasing the efficiency of RF harvester.

Table 3 shows an analytical comparison on technical aspects of energy management and power generation solutions in smart harvesting environment. For smart harvesting environment, some case studies such as personal kinetic energy management, autonomous power management, tactile Internet and solar power management are applied to maximize power efficiency and decrease energy consumption.

3.3. Energy management techniques in smart cities

Green energy consumption is very important issue in smart cities for decreasing environmental pollutants likes CO2 emissions. Managing energy consumption is a critical challenge in side of electricity systems such as smart highway lighting system using auto-parking chargeable devices and side of mobile applications such as managing town lighting systems using remote mobile applications and smart gadgets. In this category, 5 research studies are presented and discussed on technical aspects, advantages and weaknesses respectively.

Kamienski (2018) presented a system that works by Traceable graphical contexts for managing data based on scalable IoT systems in smart cities. The designed diagrams are the basic concept to illustrate the approach of this system. An application has presented where context ideas and designs are implemented. This article intends to provide an environment that these designed contexts by users should be tracked and also this system must protect the data. This system has been tested in various statuses such as error detection, revision and review of system performance goals. The scope of the context awareness framework in this system is low, and its improvement requires to additional tissue entities.

Liu (2019) have proposed a focus on the design of a Deep Reinforcement Learning (DRL) based energy efficient model for fog nodes in IoT environments. First of all, this article describes the energy management in smart cities. The software model of an IoT-based environment is proposed by edge computation. Because IoT system are applied in smart cities, a complex environment has many problems to detect and carry out reliable control measures accordingly. Accordingly the emerging DRL as a promising technology. Which consists of the construction phase of the deep nervous network (DNN).

Vinueza Naranjo et al. (2018) provided a model for minimizing network subscribers and managing the energy scale and processing speed of virtual processors. The designed architecture based on virtual network exchanges of containers are the main concept of this model that uses container motors energy. To build this architecture, interconnected clouds are used, with which servers and clients can easily make exchanges. The purpose of this architecture is to minimize delays as well as facilitate users' communication for exchanges. The positive point in this article is this that the performance of the architecture in question is tested, then compared to the performance of other resource managers, and finally implemented. This architecture has only been tested virtually, and by taking hardware tests, the results of both can be compared and the best energy performance can be obtained.

Ryoo (2017) and his group proposed an energy organized MAC project for IoT ecosystem framework this framework includes mobile IOT sensor devices. These mobile sensor devices gather all the requested data when they move and move the gathered data to the sink node. The used energy of these sensor devices depends on length from the device to the sink node. This energy also effects on existence of IoT ecosystem. Proposed framework, 3-D GM MAC scheme, show the supreme act of energy effectiveness for IoT ecosystem. The proposed framework can also be useable in different environments like IoT, big data, and cloud and fog computing. The results show that the framework improves the energy regulation of the whole IoT ecosystem. The simulation was on C++ program, MAC and MFC environment.

Sodhro (2019) provide two algorithms named as HABPA and DSA to obtain the aim of creating green and resistant smart cities. The facilities of smart city is extended into variant sections of society such as health care system, industries, media streaming etc. equipment collaborate with each other by IOT, however they consume a significant amount of energy, hence they created those indicated algorithms (HABPA and DSA) to make a balance between energy resources and systems' requirement, preserving smart city's' efficiency and avoiding data loss. They also made effort to benefit recyclable green energy sources instead of the imitated one. Results demonstrate a good efficiency of both algorithms but there are still several challenges left; involving with buffer area, the amount of consumed energy raises. In the future they will extend developed technologies into health care system.

Table 4 shows an analytical comparison on technical aspects of energy management and power generation solutions in smart cities environment. In smart city environment, context-aware power management, edge-based service scheduling, 3-dementionalMAC protocol and hybrid adaptive bandwidth mechanism are applied for managing energy consumption in IoT environment.

3.4. Energy efficiency approaches on smart building

Today, commercial building environments have hot points by focusing on managing urban density, minimizing power consumption and energy monitoring and controlling in smart building. In this category, 5 research studies are presented and discussed on technical aspects, advantages and weaknesses respectively.

