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Review article

A review of residential blockchain internet of things energy systems: Resources, storage and challenges

Azana Hafizah Mohd Aman [a], Norazuwana Shaari [b], Zainab S. Attar Bashi [c], Saman Iftikhar [d,*], Shaikhan Bawazeer [d], Siti Hasanah Osman [e], Nor Shahida Hasan [f]

[a] Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[b] Fuel Cell Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[c] Faculty of Information and Communication Technology, International Islamic University Malaysia, 53100 Gombak, Selangor, Malaysia
[d] Faculty of Computer Studies, Arab Open University, Saudi Arabia
[e] Science University of Malaysia, Malaysia
[f] PETRONAS Research Sdn. Bhd., Kawasan Institusi Bangi, 43000 Kajang, Selangor, Malaysia

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ABSTRACT

The Internet of Things (IoT) and Blockchain paradigms have offered significant benefits in recent technological innovations. Blockchain has been rated one of the top ten strategic technologies in a recent Gartner survey, and it is increasingly being employed in a range of industries. Blockchains provide transparent, tamper-proof, and secure platforms that, enables ground-breaking commercial solutions. Nonetheless, the use of blockchain technology for IoT Smart Residential energy systems looks to be relatively unexplored. In fact, most IoT devices are powered by a battery with a short life span. Generating and managing energy on an infinite scale is a much more ambitious goal than relying solely on battery power. Hence, this topic is addressed in this article, focusing on the IoT energy systems, renewable energy resources, and how energy is successfully stored. By thoroughly evaluating the literature and existing research cases, this article contributes to the state-of-the-art. Our study examines the opportunities, challenges, and constraints for the evolving peer-to-peer energy systems and blockchain-IoT applications. The study concludes with the hurdles that technology must overcome in order to move beyond the hype phase and into mainstream acceptance.

1. Introduction

Globally, the expected number of connected devices is growing more than tens of billions (Yaici et al., 2021; Mohd Aman et al., 2021). The Internet of Things (IoT)is predicted to raise relatively fast in the next years as the number of connected devices throughout the world continues to expand at an exponential rate (Hasan et al., 2022; Mahbub et al., 2020). The IoT is proven to be beneficial in an extensive range of applications, collecting data that can be used in a variety of ways (Aman et al., 2020). In terms of architecture, the IoT systems connect a wide variety of smart devices, sensors, and controllers, which can be located on-site or in the cloud. Sensors acquire and transmit data on the surrounding in real-time. The controllers then use this information to provide short-long-term and instant responses. The controllers can use adaptive and predictive algorithms to ease the execution from simple to complex responses. One basic IoT example is turning on lights in a dwelling space depending on occupancy sensors, optimizing the humidity and air flow for air conditioning system for a residential area in a long-term intelligent grasp of usage and climate trend conditions. The IoT applications have been expanding, as IoT is now incorporated with blockchain technology (Ray, 2018).

Decentralization of electrical power grids has become more significant as transmission system and distribution system have become more cognizant of energy efficiency and environmental challenges (Casquico et al., 2021). This has been particularly true during the previous two decades. People in the residential and industrial sectors are increasingly getting their energy from local sources. It is critical to use smart ecosystems, and applications that can provide real-time information about the available energy resources, energy storage, how much energy people use and how much energy they produce. To overcome this criticality, a decentralized electrical power system utilizing blockchain in the smart residential applications of sensors of the IoT comes very handy and

* Corresponding author.
E-mail address: s.iftikhar@arabou.edu.sa (S. Iftikhar).

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practical. Basically, the IoT is a network of networked smart devices or sensors to systematize many elements, making things easier in human life via smart applications. It contributes to the development of diverse tasks that are supported out in the utmost resource-well-organized manner.

Blockchains are decentralized ledgers or structures that is used to safely keep digital communications in the absenteeism of a dominant authority to keep track of them (Andoni et al., 2019). Aside from that, blockchains allow execution automation of smart contracts on one-to-one networks. Blockchain also enables multiple concurrent ledger changes, resulting in a large number of different chain versions to be created. A distributed ledger is used as an alternative of a solitary trusted center to run the ledger since individual network respectively possesses a replica of the records' chain and utilizes consensus to agree on the authentic status of the ledger. The precise technique for gaining agreement is still under development and may differ in order to accommodate a widespread of application fields. Blockchain networks are resilient and safe since it independently verifies legitimate transactions, resulting in records that are transparent and tamper resilient. Referring to reports from Gartner, German Energy Agency, and Deloitte, blockchains have a very high potential in the energy industry as shown by the expanding number of revolutionized and engagement, prototypes, trials, and other research activities (Andoni et al., 2019). Several electric utility companies have shown an attention in investigating the possible advantages of distributed ledger technologies as a sustainability facilitator and low-carbon transition, as well as the possible risks. Furthermore, blockchains are likely to transform energy-based devices and commodities to digital assets with exchanged interoperable. Research and commercial activities conducted so far indicate that blockchain technology has the ability to deliver resolutions to some of the encounters face by the energy industry (Andoni et al., 2019).

It is necessary to improve the applications for which IoT systems are intended. As a result, energy resources and energy storage are critical and sensitive concerns that must be addressed. The design of energy management presents a set of challenges and probable resolutions. A continuous supply of energy at a regular pace is necessary for a lengthy period of time in this industry. This requirement continues over a longer annual period to ensure that IoT energy resources can operate efficiently. The three primary criteria, as described in Fig. 1, (a) Storage of energy reserves, (b). Distribution of power resources, (c) energy harvesting. A battery pack is a common power source for wireless sensor network applications. Regrettably, this method is incapable of meeting the present requirements of the 14 years of research. This statement is supported by the fact that energy harvesting for this application increased to 1500 kWh in 2017, up from 40 kWh in 2004 (Kocakulak and B.I, 2017). Although this invention is deemed effective because of its great accomplishments, it ignores a slew of other aspects that will affect the system's actual efficiency. For instance, changes in processes and stabilized energy output may impair the system's ability to adapt to energy variations. As there is an immediate need to fix this issue, this article discusses in length and comprehensively the obstacles associated with open concerns with IoT energy resources and smart technology in the modern era.

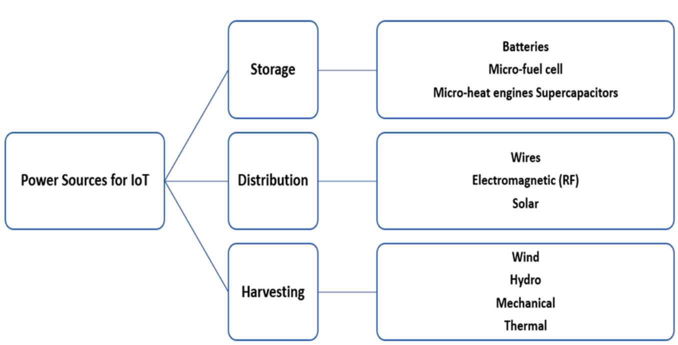

Fig. 1. A list of the various power sources for IoT networks that are now viable.

Lighting, humidity and air conditioning, as well as energy consumption, can all be automated in a smart building through the IoT applications, such as smart meters (Yaici et al., 2021). While occupant comfort is critical, the key objective is to improve energy effectiveness by minimizing energy fatalities and guaranteeing that energy is effectively used. The applications architecturally includes mobile device monitoring and control, geolocation automatic controls, cloud services for analytic processing and storage (Pan et al., 2015; Saleem et al., 2019). Many countries have begun to implement smart meters, which indicates that energy systems are on the cusp of a digital revolution because of distributed renewable energy resources. A further safer and sustainable energy system will demand a yearly venture of more than €100 billion in generation, transmission, and distribution infrastructure improvements, as well as improvements in energy efficiency in the EU alone (Talari et al., 2017; Shakerighadi et al., 2018). By 2030, it is estimated that more than $1 trillion in electrical advancements would be required in the United States (Talari et al., 2017; Shakerighadi et al., 2018).

1.1. *Contribution*

In order to regulate required investment, smart control management is essential. These tasks are getting increasingly complex as energy systems grow more dynamic, decentralized, and intelligent with an increasing number of smart functions available. Power network elements that are interconnected with IoT are becoming increasingly dependent on advanced communication and data exchanges, making central control and operation more challenging to maintain. It is vital to employ local dispersed control and management systems in order to keep up with the decentralization and digitalization advancements. Due to this, blockchains in residential energy system is being prioritize. It is proven that blockchains is very effective in tackling the challenges that decentralized energy systems experience. An increasing number of research works, as well as industrial white papers and reports, most of which have been produced by well-established consulting firms, demonstrate that efforts in the blockchain, IoT and energy sectors are still in the works and very crucial (Andoni et al., 2019). The importance and pertinency of blockchain IoT technology to the residential energy system, on the other hand, requires a rigorous and precisely well-versed tactic the selected perspective. As a result, more specifically, the following contributions have been made:

- A highlight of recent review articles to shed light and clarify on the areas in which this publication is significantly different from earlier studies and provide context for those differences.
- An in-depth analysis examining the impact of integrating blockchain technology in residential usage and the utilization of the Internet of Things on the functioning of energy systems.
- A potential finding that might be employed for the advancement of future technological acceptability, limitations, and the probability of broader ramifications arising from the extensive adoption of blockchain technology in the Internet of Things.

Table 1 presents a summary of most related review paper from 'blockchain internet of things energy system' keyword search from Web of Science database for the past three years (2019 – 2021). As noted in the literature, there are several reviews of IoT systems that have been highlighted. In 2019, the smart grid blockchain IoT was the focus area, while in 2020, most of the discussion was on energy systems without blockchain or IoT without blockchain. As for the year 2021, most of the focus moved to the energy blockchain without IoT. Hence, there appears to have been no survey of blockchain IoT infrastructures relevant to residential energy systems. However, this review does not attempt to retrace the vast amount of industry or academic literature that has

Table 1
Recent related review articles.