Le et al. (2019) introduced a prosperous business pattern in Vietnamese to evaluate an IoT start-up and to create a production business pattern for managers. The researches results of CYFEER and its main result CyHome SMS supplied intelligent concepts for IoT-oriented start-up in totally special and necessary providences. CYFEER strategies helped the market find a way and standard for other service suppliers to attain their outputs without any technical obstacles and with minimum costs by helping to build a dynamic network for other applications based on IoT at a SaaS platform service that different partners could attain their outputs in a joint platform. Partners could also be potential providers who invest on CYFEER channels to start being in the market by attaining different services related to IoT. The corporation also created the development way and new clients by using bottom-up and resident oriented methods. By making the opportunity to change and ruining the old market they could train proficient operational and technical personnel. They tried to experience their costumers' perspectives to have deeper understanding of their activities.

Minoli et al. (2017) have proposed a survey on created chances by IoT and problems which it has to deal with in smart flats. The idea that is followed by this research is to maximize the IP-aware devices to be managed by IoT facilities. Having a same physical communicating system and a basic communicating protocol for all devices is an important solution for that. In this paper, a BMS system have been used to observe and Integrated control of different parts of a flat, and coordinate them to optimize consumed energy. The key feature of this article is how to use IoT system to manage consumed energy in a flat, for example we can make use of intelligent lightening(PoE and PoE++) and HVAC (Heating, Ventilation, and Air Conditioning) system. The advantage of this work is to define architecture styles and needed thing for using IoT in different flats. But the disadvantage in not considering all aspects of implementing IoT and not covering all IoT systems.

Terroso-Saenz (2019) have designed the IoT energy platform (IoTEP) to resolve energy operation problems including the high amount of consuming and wasting energy in the houses. They believe that there are not enough methods to resolve the existing challenges in that field, For instance, sensing system of apartments are not capable to control the energy loss. Therefore, they started IoTEP approach which optimizes the organization of energy in buildings by data probing, energy saving predicting the required energy. IoTEP not only avoids energy loss significantly, but also is capable to benefit personated energy criticism for further developments. In the future, other schemes can be synced with the presented approach. They hope that these combinations would lead to obtain better results in this zone.

Yu (2015) presented an approach which tries to optimize energy consumption in buildings, preserving the comfort of residents, in order to gain this purpose, they designed a system based on cloud computing and IoT, and used CFS algorithm. These infrastructures, not only provide cooperation among sensing devices of the building and enhance their output, but also improved the organization system of the smart building. Authors benefited BMC server to

Table 3
A side by side comparison for technical aspects of energy management in smart harvesting.

Reference	Case study	Applied algorithm	Evaluation factors	Applied tool	Evaluation method
Nouman Ashraf 2019	IoT Solar-power Harvesting	-Model linear -Model nonlinear -Model Asim	Energy, time, Capacity	MATLAB	Simulation
Salvador Carreon-Bautista 2016	Harvesting Power Management for IoT Applications	maximum power point tracking (MPPT)	Cost, energy. Efficiency.	–	–
Qianao Ju	Harvesting energy by IoT wearable sensors	off-line optimization algorithm	Average transmission cost	—	Simulation
Saroj Mondal	managing solar energy	MOSFET models	Output power, Output voltage Time, efficiency	CMOS	Simulation
TSenempis 2019	Smart city Smart home	–	Energy Power Efficiency	–	Implementation

choose a suitable device specification subgroup and they could successfully reduce a significant amount of energy, thanks to this method. In the future they will put effort on anticipating the amount of consumed of energy in buildings and consider some analysis in that area.

Yu (2016) provided an architecture which contains several Web of Objects (WoOs) to prevent devices and objects resistance to automatic connection and cooperation applied to IoT. They employed fog computing environment to depict service implementation structure over smart home IoT framework. A specific WISE management platform has been proposed which allows all of devices and objects. Presented method in this paper provides various devices and item of web services including service combination and constitution, object and service management, device fault tolerance, error handling and context administration, with device database and object profile and sensing value from WISE GW. The research team asserted that their recommended approach permits to make up all appropriate items or services suiting an arriving user appeal, and decrease the grouping cost by curbing pointless object or service-petition matching operations. The proposed location data likes weather statistics and other atmospheric data have been used in this investigation, and smart building energy prognosis has suggested based on sparse representation (SR) strategy. This minimization issue has been resolved in polynomial time utilizing standard linear programming technique.

Table 5 shows an analytical comparison on technical aspects of energy management and power generation solutions in smart building. Some case studies such as skyrocketing market perspective, power over Ethernet, virtual temperature monitoring and air-conditioning-based energy consumption prediction were applied to smart building environment in IoT environment.