Ref	Year	Focus Area	Energy	Blockchain	IoT	Residential
(Andoni et al., 2019)	2019	survey of energy sector blockchain developments and activity	✓	✓	✓	
(Viriyasitavat et al., 2019)	2019	examining BCT and IoT's role in new business models		✓	✓	
(Alladi et al., 2019)	2019	blockchain in the smart grid	✓	✓	✓	
(Musleh et al., 2019)	2019	blockchain technology in the smart grid applications	✓	✓	✓	
(Bin Qaim et al., 2020)	2020	energy-efficient solutions proposed for diverse wearable IoT applications	✓		✓	
(Motlagh et al., 2020)	2020	general IoT applicability in energy systems	✓		✓	✓
(Joseph and Balachandra, 2020)	2020	focused on global national electrical systems	✓			
(Kumar et al., 2020)	2020	The smart grid and applications of AI, IoT, and blockchain	✓	✓	✓	
(Pieroni et al., 2020)	2020	the convergence between Blockchain and IoT		✓	✓	
(Mohd Aman et al., 2021)	2021	IoT smart applications	✓		✓	
(Casquiço et al., 2021)	2021	decentralized electrical power grid	✓	✓	✓	
(Hasankhani et al., 2021)	2021	smart grid structure for blockchain application	✓	✓	✓	
(Asif et al., 2021)	2021	the data and device security	✓	✓		
(Wang et al., 2021a)	2021	review on energy blockchain technology	✓	✓		
(Paiho et al., 2021)	2021	focus on Germany and Finland energy management	✓	✓		
(Lo Cascio et al., 2021)	2021	smart grid concept		✓	✓	
(Escobar et al., 2021)	2021	technologies in Smart Grids and their applications		✓	✓	
(Ibrahim et al., 2021)	2021	Medical IoT applications and systems	✓		✓	

accumulated around energy solutions in the past three years. Instead, it focuses on a more specific but comprehensive assessment of residential blockchain IoT energy systems.

1.2. Paper structure

The first section of this paper delivers an indication of the core ideas of energy system for residential blockchain IoT. Various research from residential IoT applications, blockchain IoT system topologies and consensus mechanisms that determine the essential technical aspects of energy systems specifically on energy resources and energy storages. Before moving on to specific energy-related research, the initial section of this paper gathers critical information from a variety of sources in order to offer the reader with a thoughtful of the broader residential blockchain IoT applications, architecture and the communication protocols. Basically, the sections of the paper are illustrated with question dan description highlights shown in Fig. 2.

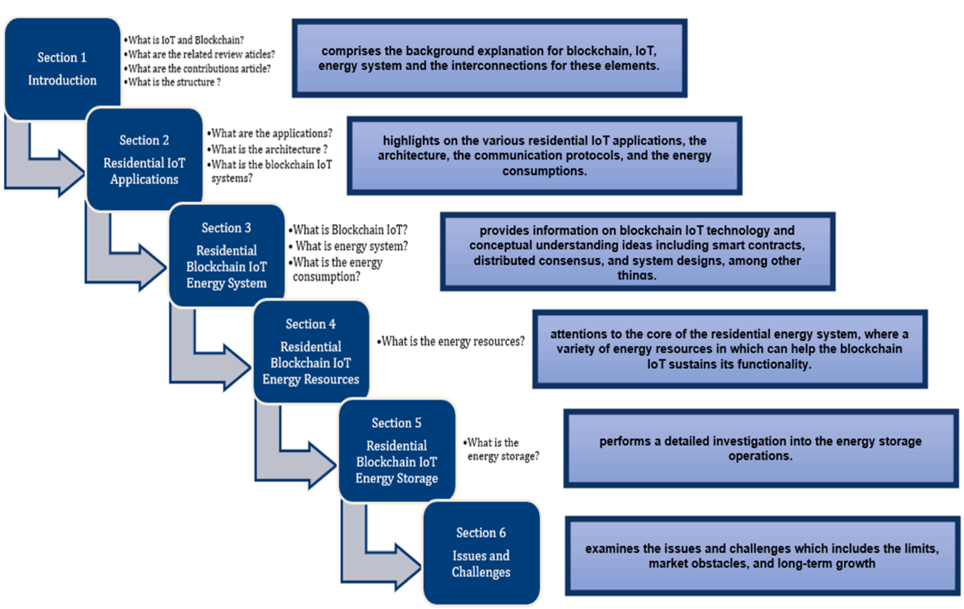

Fig. 2. Paper structure highlight.

2. Residential internet of things applications

Due to the rapid rise of residential smart applications and technology, many manufacturers have been able to tweak existing systems and develop new applications to fit residential needs. As a result, many technologies such as smart grid and smart metering, which many are based on the IoT, which is part of the fast-gaining popularity in the energy industry (Escobar et al., 2021; Alkawsi et al., 2021).

2.1. Smart residential

A ground-breaking idea that blends cutting-edge smart technology and the traditional residential appliance to enable individuals to more efficiently monitor and regulate their living environment, ultimately increasing the overall quality of their surrounding (Alkawsi et al., 2021). Each era, from early electronic appliances through automated appliances to recent smart residentials, represents high-tech advancement and rises forward. It is a modern household model that incorporates innovative technology which includes computer, IoT, and automatic control. The use of the IoT to monitor residential living environments is becoming more prevalent as people's expectations for a comfortable living environment increase. Intelligent interior security and automated home control are the two most common uses of the IoT currently (Alkawsi et al., 2021; Viswanath et al., 2016).

One type of smart sensor technology application is the installation of various sensor nodes in the residential interior to detect heat, poisonous and dangerous chemicals, and connecting these nodes to a network using wireless communication technology (Mohd Aman et al., 2021). The technologies of the IoT also allow efficient indoor environment monitoring, that involve processes such as transmission, collection, reporting, and response toward dangerous vapors. These technologies incorporate a variety of electrical devices found in the home, such as air conditioners, in order to provide an effective monitoring of the interior residential surrounding. Additionally, several types of devices, including as electric switches, gas, and lights are now associated to the Internet, allowing them to be remotely monitored and controlled, which include functioning state that can be altered as needed. Fig. 3 summarizes the described smart technology applications for residential.

2.2. IoT architecture

To form a complete system, IoT must adhere to a number of elements, such as the architecture layers and the communication protocols. As for the residential IoT layers, described in Table 2, the architecture is separated into four key layers: the physical layer, the communication layer, the cloud-based service layer, and the application layer. There is also other standard such as application layer, contract layer, consensus layer, network layer and data layer (Viswanath et al., 2016). The physical layer is the lowest level of the IoT hierarchy also known as the device layer. The data layer layout the blockchain IoT devices, as for the network layer combination of lightweight and full node, blockchain-based (distributed-based consensus, contract and non-smart contract based), and the applications are for the end user systems.

The IoT communication layer uses the network protocols such as in Table 3, it is necessary to standardize software protocols since the IoT is composed of a high number of devices and a communication-intensive architecture. This will allow all devices to interact to each other and share diverse features. Basically, the technology and the communication protocol used effect the IoT sensors energy system (Yaici et al., 2021). As shown in Table 4 some criteria such as transmission type, message processing, scheduling mode, network topology contributed to the

Table 2
Residential IoT Architecture.

Layer	Component	Description
Device Layer	Sensors, actuators, microcontroller, appliances	1. made up of two sub-layers, the first of which is the device layer itself. 2. in charge of perceiving the surrounding environment, collecting data from them, and regulating them.
Network Layer	Switches, Routers, Repeaters	1. links the devices to the services and applications
Cloud Services Layer	Internet, Cloud Service Providers	1. holds the information storage and retrieval 2. manage the authentication, user-data management, among other functions.
Application Layer	End user systems	1. in charge of offering end-user the services.

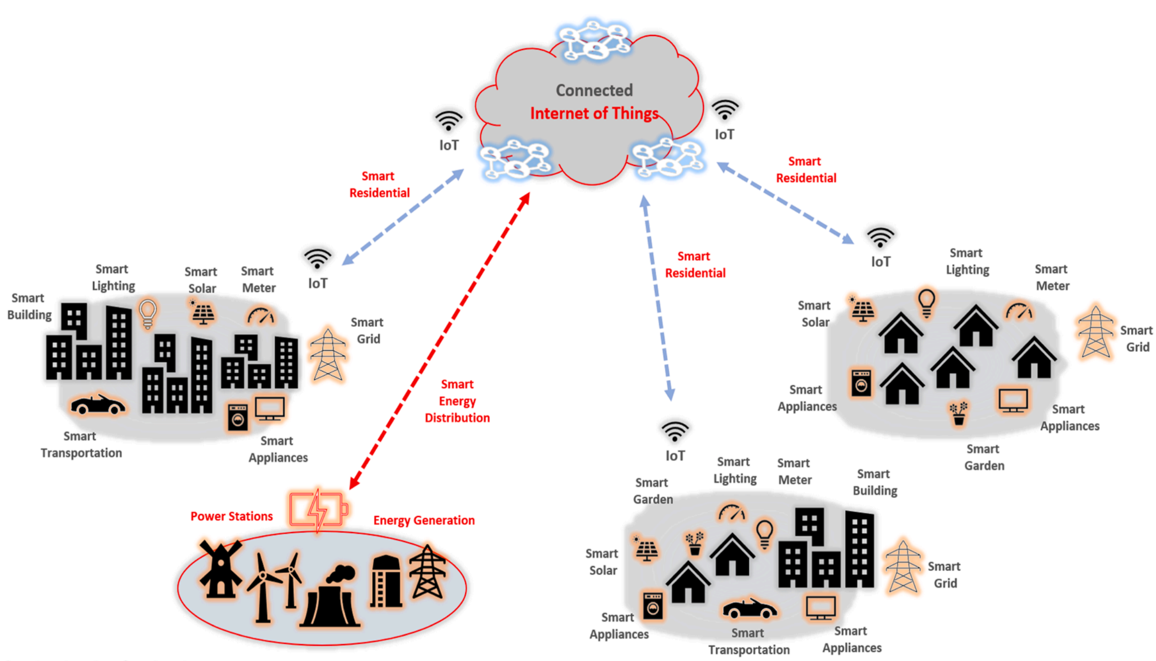

Fig. 3. Residential cloud IoT applications.

Table 3
IoT Communication for Smart Application.

Communication	Distance		Energy consumption	
	Short	Long	Less	High
RFID, NFC, BLE, Zigbee, Wi-Fi	✔		✔	
6LoWPAN, LoRa, Sigfox, WiMAX, Cellular		✔	✔	
NB-IoT		✔		✔

Table 4
IoT energy consumption based on communication technology criteria.

Criteria	Description	Energy consumption	
		Less	High
Transmission	Short distance	✔	
	Long distance		✔
	Congestion/Interference		✔
Message process	Clustering	✔	
	Modulation	✔	
	Centralize		✔
	Decentralize	✔	
	Lightweight	✔	
	Integration		✔
Scheduling mode	Active		✔
	Idle	✔	
	Sleep	✔	
Network topology	Multipath	✔	
	Virtual	✔	
	Scattered		✔

energy usage. These criteria are used according by the IoT applications, Table 5 shows some example of the reduced energy usage according to its functionality.

2.3. IoT cloud

Another merging technology is the usage of cloud for Blockchain IoT architecture (Zhu et al., 2020; Ferrag and Shu, 2021; Arif et al., 2020). Cloud computing is mostly employed in smart residential systems that are connected to the IoT. Owing to the repetitious structure, limited scalability, and effort of subsequent care associated with the IoT-based smart residential monitoring system, it is required to optimize the system. Cloud computing has the potential to make these difficulties more effectively resolved (Viswanath et al., 2016). It is feasible to increase the storing capability of the monitoring system while increasing the efficiency of data information processing using cloud computing technologies. The smart residential system is associated to any part of any region at the same time thanks to the pooling and transparency given by cloud computing, allowing it to transcend time and space limits and realize its full potential. Cloud computing is used at the application layer of the IoT, and the resources generated by data processing in the computer network center are returned to users (Wang et al., 2021b). In cloud blockchain IoT (Fig. 4), massive stream data information is uploaded to distributed knowledge slice layer where edge knowledge aggregation of artificial intelligence resides. Next is the unified knowledge base of blockchain for the services, followed by the user interface consisting of intelligence services and applications.

Table 5
Energy Reduction According to IoT Functionality.

IoT Function	Application	Reduce rate
Reporting	Cloud-based energy information system	> 5%
Robotics	Automated system	> 10%
Illumination	Light controls	> 20%
Shade	Automated shading system	> 20%
	Smart window	> 20%
	Switchable window	> 30%

3. Blockchain internet of things energy system

Blockchain inventors initially formed digital transaction systems that are completely decentralized and allow for one-to-one energy transfer. The inventors put together local energy markets and IoT applications that will be crucial to the smart grid concept's success. The energy market heads to further supple price changes, with frequent energy trade, as well as varied energy scheduling, and regular energy trade liquidation. Blockchains can also be categorized based on the reason for which they are being developed, for example, general purpose blockchains versus particular purpose blockchains. A blockchain IoT system model can maximize the utilities by exchanging information and settling transactions in the electricity trading system (Fig. 5) via smart contracts. This technology does not optimize energy trading or scheduling directly. All node data, such as renewable energy system resources, on-off-peak hours, electricity tariff, and load request is stored using blockchain as in Fig. 5. The domestic users are linked to the smart controller for energy management (Haider et al., 2016).

The primary goal of implementing the smart contract system is to enable efficient energy trading for residential microgrid utility usage without involving a third party. The smart IoT appliances store the data in a ledger with the functions, events, state variables, and modifiers of the smart contracts building blocks. The system handles the entire trading process and scheduling with minimal manual intervention. The system has lower operating costs, and the data is traceable and secure. Prices, quantities, timestamps, and days are provided by energy providers, and consumers purchase energy from sellers based on price, quantity, and time. Node members compare their ledgers, like distributed voting (Andoni et al., 2019), checking the ledger validity state.

The method of validating and consolidating the ledger differs by blockchain type, but in general, network nodes check the types of the ledger to reach consensus the ledger validation with distributed consensus algorithms. Blockchain systems use peer-to-peer connectivity and powerful cryptographic algorithms to achieve data veracity and security. The entire potential of blockchain technologies can only be reached when they are linked with smart contracts, which are user-defined programs that establish the rules for writing in the ledger. Smart contracts are executable programs that alter the ledger and can be executed automatically if specific circumstances are met. Smart contracts are self-enforcing and tamper-proof, which reduces transaction, contracting, enforcement, and compliance expenses (Andoni et al., 2019). Blockchains can make low-value transactions more cost-effective, and they can ensure transaction system interoperability.

In community microgrid energy system, residential consumers can maximise the utilities by exchanging information in an energy trading system, each consumer has their own IoT smart meter for exchanging information. A community microgrid generates and distributes energy from solar, wind, and other renewable sources to multiple users to reduce electricity bills, improve community economics, and assist the environment by using renewable energy sources. Hence, to meet residential needs, consumers can select from a variety of energy generation options (Afzal et al., 2020). Energy can be purchased from a residential microgrid or the utility grid. In the absence of local generation, energy is

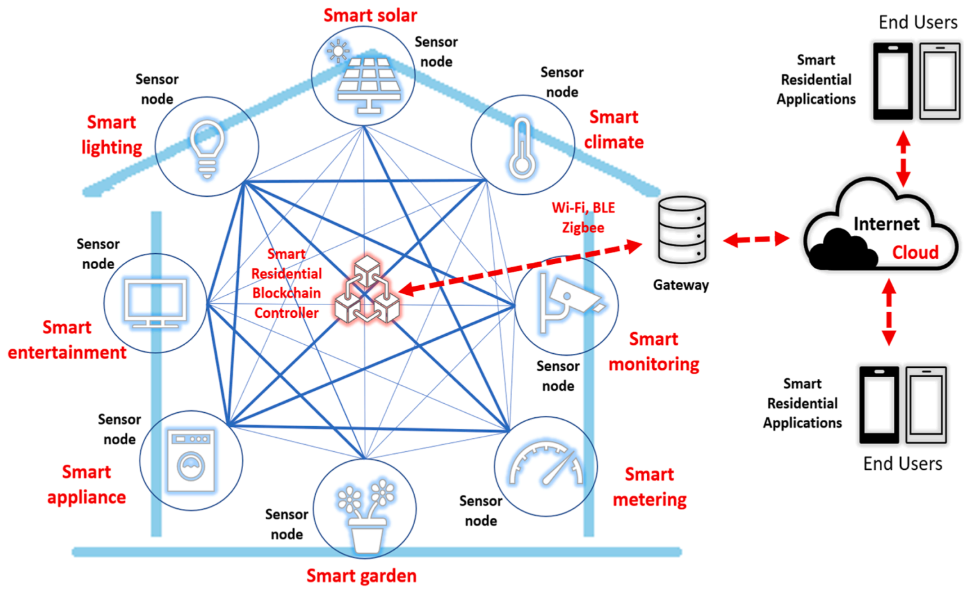

Fig. 4. Residential Blockchain IoT interconnection.

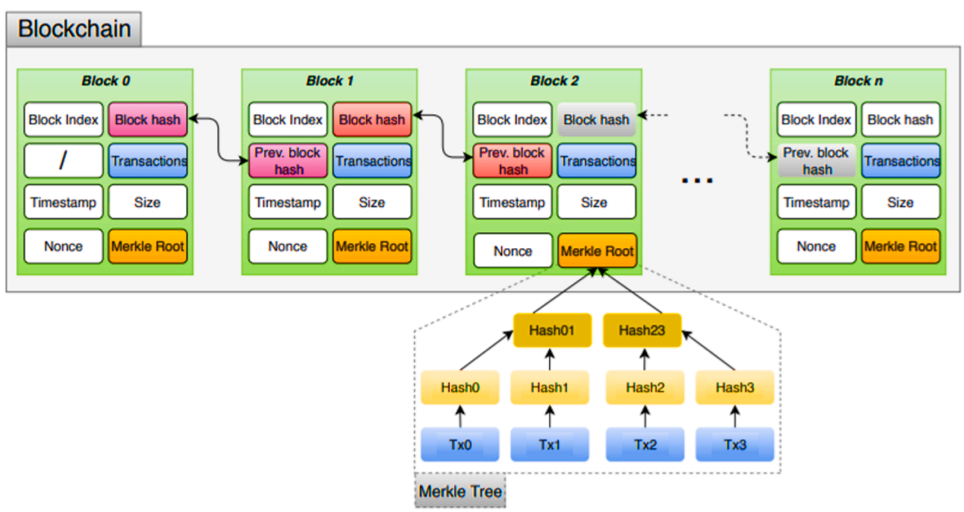

Fig. 5. Blockchain Structure for Electricity Trading System (Ferrag and Shu, 2021).

purchased from the utility grid to ensure continuous availability for users. A controller is used to schedule the manageable appliance loads by managing the electricity demand. The system supplies scheduling interval for the appliance through the blockchain in order to run in low-cost energy areas. An end user application that connects a community's smart homes to the blockchain. This simplifies the trading and monitoring of distributed systems in a community. A ledger is a distributed database that stores shared data for all homes, such as energy data and pricing. Smart contracts are performed automatically on the basis of the data from the ledger.

Smart contracts use predefined negotiation rules to help users buy electricity directly from producers or energy providers (community microgrids or utilities). The smart contract checks the availability of required electricity as well as electricity prices automatically. The immutability of smart contracts is a benefit of the proposed system. To begin, use smart contracts to define the agreement, and then send the funds to the escrow account's predefined address. After that, the electricity process begins. Blockchain IoT controls the flow of energy between producers and consumers, as well as consumer smart appliances in the home. Blockchain technology improves aspects like; distributes energy for the community in a decentralized manner; transmits transactions peer to peer; reduces costs and improves security; provides traceability of electricity usage, allowing for transaction supervision; and it executes smart contracts automatically without the intervention of a third party. As a result, energy and financial transactions between energy providers and consumers have been streamlined. This sends control signals to turn appliances on and off automatically in order to participate in the smart community.

The most typical blockchain components are network validators and consumers. Consumer nodes initiate and receive transactions and keep a ledger clone. Validators approve ledgers with read access. This approval process involves ledger modifications and network consensus on its validity. Access rights, including limited, global, and validation privileges, may vary by system configuration. A public blockchain system is open to everyone with the Internet. Private blockchains are only accessible to authorized users. Any network user authenticating transactions ensures permissionless ledgers circulate completely, reducing censorship and interference. Permissioned ledgers allow only designated validator nodes to modify the blockchain, giving them write access. Game-theoretic equilibria and rewards establish the cooperative effort and confidence needed to maintain ledgers in public and permissionless systems because users and validators are unfamiliar with each other. To deter self-centeredness, incentives like computation time, electricity, or fines are often created. Since validator nodes are trusted to complete their commitments, artificial incentives to preserve system efficiency are unnecessary. As a result, permissioned and private ledgers are quicker, extra supple, and less resistant to censorship. Furthermore, few ledger designs can be classed as blockchains consortium, which are hybrids of private and public blockchains (Eid et al., 2016; Fernández-Caramés and Fraga-Lamas, 2018).