3.5. Energy and power management in smart grid

Managing electrical power generation and monitoring power supply have important roles in smart girds to enhance energy efficiency in IoT environment. In this category, 4 research studies are presented and discussed on technical aspects, advantages and weaknesses respectively.

Amarnath and Sujatha (2018) suggested a system of monitoring that save power by using WSN. They observed load side power and sent those data to the monitoring section. The module of IoT controls the solar panel every three seconds and the power consumption is minimal. The application of web browser shows defective solar panel with using IoT. The voltage is within 5 V and 25 V in the experimental sector, whenever changes from 0 V to 5 V are observed at the output voltage by the voltage sensor. Based on the load valence the power provenance solar boards are connected or disconnected. Grid could make changes in dynamic load and power source could be changed matching with the load on the grid. The power source in the grid must exceed the load capacity of +50% to with-

Table 4
A side by side comparison for technical aspects of energy management in smart cities.

Reference	Case study	Applied algorithm	Evaluation factors	Applied tool	Evaluation method
Carlos Kamienski	Scalable IoT systems in smart cities	Tracking Algorithm	Context Tracker Performance	–	Design
Yi Liu, (2019)	Edge Computing for IoT - Based Energy Management in Smart Cities	DRL algorithm Q-learning	Cost Energy-Delay comparison energy		Design
Naranjo 2018	Cloud-IoT based study for reducing delay	PABP resource management algorithm	Energy		Design
Intae Ryoo 2017	Energy efficiently on mobile sensor device	topology control algorithm technique	The maximum distance that the sensor node can communicate, energy of the sensor node, f transmission distance reference and etc.	Application distance of ZIGBEE, C++,	Simulation
Sodhoro 2019	Smart city	HABPA DSA	Energy Bandwidth Delay time	MATLAB	Simulation

stand sudden load changes. Then another power supply is added to the network when the changes in each load current close to fifteen percent of the total grid capacity. General power provenance is schemed to the highest load valence and based on the load existence dynamic power provenance is joint in the lace. Eventually the authors confirmed by achieved result from the data that the projected mechanism is better than the usual systems.

Li et al. (2018) proposed a solution to enhance security related to the active distribution network (ADN) against different cyber-attacks. Traditional intensive energy management schemes against cyber-attacks are highly vulnerable, suggesting a secure decentralized energy management framework against cyber-attacks, the proposed framework can secure the communications of the IoT devices in ADN using the network technologies defined by the software as well as improve the performance of each machine. In this paper, it is suggested of distribution system operator (DSO) has been used to manage operations related to the activities of distributed power systems, and software defined networking (SDN) technologies have been used to secure data streams. This paper presents a view for the use of operational technologies such as energy, decentralized, management and information technology edge technology, soft defined networking and blockchain for automatic, efficient. This paper presents a view for the use of operational technologies such as energy, decentralized, management and information technology edge technology, soft defined networking and blockchain for automatic, efficient, and secure distributed power management activities and can play an important role in enhancing productivity, reliability, flexibility and sustainability of energy services in the activities of power distribution systems.

Pawar and TarunKumar (2020) proposed an intelligent energy management system based on IoT without constraining and limiting energy consumption for renewable sources. The proposed system is designed and implemented to demonstrate the evaluation of different models.

Tom et al. (2019) provided an IoT-fog based method, in order to analysis and manage energy consumption and move to extend environment-friendly, green energy usage. Since IoT facilitated homes and devices to be connected to the internet, it is possible to collect information about consumption status, residents' requirements, high consumptive devices, peak hours and the costs produced by each of them. Hence by these measurements they can detect the energy consumption template of smart homes which leads to anticipating the approximate energy utilization, peak hours and resident requirements for the next 3 days and broadcasts the results to the users by demand response (DR) program. These analysis follow the purpose of mitigating energy usage in peak hours and reducing the consumption and outcome costs. The residence may allow the utilities, manage and auto-control devices as well.

Table 6 shows an analytical comparison on technical aspects of energy management and power generation solutions in smart building. For smart grid environment, some case studies are used to manage power efficiency and decrease energy consumption such as solar power management, blockchain-based transitive energy management, renewable energy generation and intelligent power metering.

3.6. Power and energy efficiency solutions in smart industry

Power sustainability and energy efficiency solutions in industrial equipment have managerial role in smart industry and manufacturing environments. In this category, 4 research studies are presented and discussed on technical aspects, advantages and weaknesses respectively.