4. Residential blockchain energy resources

According to Gielen et al. (2019), the share of renewable energy in power sector would increase from 25% in 2017 to 85% by 2050. Even though this global energy transition will cost USD 1.7 trillion by 2050, the cost-savings from reduced air pollution, better health and lower environmental damage would greatly outweigh these costs. Renewable resources are particularly abundant but the amount that can be accessible per unit of time is limited. The available renewable energy resources that can assist the IoT system, particularly in residential blockchain, can be classified into thermal (heat gradient, body heat, machine heat), light (artificial, solar), electromagnetic (E field, M field, EM field), chemical (biochemical, substance transformation, reaction) and mechanical (flow, vibration, motion, deformation), as illustrated in Fig. 6.

4.1. Thermal

Heat is a form of energy that is constantly circulating inside or outside a structure. Heat is easiest to detect from the body and electronic gadgets like cars, laptops, and others. Solar heat, exhaust heat, system internal resistance heat, and heat flow are thermal energies. Temperature and time substantially affect thermal energy. Thermal energy can be collected on small to large scales to offer uninterrupted and sustainable power to meet the IoT system's capacity. Because of its widespread application in industry, this heat collection method is smart and profitable. Thermal energy storage systems must have a long lifespan and great durability due to the materials employed and a high heat exchange capacity efficiency (Haider et al., 2016). Adiabatic Compressed Air Energy Storage is one of the examples where thermal energy is collected during the compression stage and to be used during the expansion stage for wind turbine application (Hasan et al., 2013; Barbour et al., 2021). Additionally, the subsection in Fig. 6 for thermal energy can be described as follows:

Heat Gradient: Utilizing temperature differences in the environment, such as the temperature contrast between indoor and outdoor spaces, to generate power through thermoelectric generators.
Body Heat: Harvesting the heat generated by individuals in a residential setting to power IoT devices, especially wearables or smart clothing.
Machine Heat: Capturing and converting the heat generated by household appliances or machinery into usable energy for IoT applications.

4.2. Light

Light energy gets the greatest attention and is developing as the world's energy source. It has been extensively investigated since it works in many applications and systems. Sunlight is the main energy source in open work systems, while artificial light is in closed ones. Accordingly, during peak hours, solar irradiance can reach up 1000 W/m^2 for 395 W (Svarc, 2022). Light energy collecting is typically used to transfer low-powered IoT system applications, such as smart residential and large-scale smart farming (Akhtar and Rehmani, 2015). Solar energy is extremely weather-dependent, providing low capacity at low temperatures and great capacity at high temperatures. Libelium Waspmote is a platform sensor device technology that has been widely utilized in IoT technology. It is made up of solar panels that can capture up to 12 V and 500 mA of energy.

Solar energy is divided into two categories: solar thermal and solar electricity. The solar thermal can directly be used after being converted to thermal for use in industry or residentials using a controlled solar thermal (Reddy et al., 2013; Li et al., 2016; Muñoz et al., 2017). This differs from solar electricity where a semiconductor material is employed to handle the direct conversion of sunlight into electricity. The quality of the semiconductors used has a significant impact on the cost and performance of PV solar cells (Lim et al., 2016). These crystalline silicon solar cells also outperform organic solar cells in terms of stability and performance (Cheng and Zhan, 2016). As shown in Fig. 7a, many water desalination systems have been used in solar energy as an energy source. In the water desalination system, solar energy is shown as a secondary source in Fig. 7b. In comparison to conventional processes without PV, PV-RO integration systems have contributed more than 50% to this process (Ali et al., 2011). Moreover, the subsection in Fig. 6 for light energy can be described as follows:

Artificial Light: Using indoor lighting or specialized light sources to power IoT devices, especially in areas with limited access to natural sunlight.

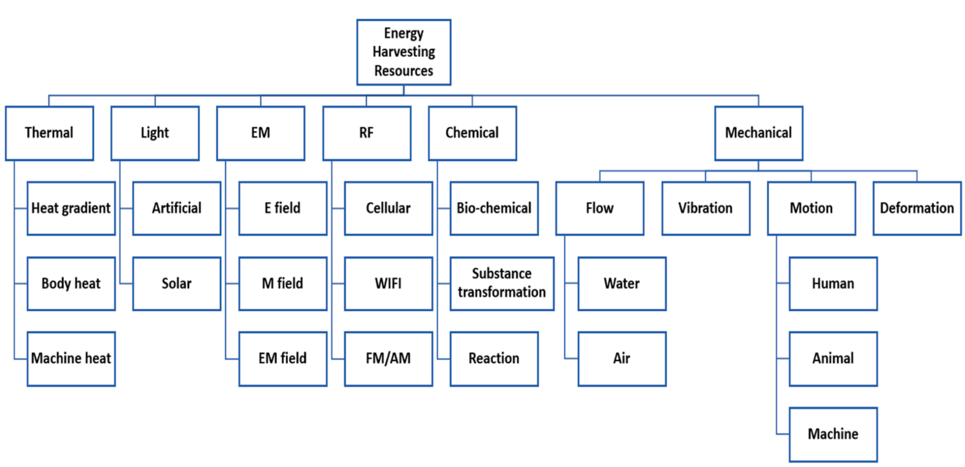

Fig. 6. Clustering of sources of energy for IoT.

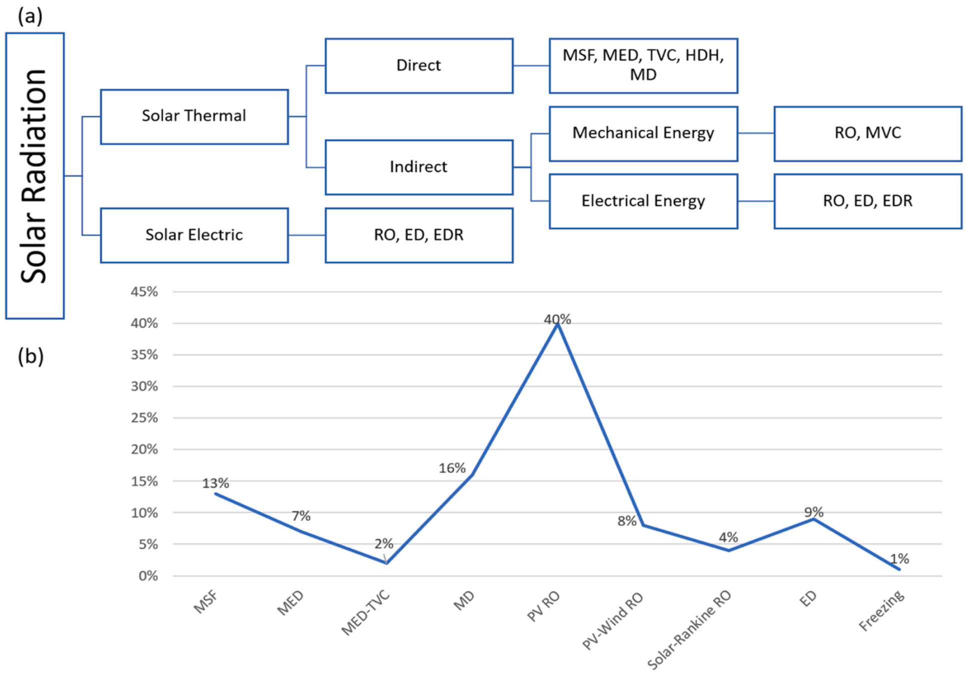

Fig. 7. a) Solar energy used in water desalination, 7b) Diagram of a conventional PV-RO driven desalination plant.

Solar Energy: Harnessing sunlight through photovoltaic cells to generate electrical power for IoT devices, including solar-powered sensors and smart home components.

4.3. Electromagnetic

Electricity, magnetic field, and electromagnetic field are the three kinds of electromagnetic energy. Because it can be connected wirelessly and uses high and sufficient electromagnetic rays as a source of energy, electromagnetic energy contributes significantly to the function of IoT systems. It has the ability to generate in both close proximity to the field and further away from the field, depending on the size and specifications of the system. The magnetic field and electromagnetic are the foci in the near-field where the generated electrical energy is flowed to provide the cushion to the wireless communication equipment. Only electromagnetic (in the microwave signal) is employed as the flow center to convert the signal receiver, antenna, and DC operating node to electricity, in contrast to the far-field. A distant field is defined as a few kilometers of guidance distance, and a near-field can be as close as one kilometer. The electromagnetic energy harvesting process has an efficiency of more than 80% (Ku et al., 2015). In this day, the most common sources of electromagnetic energy are television broadcasts and cell transmission. Moreover, the subsection in Fig. 6 for Electromagnetic energy can be described as follows:

Electric (E) Field: Harvesting energy from electric fields in the environment, which can be generated by various electrical devices, to power low-energy IoT sensors.
Magnetic (M) Field: Utilizing magnetic fields, either ambient or generated by specific devices, to generate electrical power for IoT applications.
Electromagnetic (EM) Field: Tapping into the combined energy of electric and magnetic fields, such as radio frequency (RF) signals, to power wireless IoT devices.

4.4. Mechanical

Mechanical energy is well-known in ecology and the environment. Mechanical energy comes from vibration and motion. Vibration may be accessed from large and small domains, making it a versatile energy source. Particle vibration is found in many types of life, infrastructure, and manufactured objects. Machine motion, speed acceleration, friction, and kinetic strength are examples of widely available technical breakthroughs. Highways, electrical appliances, buildings, autos, biomotion, streets, and industrial equipment surround us. Depending on the amplitude and frequency of the vibration, the power density and intensity produced by vibrational energy varies from low to high (Roundy et al., 2003a; Roundy, 2005).