Kiran et al. (2018) have proposed a new power management design of IEEE 802.15.4 MAC for IoT networks that reach the customer specified dependability with minimal power usage at the nodes. The algorithms that used in this paper was 3D Markov chain and M/G/1/K queue. Using those algorithms, they were able to model on IEEE 802.15.4 Mac layer and form queues of knots. They implemented their proposed model that the results showed the accuracy of the real test and simulation was higher, reaching 94% and 97%, respectively. Also, the study on efficiency showed that the proposed power management plan has been able to provide energy storage of about 75%. Finally, the strength of this article is that the proposed model, in addition to simulation, has been compared with the actual results, and on the other hand, its weakness is that the tools used, have not been introduced.

Shao (2018) and his group presented NOMA it's a various admission technique, this technique allows us to reach the transmission service between the fog layer and IoT layer of fog. There are two stages to solve the security and response time problems in fog. First stage is a dynamical IoT system designed to decrease the difficulty and time lag for IoT devices. In The Second stage they use NBS for each cluster to make sure of the equality between IoT devices. The results show that the proposed framework can reach a higher range between lot devices than the other proposed frameworks. They used a power allocation algorithm for their framework.

Shen (2017) presented a new energy method for IoT call EECRP this new method helps them to upgrade the presentation of IoT networks. This framework helps to control the energy of WSN-assisted IoT by arranging clusters. EECRP has 3 main sessions: (1) deliver cluster which helps community nods for better management of energy. (2) an optimized algorithm which helps the modify clusters and head cluster to participate in the energy between all sensor nodes. (3) new framework that helps us to increase the usage of energy for trunk call contacts The results show that EECRP is perfect for the network that needs a long lifespan and a BS in the main network. This group wants to develop their work by adding many-hop route from CH to BS nods in the future.

Wei et al. (2016) presented an IoT based model for the purpose of optimizing energy consumption in the industries, the proposed model manages the facilities' communicative parts to be involved with each other and exchange information; all benefiting a unit scheme. Therefor IoT and FSGIM based models facilitate communication among internal devices of a system and this leads to the reduction of energy, costs, time, complexity of utilization and assembling. In the future, authors will effort to apply deep learning model into a cyber-physical system and promote the proposed IoT based approach to equip the system by using facilities like chargeable batteries and solar panels. They will also perform the model into an actual environment.

Table 7 shows an analytical comparison on technical aspects of energy management and power generation solutions in smart building. For industrial environment, some case studies are applied to enhance energy efficiency and power consumption including centroid-based routing protocol, non-orthogonal multiple access management, and demand response power management.

4. Discussion and new research directions

In this section, a comparative and technical discussion of existing energy management solutions in IoT is presented. According to the analytical questions in section 2, some technical and statistical answers are responded as follows:

- AQ1. Which case studies were applied for showing improvement of energy efficiency in IoT environments?

According to Fig. 2, variety of published research papers with 7 studies in smart home have highest percentage. Also, energy management on smart harvesting, smart cities and smart building has been studied with 15 papers respectively. Finally, smart grid and industry environments have totally 8 research studies in IoT environments.

Existing case studies are categorized for managing energy efficiency in smart home environment including big data, activity recognition for home applications, tactile Internet and context-aware management. For smart harvesting environment, some case studies such as personal kinetic energy management, autonomous power management, tactile Internet and solar power management are applied to maximize power efficiency and decrease energy consumption. In smart city environment, context-aware power management, edge-based service scheduling, 3-dementional MAC protocol and hybrid adaptive bandwidth mechanism are applied for managing energy consumption in IoT environment. Some case studies such as skyrocketing market perspective, power over Ethernet, virtual temperature monitoring and air-conditioning-based energy consumption prediction were applied to smart building environment in IoT environment. For smart grid

Table 5
A side by side comparison for technical aspects of energy management in smart building.

Reference	Case study	Applied algorithm	Evaluation factors	Applied tool	Evaluation method
Duc Nha Le 2019	Smart building	bottom-up/ resident oriented	Cost/ Trust / Security		
Daniel Minoli	Optimization Energy in Smart Buildings by IoT	SDN(Software Defined Network)	Principal Building Activity(Energy or electricity used)	–	Design
Terrososan 2017	Smart building Smart city	Data volatility calculation k-means DBSCAN clustering	Energy Power Efficiency	Matlab lightweight RESTful APIs NGSI	Simulation
Yu 2015	Smart building	ANN, Decision Tree, Multi-Class SVM and Naïve Bayesian	Energy Power Efficiency	BMS server	Data mining
Yu Jaehak 2016	COEX Complex Mall in Korea.	Artificial neural network (ANN), support vector machine (SVM), decision tree (DT)	Time, energy, Cost	Standard linear programming	Data mining

Table 6
A side by side comparison for technical aspects of energy management in smart grid.