The average vibration energy range is 60 to 200 Hz, which corresponds to 0.5 to 10 m. 81 In addition, a collector's mass factor and vibration mass have an impact on the yield of vibration energy. Depending on the amplitude and frequency of the vibration, the power density and intensity produced by vibrational energy varies from low to high (Kausar et al., 2014). Furthermore, the collector's mass factor and vibration mass greatly affect vibration energy. Vibration is caused by multiple frequencies interacting. Quantifying vibration energy during harvesting and gathering is difficult, but it is regulated well. Mechanical energy may come from two main sources: wind and water.

Wind energy is a sort of renewable energy that is gaining popularity due to its ease and low cost of production (Lei et al., 2009; Schilling and Esmundo, 2009). Wind turbines, often known as windmills, are machines that transform kinetic energy from the wind into mechanical power and then electrical energy. Despite the fact that wind turbines are often big in size, wind energy can be absorbed and collected from the environment by placing a small scale turbine in the exact location, such as on a roof (Grieser et al., 2015). The early techniques and technologies for obtaining energy from wind and water movement were wind farms and hydroelectric power producers. Generators, on the other hand, can produce a lot of energy that isn't confined to wind or water.

Wind power capacity is greatly affected by global weather conditions; thus, water supplies must be considered. Water harvesting is used to capture energy, and wearable technology regulates energy levels by controlling blood circulation. Capacity assumptions can be made, however location or limitations may limit water or wind flow regulation (Gandhidasan and Al-Mojel, 2009). Utilizing ocean water generates several sources of energy. The system includes kinetic and chemical energy from tidal and wave movements and ocean flow pathways. At short intervals but high intensity, ocean energy becomes a more profitable option than solar or wind energy for the production of natural electricity (Lehmann et al., 2017). The potential energy of ocean waves has the highest power density and can be transformed into electrical energy using an energy transducer (Bilgili et al., 2015). Another way to create electricity is via deforming a material's molecular structure. Electric currents result from the displacement of ions like electrons and protons during the transition. Moreover, the subsection in Fig. 6 for Mechanical energy can be described as follows:

Flow: Capturing energy from fluid or gas flow, for example, using small turbines or piezoelectric materials in water pipes to generate power for IoT devices.
Vibration: Harvesting energy from vibrations in the environment, such as those caused by machinery or human activities, to power sensors and devices.
Motion and Deformation: Utilizing mechanical motion or deformation in various forms, such as kinetic energy from footsteps or mechanical vibrations, to generate power for IoT applications.

4.5. Chemical

Chemical energy is obtained through a variety of processes, including naturally occurring chemical reactions, chemical compound transitions, and biological cycles. A biochemical cycle is a mechanism in the human body that produces chemical energy from the body's nutrition or chemicals. Battery technology is a man-made art form that operates by converting chemical energy into electrical energy. In the presence of chemical energy, the same method can be used to generate energy for IoT sensor nodes. Bio-waste and corrosion of materials are two further examples of chemical energy production. Meanwhile, Hosseinzadeh et. al. have studied the mechanism, technical and operating conditions, economic and environmental aspect which emerging in hydrogen production from bio-waste to be as a renewable energy resource (Hosseinzadeh et al., 2022). Moreover, the subsection in Fig. 6 for Chemical energy can be described as follows:

Biochemical Processes: Using biological organisms or processes to generate energy, for instance, microbial fuel cells that convert organic matter into electrical power for IoT devices.
Substance Transformation: Harvesting energy through chemical reactions or transformations, such as the conversion of specific substances in the household environment into electrical power.

5. Residential blockchain energy storage

Energy storage could be preserved instantaneously (for example, in a battery) or converted into a different phase of storage and recycling (for example, hydrogen via electrolysis/fuel cell). Fig. 8 depicts how the electricity and hydrogen buses are linked in series-parallel to two distinct options from the many available. Since system effectiveness is vital, as it is in most stand-alone systems, the parallel structure in which energy is tightly used to limit the flow of output by hydrogen pathways should be adopted, as Kalghatgi discovered (Kalghatgi, 2018). Energy storage systems are essential for blockchain IoT devices in areas with limited, unreliable, or unavailable electrical grids, which are isolated from the main energy supply. Fast load transitions and stability during power and load changes depend on instant storage facilities like batteries and supercapacitors. Fast, dynamic energy storage like supercapacitors is best for grid connectivity fluctuations. However, supercapacitors' high installation costs sometimes need their integration with battery energy storage devices. This battery will be in charged when the supercapacitor approaching its minimum state of discharged (Díaz-González et al., 2022). Various other storage solutions, such as magnetic storage, pumped hydropower storage, geothermal for long-term load-leveling applications, and compressed air energy storage for extremely large systems, currently exist for various uses and sites.

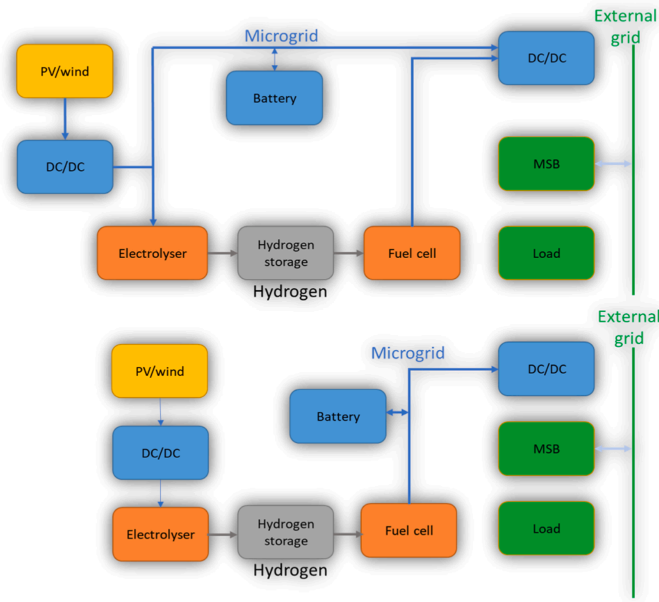

Fig. 8. Approaches for increasing solar and/or wind DC input with hydrogen as an energy carrier in renewable power supply routes.

Hydrogen can also act as an energy supplier (or vectors) that assist energy resources in their power generation. Hydrogen is essential as an energy carrier because of (a) the long-term viability of the entire series in which hydrogen is produced by water splitting and water is the yield of direct oxygen combustion with heat-formed or the oxidation process used to harvest electricity in fuel cells and (b) its universality. The fuel cell is ideal in small-to-medium energy technologies for static, portable, and vehicle industries due to its direct production of hydrogen electricity without needless waste materials. based on fuel cell or electrolysis applications that play a role in the conceptual machine perspective which is a facilitator as a transformer between energies but there are obstacles and challenges to get good performance through this application as illustrated in Fig. 9 the combined result of hydrogen storage and electrolysis where this is particularly effective in energy storage strategies that drive towards battery energy saving.

Interestingly, Abdin and his team (Abdin et al., 2015) explore the challenges within the context of stand-alone hydrogen-based energy solutions and hybrid power prototype technology, which included hydrogen storage. The density of hydrogen can theoretically reach a maximum when the hydrogen atoms are dissolved in the substance (e.g., borohydride), but this must be monitored because greater temperatures are necessary to charge and release hydrogen. Interstitial metal hydride is a well-known solid-state hydrogen storage composition in which dissolved and absorbed hydrogen atoms are easily transferred to the receiving metal's crystal structure. Metal hydrides, such as batteries, have nearly linear chemical potentials for releasing and absorbing energy. Due to the relatively large low gravimetric energy density of metal tubing, metal hydride appears to be the only reversible solid-state hydrogen storage (rechargeable in situ rather than externally reused) that has been marketed. Gray and his colleague (Gray et al., 2011) discussed the origin of enthalpy, as part of the heat strategy plan, the overall hydrogen subsystem efficiency in the creation of power and functional heat is extremely high when gathered and utilized by electrolyzer and fuel cell.

The incorporation of power and/or hydrogen storage into the microgrid implies alternatives for how the microgrid runs inherently and how the hydrogen component is connected. Hydrogen is stored in the form of a metal hydride. The fuel cells are used in the scheme to store energy and are activated when the battery's state of charge (SOC) falls below a certain level, such as 20%. An energy management system

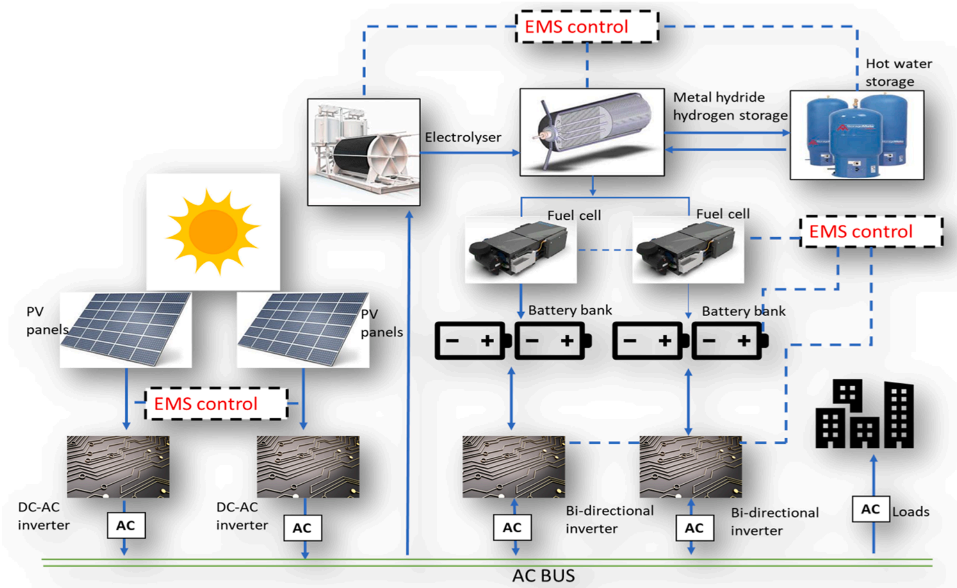

Fig. 9. The real system design of a hydrogen fuel cell is depicted in this illustration. The main electronic parts are duplicated for the sake of duplication and durability.