Reference	Case study	Applied algorithm	Evaluation factors	Applied tool	Evaluation method
D. Amarnath 2018	Power grid	CRSN SG	Energy Security Cost		Design
Zhiyi LI 2018	Network grid	SDN, DSO	security, efficiency, reliability, resilience	–	Design
Prakash Pawar October 2019	Smart potential grid	ANN, PSO based ANN, SVM, PSO based SVM	Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE)	PV Sources (solar photovoltaic power generators)	Data mining
Rijo Tom (2018	Smart home Smart city		Energy Cost accuracy	Smart meters DR programDataset	Data mining

Table 7
A side by side comparison for technical aspects of energy management in smart industry.

Reference	Case study	Applied algorithm	Evaluation factors	Applied tool	Evaluation method
Kiran et al. 2017	Power Management for IOT Networks	Markov chains, M/G/1/K queue	Energy, Performance analysis, Simulation	Java environment	Simulation,
Shao 2018	Security of IoT devices	power allocation algorithm	Carrier frequency,Path-loss, Minimum distance	downlink NOMA system.	Simulation
Jian shen 2017	Improvement of IOT networks	A clustering algorithm	Number of sensor nodes bandwidth	ns-2 simulator	Simulation
Min Wei 2015	Service chains	Deep learning algorithm	Energy Time Complexity Costs	Enterprise Architect (EA)	Simulation

environment, some case studies are used to manage power efficiency and decrease energy consumption such as solar power management, blockchain-based transitive energy management, renewable energy generation and intelligent power metering. Finally, for industrial environment, some case studies are applied to enhance energy efficiency and power consumption including centroid-based routing protocol, non-orthogonal multiple access management, and demand response power management.

- AQ2. What are the evaluations factors effect on the enhancement of energy management in IoT?

According to Fig. 3, we observed that all research studies have evaluated energy and power efficiency factors generally. Also, based on other QoS factors we observed that time with 27%, bandwidth with 20%, cost with 17%, Mean Absolute Error (MAE) with 11% , accuracy with 11%, security with 7% , reliability with 4% and trust with 3% were evaluated in total number of published papers.

- AQ3. Which technical methods and algorithms were applied to enhance energy efficiency on the IoT environments?

According to Fig. 4, we observed that the highest percentage of applied algorithm in evaluation of energy management techniques is conducted by Deep Refinement Learning (DRL) method with 16%, clustering methods have 10%, particle swarm optimization (PSO) algorithm has 13%, Artificial neural networks (ANN) has 10%, Support-Vector Machine (SVM) has 8%, Decision Tree has 8%, power and energy allocation algorithms have 8%, K-means has 8%, Markove chains has 5%, Naïve Bayes has 5%, and linear regression has 3% of all types of used methods. Also, Maximum Power Point Tracking (MPPT) algorithm with 3%, offline optimization algorithm with 3% have lowest usage for evaluating energy management techniques in IoT environment. Formal verification methods can be applied to prove the correctness of energy management scenarios for critical real-time systems in IoT environments such as industrial equipment, transportation and smart grid.

- AQ4. Which evaluation environments and tools applied to assess energy efficiency management in the IoT environments?

Based on Fig. 5, the highest percentage of evaluation methods for assessing energy management techniques is related to data mining methods with 36%. Also, 30% of studies applied simulation environments to evaluate existing algorithms with 30% of usage. Finally, other research studies have used implementation and design procedure for assessing energy management and power consumption algorithms with 17% respectively. Also, some famous tools