(EMS) connects all designs on the microgrid to regulate the power flow and assure safety and dependability. Table 6 provides an overview of the peak powers measured via various methods. The energy density (E) and power density (P) of each power resource method are different (E). The table shows the most important strategy, in which the tiny-powered battery source is drawn from the main battery. The two primary types of batteries that are always utilized in life are zinc-air batteries and lithium batteries. Because it has a constant voltage, the primary battery may generate electricity straight to the electronic equipment without the need for additional power. a variety of possibilities in terms of tiny size, even if it does not provide a huge amount of electricity because power savings are achievable.

Table 6
A comparison of energy sources for IoT networks.

Energy Resources	P/cm^3 (mW/cm^3)	E/cm^3 (mWh/cm^3)	P/cm^3/yr (mW/cm^3)	Subordinate Storing Required	Accessible Economically	Weakness	Ref
Primary battery (Li coin cell)	110	670	0.076		✓	Voltage regulation isn't required, hence it's cost-effective.	(Raj and Steingart, 2018)
Secondary battery (Li-ion 18650)	2170	760	0.087	-	✓	Take into account the unit's lifespan while saving peak power.	(Raj and Steingart, 2018)
Fuel cell	145	-	-	✓		Poor efficiency and issues with fuel storage and transport There's no need to recharge the batteries because they're always on.	(Zou et al., 2016)
Micro-heat engine	-	-	-	✓		Issues with scalability, efficiency, and thermal management	(Ju and Maruta, 2011)
Supercapacitor	128	7.4	-	✓	✓	Self-discharge, limited energy density	(Meng et al., 2014)
Dedicated RF	0.440	-	-	✓	✓	Expensive, limited in range, and requiring AC input for the RF source	(Lu et al., 2014)
Solar (outdoors)	26.7	-	-	✓	✓	Intermittence of the sun	(Green et al., 2017)
Solar (indoors)	0.0926	-	-	✓	✓	Expensive	(Mathews et al., 2015)
Air flow	0.03	-	-	✓		For several Iot network, the situation is unpredictable and inaccessible.	(Carli et al., 2010)
Water flow	1	-	-	✓		For several Iot network, the situation is unpredictable and inaccessible.	(Hoffmann et al., 2013)
Temperature	1.8	–	-	✓		Transformation limitations, voltage regulation requirements	(Lu and Yang, 2010)
Mechanical (piezoelectric)	0.375		-	✓	✓	Long-term sustainability issues that are unclear	(Roundy et al., 2003b)
Mechanical (triboelectric)	5	-	-	✓		Long-term sustainability issues that are unclear	(Wang et al., 2015)
Mechanical (active human motion)	8.5	-	-	✓	✓	Unknown, long-term sustainability issues are undeniable.	(Zeng et al., 2011)
Mechanical (physiological motion)	0.0012	-	-	✓		IoT strength is visible, but it is insufficient.	(Dagdeviren et al., 2014)

Primary and secondary batteries, in general, are well suited to mobile applications such as laptops and mobile phones, where the various macro sizes differ in terms of reusability. Without a primary battery, the capacity of the secondary battery is usually insufficient to turn on the wireless sensor and turns out to require additional primary power to charge it. In terms of chemical reactions, the mechanism that occurs in a fuel cell system is the same as that occurs in a battery. It has been demonstrated that using hydrocarbons or any other fuel in fuel cells yields more efficient than batteries. Methanol fuel, for instance, has a 17.6 kJ cm energy density, which is six times that of lithium batteries (Chauhan and Saini, 2014). The voltage is constant; however, the current density has an effect. As a result, to remedy this weakness, the fuel cell that serves as the system's power source necessitates the installation of a backup power plant. The demands of human life have long been driven by fossil fuels, which are a large source of power. With 12.7 kJ/cm, it is capable of producing high-power density fuel at a low cost when compared to other sources. Unfortunately, this fossil-based fuel-burning heat engine technology has numerous shortcomings in terms of maintenance procedure, transportation, and huge size. Regarding that, scientists have attempted to invent miniature heat engines. There are numerous advantages to using micro heat engines in general, which have a high-power density and can be used for a long power supply. Interestingly, for wireless sensor applications, several further changes are required.

5.1. Integration of lithium batteries as smart energy technology

Photovoltaic energy is proving to be quite effective all around the world. The system has experienced tremendous progress, and its cost has dropped substantially, making it more appealing and economical. Even though systems are still primarily comprised of monocrystalline or polycrystalline wafer silicon solar cells, the cost of solar panels has reduced dramatically. Thin-film solar panels are becoming more common, but they have yet to become market leaders. According to Haitz's rule, the lighting trend has shifted dramatically from light bulbs to extremely efficient light-emitting diode (LED) lamps at a lower cost (Steele, 2007). Overall, charge controllers and inverters are the same. Including its short lifespan, the lead-acid battery has a shortcoming, particularly concerning various other off-grid components. The battery quality has greatly improved; nonetheless, for new cost reasons and regulated recycling, the photovoltaic sector frequently uses primarily acid batteries.

The solar panel in a photovoltaic PV System has a life expectancy of more than 25 years, and LEDs have a life expectancy of about half a million hours (approximately 15 years) (Pode and Diouf, 2011). To achieve the 15-year target and maximize system durability, the battery lifetime must suit the LED lights from the lowest to the stage of about 5000 cycles with an 80% length of discharge. Lithium-ion batteries are a relatively new battery development entrance (Li-ion) (Khoon et al., 2019). The Li-ion and VRLA battery sectors are expected to grow in the next years. Nonetheless, Li-ion is expected to outperform VRLA in certain applications where mass, lifetime, or capacity are critical. With technological advancements, lithium-based batteries will alter the PV sector and sustainable energy, making essential services more accessible (Lee et al., 2019). The expansion of related industries such as electric cars electric bicycles and consumer electronics might flourish, providing limitless opportunities for lowering the cost of refillable lithium batteries, making them desirable targets for shared storage in off-grid renewable resources (Dahn et al., 2005; Thackeray et al., 2012).

Furthermore, Li-ion batteries may have two crucial characteristics that make them ideal for stationary storage: low average cycling costs and extended life. If the life expectancy of Li-ion batteries is measured, the cost per cycle could be lower than that of lead-acid batteries. Consequently, despite the higher initial costs, investing in Li-ion rather than lead-acid may be preferable for a longer-term outlook, notwithstanding the current expanding position. The peculiar energy storage in renewable energies, on the other hand, is not suitable for mass manufacture in the Li-ion industrial sectors. To incentivize the production and distribution of renewable energy, several developing countries advocate grid-tied 'net metering' style approaches, in which the transformed energy is injected directly into the grid through a regulator. Such rules have created a favorable climate for the PV panel industry to grow, and subsequent commercial manufacturing has reduced costs. Particularly in developing countries, where batteries are most needed due to the visible off-grid PV systems, they may be less accessible based on population income (Diouf, 2016; Youm et al., 2000). This was a significant disadvantage for what would otherwise be a large Li-ion storage industry, and it remains a major factor throughout the widespread use of Li-ion batteries as primary renewable energy storage devices.

The renewable energy market appears to gain mainly from the development of Li-ion batteries and will never be the industry's leading purpose. The expansion of industries that drive costs, technological advancement, and security solutions obtained via technology and development in Li-ion batteries is conducive critical to realize and deploy. The future of renewable energy should be studied in tandem with the future of hybrid automobiles. To become more widespread, Li-ion batteries are more cost-effective and must be made safer. The advancement of Li-ion batteries is being paralleled by a surge in demand for electric vehicles. Furthermore, the production of electric vehicles is motivated by the goal of replacing the internal combustion engine with a more autonomous range, longer lifetime, strong performance, and faster loading, hence improving energy and power efficiency while increasing security concerns (Wen et al., 2012; Armand and Tarascon, 2008). Table 7 lists several advantages of Li-ion batteries over lead-acid and nickel-metal hydride (NiMH) batteries.

5.2. Integration of supercapacitors as smart energy technology

Energy storage (ES) technology is becoming more popular, with renewable energy production and advances in electrification (Aneke and Wang, 2016; Zhao et al., 2015). Owing to their power output, processing time, and life span of the ES, supercapacitors (SCs, also known as ultracapacitors) have emerged as excellent prospects for implementations such as electric vehicles (EVs) (Zhang and Li, 2020), electric airplanes (Cheng et al., 2020), electrical power grid (Mohamad et al., 2018), wind turbines (Ren et al., 2017), commuter trains (Ciccarelli et al., 2014), photovoltaic (PV) installation (Masaki et al., 2019) and so on. On either hand, novel ideas and newer materials, such as hybrid SCs with increased energy density, have been proposed to generate the new potential for usage in SC (Jasni et al., 2018). SC solutions will address efficiency, reliability, preservation, and budget constraints on either side. Supercapacitors play an important role in the adoption of renewable energy-producing technology. Three points are highlighted:

1. High power density of supercapacitor significantly increases the performance of renewable power generation by rapidly response to any voltage fluctuation. Renewable resources (PV/wind/etc) may be able to disconnect from grid system if an energy storage fails to respond to any changes in renewable resources (either PV/Wind).
2. If the renewable energy generation process fails, the supercapacitor energy storage can be employed. Supercapacitors might occasionally be load-enforceable in a variety of scenarios, such as at night, during solar power production, when there is no wind, or during maintenance time, among others. The capacity of the power storage device is determined by the load requirement. In case of renewable energy turns into halt for a while, energy storage will come in while waiting for the renewable resource to respond. If there is still no respond from energy resource, this energy resource will stop supplying the load and the conventional generator will continue the supply.
3. Supercapacitor would also be an ideal solution for the power storage subsystems of the short duration UPS in the field of reinstatement power production.

Table 7
The distinctions among several battery systems.

Specifications	Lead acid	NiCd	NiMH	Li-ion		
				Cobalt	Manganese	Phosphate
In practice since	Late 1800 s	1950	1990	1991	1996	1999
Internal resistance (mU)	< 100 12 V pack	100-300 6 V pack	200-300 6 V pack	150-300 7.2 V	25-75 per cell	25-50 per cell
Specific energy density (Wh/kg)	30-50	45-80	60-120	150-190	100-135	90-120
Fast charge time	8-16 h	1 h typical	2-4 h	2-4 h	1 h or less	1 h or less
Cycle life (80% discharge)	200-300	1000	300-500	500-1000	500-1000	1000-2000
Overcharge tolerance	High	Moderate	Low	Low. Cannot tolerate tickle charge		
Cell voltage (nominal)	2 V	1.2 V	1.2 V	3.6 V	3.8 V	3.3 V
Peak load current	5 C	20 C	5 C	> 3 C	> 30 C	> 30 C
Self-discharge/month (room temp.)	5%	20%	30%	< 10%		
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20		3.60
Discharge cutoff voltage (V/cell, 1 C)	1.75	1.00		2.50-3.00		2.80
Best result	0.2 C	1 C	0.5 C	> 1 C	< 10 C	< 10 C
Charge temperature	-20 to 50 ∘C (−4 to 122 F)	0 to 45∘C (32 to 113 ∘F)		0 to 45 ∘C (32 to 113 ∘F)		
Discharge temperature	-20 to 50 ∘C (−4 to 122 ∘F)	-20 to 65 ∘C (−4 to 49 ∘F)		-20 to 60 ∘C (−4 to 140 ∘F)		
Safety requirements	Thermally stable	Thermally stable, fuse protection common		Protection circuit mandatory		
Maintenance requirement	3-6 months (topping charge)	30-60 days (discharge)	60-90 days (discharge)	Not required		
Toxicity	Very high	Very high	Low	Low		

As shown in Fig. 10, SCs are categorized into three categories based on charge storage philosophies: electric double-layer capacitor (EDLC), pseudocapacitor (PC), and a hybrid supercapacitor (HSC) (Zhi et al., 2013). The standard electrode material and storage technique are also discussed. Some divisions could be created in addition to PC and HSC (Shao et al., 2018). Furthermore, Li and Wei (Li and Wei, 2013) identified EDLC and PC as symmetrical SCs and demonstrated the asymmetrical characteristic from the substrate and electrode construction angle. Shao and his team (Shao et al., 2018) classified SCs into three types: EDLC, PC, and There are two kinds of strategies principles for the charge storage of SCs, which are entirely dependent on the electrode material (a) Pseudo-capacitance, which is launched as a result of the redox reaction of the electrode material with the electrolyte and (b) Electrical dual-layer (EDL) capacitance, which results as a result of the EDL near the outer part of the electrode, whose gathering of electrons at the electrode is a non-Faradaic method (Masaki et al., 2019; Zhi et al., 2013).

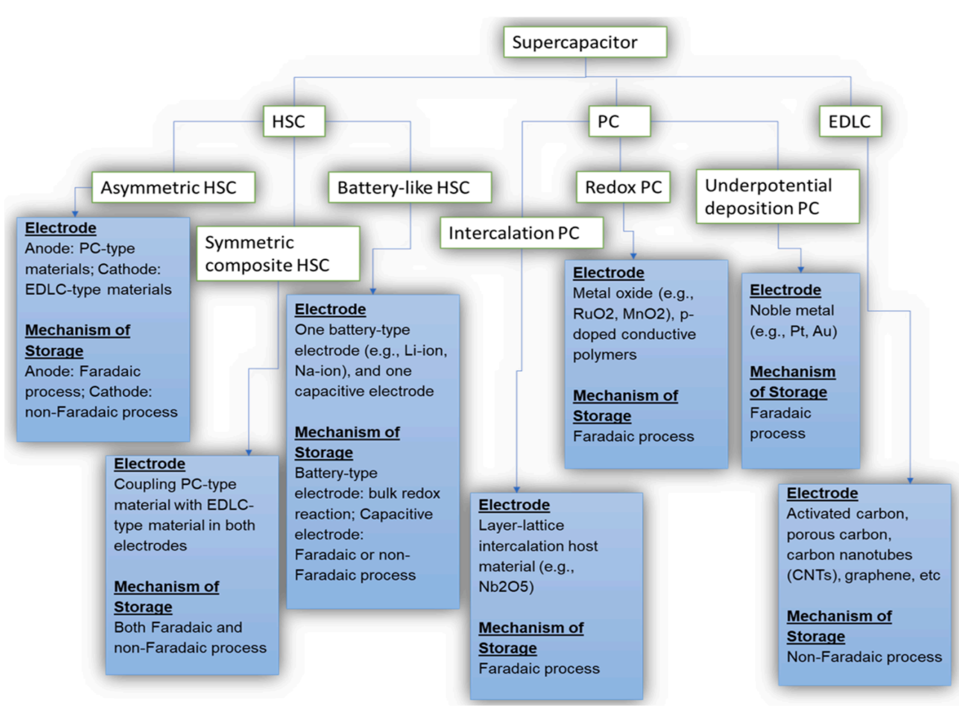

Fig. 10. Supercapacitor classification, electrode materials, and storage technique are all factors to consider.

6. Open issues and challenges

Although the blockchain IoT technology has immense potential, the application of blockchain IoT for electrical energy sector continues to present considerable difficulties for experts. Innovative thinking and experimentation are critical in all areas of blockchain IoT technology and application development. There are several recognized technological limits, which includes security, infrastructure, scalability and resources.

6.1. Security

The gathering, exchange, and use of data as a result of the IoT has raised legitimate concerns about data security and privacy. Moreover, blockchain's security has yet to be established to the point where it attracts the attention of cyber criminals. This is due to the fact that blockchain has not yet been proven to be secure. In addition, once blockchains are adopted, there is a risk of a lack of flexibility, besides user-friendliness issues the data protection, and the key management must also be addressed (Fernández-Caramés and Fraga-Lamas, 2018). However, because of its distributed architecture, blockchain is considered a suitable data security and privacy method for IoT applications. As one-to-one energy trading is widespread in numerous IoT scenarios, untrustworthy and opaque energy markets are a frequent source of security and privacy concerns in these situations. In terms of privacy, the concept of smart contracts in blockchain technology necessitates users to authenticate their identity using integrated smart home resource services (Tyagi et al., 2023). IoT demands ongoing generation and transmission of user data, which may expose consumers to privacy breaches (Rejeb et al., 2024). Some address the security concerns in energy trading system based on consortium blockchain technology, an executable transactions without the involvement of a trusted middleman (Li et al., 2018). Because centralised systems have a single point of failure, they are more prone to technological failures as well as hostile attacks (Armbrust et al., 2010), which makes them less secure.

Unchained ledger of transactions in chronological order is stored in a blockchain, which is a digital data structure that is shared and distributed among many users and computers. The data structure is an open-ended record of transactions and data records that may be accessed by programmers and used to create executables. Tradition has it that the solution is to utilise a single central point of authority. This authority operates as a trusted middleman between transacting parties and is responsible for storing, safeguarding the validity of the ledger, and maintaining the records' accuracy. When a large number of consumers are concurrently using the ledger, a central authority controls the concurrency and consolidates all ledger alterations in one place. The use of central administration sometimes not viable or required in some situations since it imposes intermediary costs on network users and forces them to rely on a third party to maintain and manage the system (Andoni et al., 2019). Other emerging problems are consumer privacy, anonymity, and the supervision of blockchain networks, which often violates normal residential protocols.

6.2. Infrastructure

For blockchain IoT applications energy system structure there are few primary obstacles to overcome: computational complexity, scalability (scope of network operation) (Koshy et al., 2020). These difficulties could have a bad effect on the development of certain blockchain IoT-based applications in the future. Connected central grid, point to point communities will be unable to operate independently of grid operators due to the reconciliation requirements. In addition, the energy consumption necessary for the execution of computationally demanding consensus algorithms such as proof of work is a substantial barrier in the way of widespread adoption. By 2025, the best-case scenario predicts that global energy amount will have doubled, and the worst-case scenario predicts that it will have tripled. The blockchain technology, which, if extensively implemented, has the potential to exacerbate the situation. Additionally, the difficulty of public perception, given that blockchain has just recently gained public legitimacy and the possibility of disillusionment if implementations do not meet expectations. The level of difficulty and the size of the Merkle tree determine the computational complexity. The Merkle tree is a tree in which every leaf node is labelled with the cryptographic hash of the labels of its child nodes, and every nonleaf node is labelled with the cryptographic hash of the labels of its child nodes. As the number of transactions increases, the Merkle tree grows in size, increasing the time it takes to complete a energy transaction, which is inconvenient for an IoT network.

Scalability refers to the number of transactions that a blockchain can process in a given time period. One important problem is combining scalability and affordability while keeping desirable decentralisation and security aspects. Regulatory bodies are putting pressure on utilities to be more open (Andoni et al., 2019), any cost-cutting or efficiency-improvement opportunity in the functioning of energy systems and markets should be investigated. The potential for cost savings is not confined to utilities; it can also be crucial to energy users and prosumers (Andoni et al.,), who are suffering growing energy bills. Blockchain technologies, on the other hand, must solve a number of challenges before they can be extensively deployed. Due to the fact that one blockchain design solution does not fit all applications and use cases, hybrid of private and public blockchains are required. Speed, scalability, and resource efficiency are all important performance qualities, and the resulting system architecture and consensus mechanism utilized in the system environment are both accountable for these characteristics. While blockchain's intrinsic data integrity, security, and independent domination able to assist IoT data management and allocation, it remains an architectural issue (Yánez et al., 2020). Additionally, nomenclature is extensively used to characterize digital consensus systems, algorithms, and domains of applications that are constructed on top of blockchain frameworks.

6.3. Resources

Blockchain technology is currently widely adopted and employed as a result of its support for transaction trust and security in the next generation society. Mining blockchain utilizing the IoT has been an important blockchain development trend, making blockchain more popular and decentralized. However, because to their scarcity, present IoT resources are unable to meet the enormous demands for on-demand energy consumption in the mining process in a decentralized manner (Li et al., 2019). Direct adoption of blockchain technology in an IoT-based system is now hard due to a lack of processing capacity, bandwidth, and the need to conserve electricity (Motlagh et al., 2020). Accordingly, commercial and residential buildings consume more than a third (if not more) of all energy. As a result, even minor reductions in energy use or waste can have considerable environmental and economic effects. There are significant problems in creating energy settings due to a wide range of divergent datasets and varying controller setups. Building controls that are centralised, like other centralised structures, are more efficient yet have a single point of failure. Decentralized or distributed designs, on the other hand, are more complex to construct since they usually require substantial coordination and communication across disparate regulating systems. As the amount of unified renewable energy sources such as solar and wind continues to grow, energy networks must adapt quickly to accommodate the increased demand.