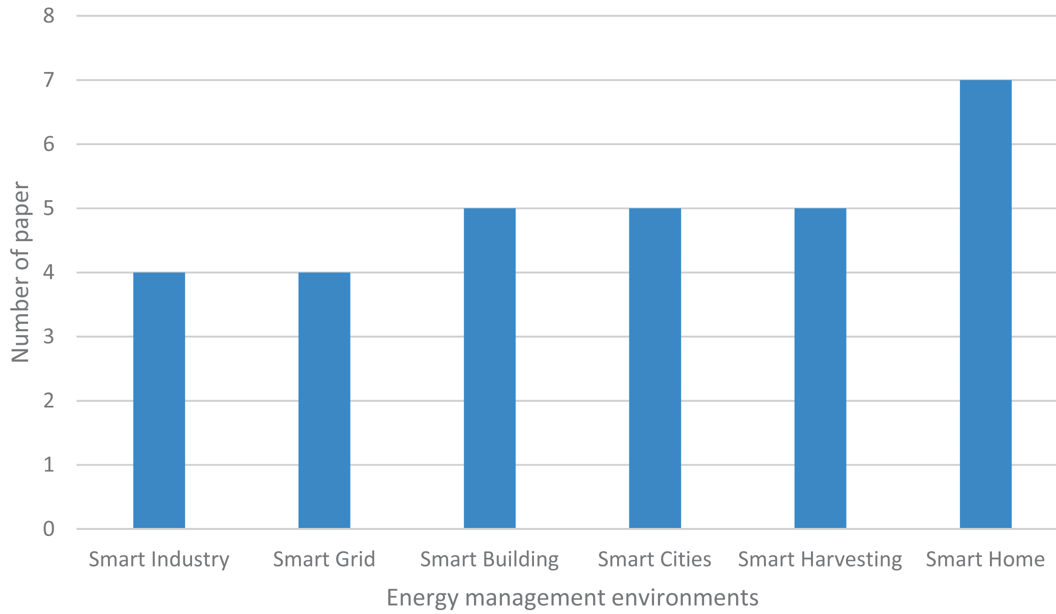

Fig. 2. Existing categories in energy management solutions per number of published paper.

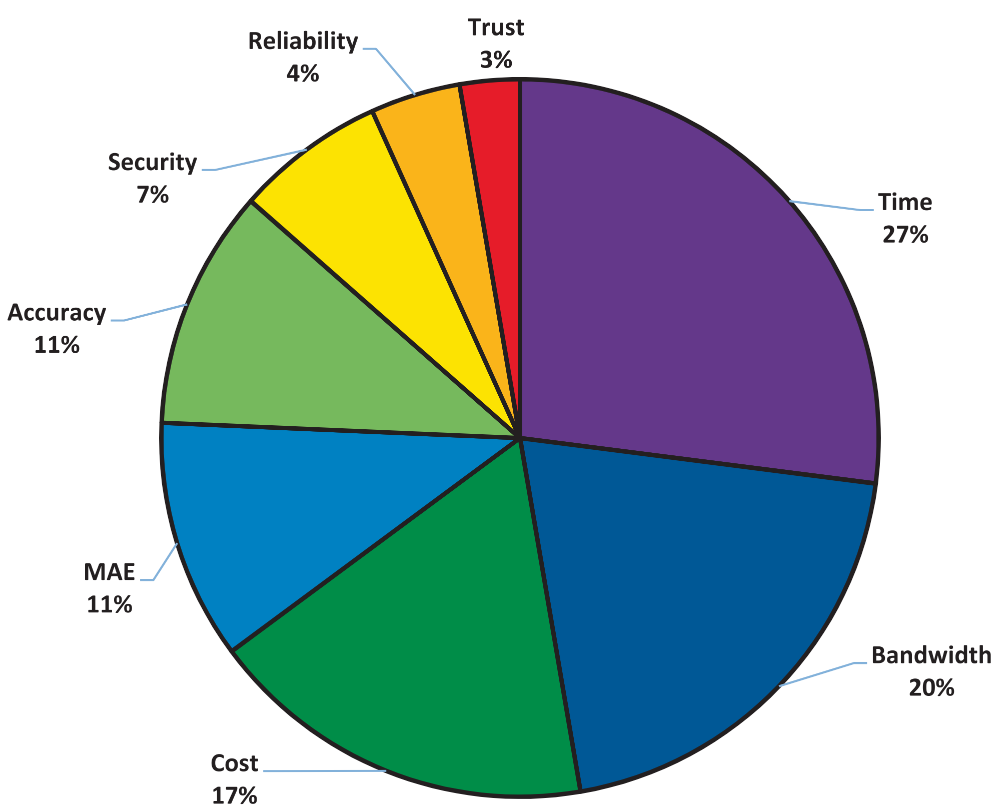

Fig. 3. Existing evaluation factors based on QoS metrics in energy management solutions.

and languages such as Matlab, NS-2, Weka, C++ and Java were applied for evaluating existing algorithm.

Fig. 6 shows the percentage of published paper per year and publisher name in energy management of IoT. IEEE publisher has highest percentage for publishing energy management and power generation solutions in IoT environments. Many conference papers have been published in IEEE and Springer conference venues.

- AQ5. What are open research directions and new challenges and efforts on the improvement of energy management in IoT?

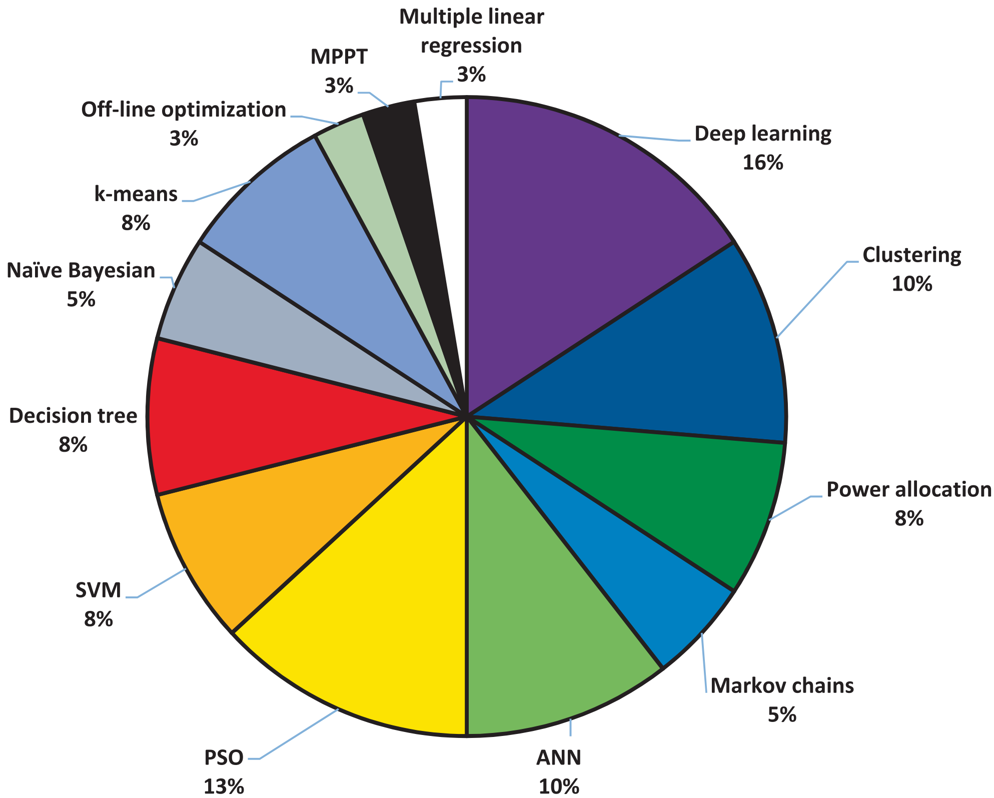

Fig. 4. Existing algorithms and method in energy management solutions per number of published paper.

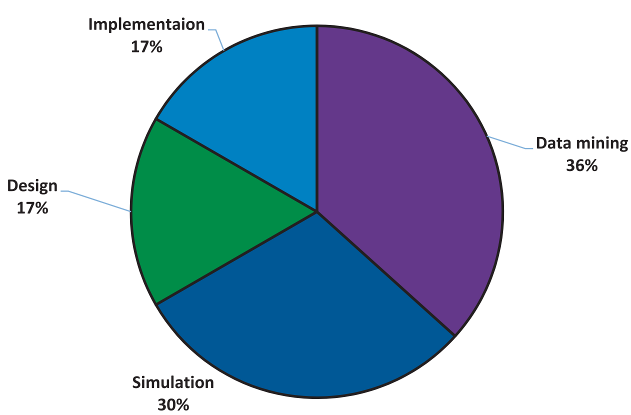

Fig. 5. Existing tools and evaluation environments for analyzing energy management solutions.

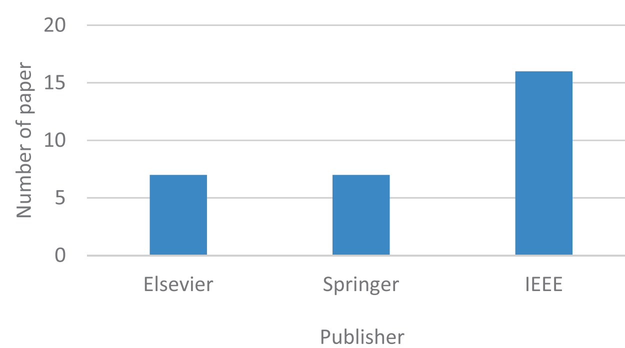

Fig. 6. Number of published paper per year and publisher name in energy management of IoT.