Over the last few years, the use of renewable energy sources has increased substantially, boosted by privatisation, decommissioning of the energy industry, energy policy initiatives, and financial incentives (Andoni et al., 2019). Because renewable energy sources are unpredictable, hard to foresee, and dependent on the surroundings climate, they present additional challenges in the administration and monitoring of electrical networks, necessitating the adoption of more flexible management and administration practises in order to maintain stability and operation safeness (Eid et al., 2016). Flexibility features involve the combination of energy storage services, fast-acting supply, and demand response, to name a few examples. Smart meters continue to be greeted with opposition from consumers, despite the numerous advantages they provide. It is necessary to do additional research to better understand customer acceptability of smart meters in order to ensure the successful deployment of smart meters (Escobar et al., 2021). As a result of these issues, researchers are developing a smart meter to determine the moderating role of occupancy innovativeness variables for residential consumers who use smart meters.

6.4. Green-IoT

The development of the world today demonstrates that concern for the environment and climate change of the world is growing. The life cycle of green IoT is depicted in Fig. 11, which considers green design, green production, green consumption, and eventually green disposal and recycling to have minimum or no environmental impact (Alsamhi et al., 2021). In the IoT industry, the same situation occurs. Much research and development have been proposed in the direction of a green Internet of Things. For example, a green cloud computing network, a green sensing network, and a green RFID tag are all examples of green technologies, as illustrated in Fig. 12. The usage of Radio Frequency Identification (RFID), which is gaining traction in society, is a prudent step toward the use of green devices (Komal et al., 2021). RFID is a small electronic device that does not contain hazardous elements and consists mostly of RFID tags and small tag readers. The system is capable of efficiently and effectively storing information in relation to what has been set in relation to what has been linked.

In general, 2 types of RFID tags are commonly used, namely active tags and passive tags. The main difference between the two types of RFID tags is the use of batteries (Albreem et al., 2021). Active tags use an external battery as a power source. Whereas, Passive Tag does not use batteries and only gets energy from the tag reader device through the infrared signal that is connected when the system is working. In order to achieve the goal of green RFID, several progressive measures have been carried out as scheduled in Fig. 12. Among the major studies conducted, the reduction of RFID tag size is able to reduce the quantity of non -biodegradable material. In addition, the use of RFID tags with small print has been explored. There are also, energy-efficient RFID tagging measures being introduced toward green RFID technology. In addition to the use of RFID systems, the green wireless sensor network (WSN) system is a technology that has the potential to be developed to achieve the goal of green IoT adoption (Nagarajan et al., 2022). Conventionally, a WSN system consists of several uses of sensor nodes with limited power resources and storage capacity. Towards achieving a green WSN system, several techniques have been identified to help achieve that goal (Thilakarathne et al., 2022). Among them, the use of idle or sleep mode on sensors is used to minimize energy consumption. Second, the use of sustainable energy source systems for the purpose of recharging and continuous use such as fuel cell systems. Third, hybridize the kinetic system from the surrounding vibrations to optimize the energy source. Fourth, data size reduction to reduce storage capacity by optimizing the context-awareness algorithm. Fifth, reduce energy consumption for system mobility. In addition, the use of green internet technology is also a major electronic device nowadays because a lot of human work and management is highly dependent on this system (Albreem et al., 2017). Therefore, the main hardware and software based on green internet are very necessary to work without reducing the performance of internet speed. Green IoT technology is leading to the development of smart grid systems, green sustainable energy, and the development of smart cities.

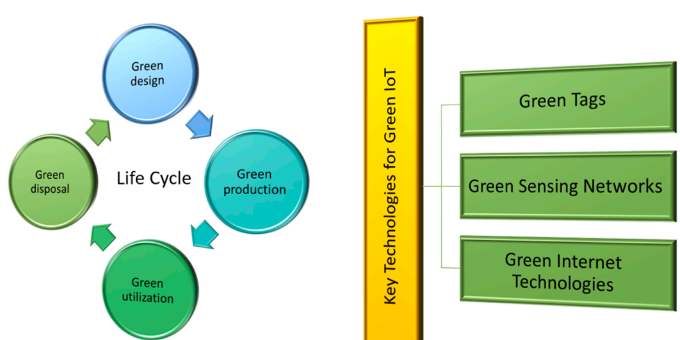

Fig. 11. Life cycle with the key technologies of green IoT (Albreem et al., 2017).

7. Conclusion

The energy for residential IoT systems appears to be the most promising, probably because it is fungible, convertible, and dispersed. Energy appears to be ideally managed using blockchain technology, as it is transparent, secure, and decentralized. To apply blockchain technology for power trade, tracking, and certification presents several technical hurdles, which includes security, resources, infrastructure and green-IoT. The most common security is on the blockchain technology's smart contract that requires users to prove their identity via unified smart home resource services. While in term of the resources, thermal, light, electromagnetic, chemical, and mechanical resources can all be used to extract energy for the residential IoT systems. Using hydrocarbons or other fuels in fuel cells has demonstrated greater efficiency than batteries. For example, methanol fuel boasts a high energy density of 17.6 kJ/cm, six times that of lithium batteries. Although the voltage is constant, current density influences performance, requiring a backup power plant to address this weakness. Traditional human energy needs have long been met by fossil fuels, offering high-power density at a low cost, but they suffer from maintenance, transportation, and size issues. To overcome these challenges, scientists are developing miniature heat engines, which offer high-power density and long power supply for wireless sensor applications. In contrast, photovoltaic (PV) systems with solar panels lasting over 25 years and LEDs with a lifespan of about 15 years are more durable. To meet a 15-year target and optimize system longevity, the battery should endure around 5000 cycles with an 80% depth of discharge, aligning with the life expectancy of LED lights.

Hybrid energy storage systems can further increase the performance of single energy storage in handling fluctuated behavior of energy resources. Integrating power and hydrogen storage into the microgrid changes its operation and hydrogen connection. Hydrogen, stored as metal hydride, activates fuel cells when the battery's charge drops below 20%. An Energy Management System (EMS) ensures safe power flow. Peak powers for IoT resources vary: Li coin cell - 110 $mWcm^{-3}$, Li-ion 18650 - 2170 $mWcm^{-3}$, Fuel cell - 145 $mWcm^{-3}$, Supercapacitor - 128 $mWcm^{-3}$, Dedicated RF - 0.440 $mWcm^{-3}$, Solar (outdoors) - 26.7 $mWcm^{-3}$, Solar (indoors) - 0.0926 $mWcm^{-3}$, Mechanical (piezoelectric) - 0.375 $mWcm^{-3}$, Mechanical (active human motion) - 8.5 $mWcm^{-3}$. Balancing the benefits and hurdles are necessary since blockchain IoT technology ease the residential energy system management. For consumers and residential renewable energy producers, blockchain IoT enables market participation and monetization. High-density and efficient usage must be achieved in future work for better energy comprehend and maximizing the possible potentials. Predictions indicated that by the end of 2020, there would be 20 billion connected IoT devices globally. In 2019, the global IoT market was valued over $1.7 billion, with consumer electronics leading the industry. Home automation was expected to grow from $76.60 billion in 2018 to $151.40 billion by 2024, showing a 12.020% compound annual growth rate. The global energy market for IoT surpassed $6.8 billion in 2015, projected to reach $26.5 billion by 2023 with a 15.5% compound annual growth rate from

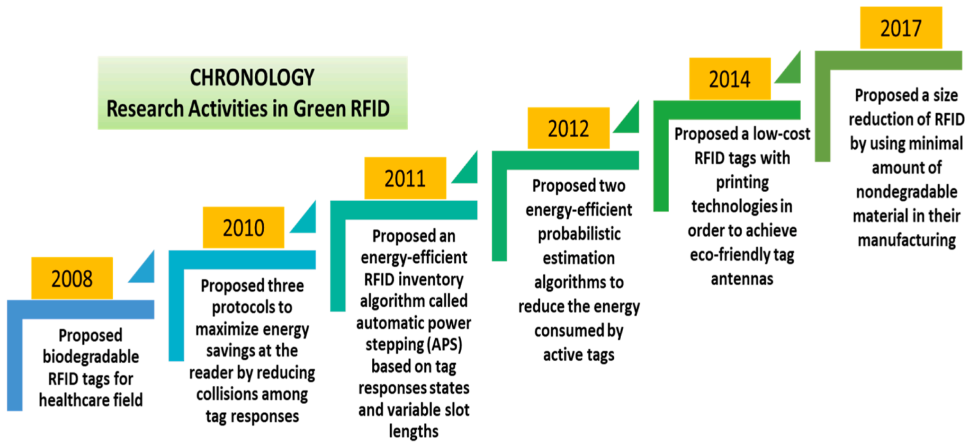

Fig. 12. Chronology of research activities in green RFID.

2016 to 2023. About 45% of connected industry projects were underway in the United States, including 7% in related industries and 3% in smart city environments. As active IoT devices increased from 7.001 billion in 2018 to 22 billion in 2025, LPWAN played a crucial role, offering low-data connectivity and low-power capabilities, enabling devices to operate autonomously for up to 10 years. The global IoT industry was expected to grow from $157 billion in 2016 to $457.0 billion by 2020, driven by a compound annual growth rate of 28.5%. Industrial IoT, smart cities, and connected health were predicted to hold major market shares at 24%, 26%, and 20%, respectively, followed by connected cars (7%), smart homes (14%), wearables (3%), and smart utilities (4%).

CRediT authorship contribution statement

Hasan Nor Shahida: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Aman Azana Hafizah Mohd:** Conceptualization, Data curation, Supervision, Validation. **Bashi Zainab S. Attar:** Conceptualization, Investigation, Methodology, Project administration, Resources. **Shaari Norazuwana:** Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Bawazeer Shaikhan:** Formal analysis, Funding acquisition, Investigation, Project administration. **Iftikhar Saman:** Data curation, Formal analysis, Project administration, Resources, Supervision, Validation. **Osman Siti Hasanah:** Conceptualization, Data curation, Software, Visualization, Writing – original draft, Writing – review & editing.

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.

Data Availability

No data was used for the research described in the article.

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