According to above question, we illustrate existing new research directions and new challenges in energy management of IoT. Fig. 7 describes a conceptual scheme for new research directions for each energy management categories in IoT environments. Some QoS factors such as interoperability, mobility, durability, and availability can be influence on energy efficiency management. Also, some new challenges can be enhanced on energy management of IoT environment such as robotics, business intelligent, machine leering and deep learning, and cloud architecture and design (Al-Turjman, 2019).

For example, managing electrical power generation and monitoring power supply chain have important roles in smart girds to enhance energy efficiency in IoT environment. Monitoring interconnections between smart devices and electrical distribution network with smart grid solutions can be enhance and facilitate energy management using IoT applications. Power sustainability and energy efficiency solutions in industrial equipment have managerial role in smart industry and manufacturing environments. Some prediction efforts such as machine learning and deep learning methods can improve quality and performance of industrial equipment by reducing energy consumption and power generation (Qadri, 2020; Ma, 2020). Finally, Internet of Energy (IoE) as one of the IoT

Fig. 7. Some important open issues and research directions for energy management solutions in IoT.

branches has a potential scientific effort for selecting new challenges on the energy management solution for IoT environment. Some technical aspects of IoE in smart home including detection of off-peak power time and exclusive peak electricity time to provide interaction of smart devices after midnight when energy and power consumption is inactivate in homes by users (Hassan et al., 2020). Some special brief topics for energy management in IoT are illustrated as follows that readers can focus on them for future research directions:

- Privacy and trust-aware techniques on Industrial IoE (IIoE)
- Energy efficiency solutions for Internet of Drones (IoD)
- Blockchain technology for energy management in IoT
- Sustainable energy efficiency for Internet of Vehicles (IoV)
- Green power generation and computing for renewable natural resources in Environmental Internet of Everything (EIoE)
- 6G enabled technology for monitoring IoE

5. Conclusion

This paper has discussed energy management approaches in IoT based on an SLR method. Screening 2151 published papers in domain of 2013 and 2019 was carried out and 30 research studies were chosen as main domain of technical analysis. For classifying existing topics on the energy management solutions in IoT, a taxonomy was presented to demonstrate technical aspects of each category of energy management. For analytical comparison of existing research studies in this issue, five research question was defined.

According to AQ1, we observed that variety of published research papers with 7 studies in smart home have highest percentage. Also, energy management on smart harvesting, smart cities and smart building has been studied with 15 papers respectively. Finally, smart grid and industry environments have totally 8 research studies in IoT environments. Based on AQ2, we observed that all research studies have evaluated energy and power efficiency factors generally. Also, based on other QoS factors we observed that time with 27%, bandwidth with 20%, cost with 17%, Mean Absolute Error (MAE) with 11% accuracy with 11%, security with 7%, reliability with 4% and trust with 3% were evaluated in total number of published papers. Also, the highest percentage of applied algorithm in evaluation of energy management techniques is conducted by Deep Refinement Learning (DRL) method with 16%, clustering methods have 10%, particle swarm optimization (PSO) algorithm has 13%, Artificial neural networks (ANN) has 10% according to AQ3. For analyzing evaluation environments and tools, we observed that the highest percentage of evaluation methods for assessing energy management techniques is related to data mining methods with 36% based on AQ4. Also, 30% of studies applied simulation environments to evaluate existing algorithms with 30% of usage. Finally, other research studies have used implementation and design procedure for assessing energy management and power consumption algorithms with 17% respectively. Also, some famous tools and languages such as Matlab, NS-2, Weka, C++ and Java were applied for evaluating existing algorithm. Finally, we presented some new challenges and open research directions based on AQ5 for managing energy consumption and green power generating in IoT environments. Some of future directions related to energy-efficient methods for IoT applications are as follows: energy-aware Software Defined Network (SDN) approaches, energy-aware virtual machine placement and energy-aware Virtual Defined Network (VDN) models. These approaches can be considered as hot topics for evaluating energy management in IoT environments. Some limitations of this review are shown as follows: (1) non-peer reviewed papers were ignored to discuss and evaluation; (2) and non-English articles were omitted in this review; (3) book chapters, white papers, reported and thesis were excluded in this review.

Declaration of Competing Interest

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

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