Integration of IoT in Energy Sector

Khandoker Hoque
Masters in Electrical and Electronics Engineering,
School of Engineering,
San Francisco Bay University,
Fremont, CA 94539, USA

Md Boktiar Hossain
Masters in Electrical and Electronics Engineering,
School of Engineering,
San Francisco Bay University, Fremont, CA 94539, USA

Denesh Das
Department of Electrical and Computer Engineering,
Lamar University, Beaumont, Texas 77710, USA

Partha Protim Roy
Department of Civil and Environmental Engineering,
Lamar University, Beaumont, Texas 77710, USA
Department of Irrigation and Water Management, Sylhet Agricultural University, Sylhet-3100, Bangladesh.

ABSTRACT
The incorporation of renewable energy sources and the efficient utilization of energy are crucial factors in facilitating sustainable energy transitions and addressing the issue of climate change. The Internet of Things (IoT) is a modern technology that has numerous applications in the energy sector. These applications include energy supply, transmission and distribution, as well as demand management. The utilization of IoT can enhance energy efficiency, augment the proportion of renewable energy, and mitigate the environmental consequences of energy consumption. This study examines the current body of literature about the use of Internet of Things (IoT) technology in energy systems, with a specific focus on its application in smart grids. In addition, we explore the enabling technologies of the Internet of Things (IoT), such as cloud computing and other platforms for data analysis.

Keywords
IoT, Energy, Wireless Technologies, Data analytics, Smart Grids

1. INTRODUCTION
The advent of the Internet of Things (IoT) marks a significant turning point in the ongoing evolution of industrial revolutions, particularly within the energy sector. The IoT, a vast network of interconnected devices capable of collecting and exchanging data, is transforming the way energy systems operate. This transformation is characterized by the integration of smart technologies that enable real-time monitoring, control, and optimization of energy production, distribution, and consumption

In recent years, the energy sector has increasingly adopted IoT technologies to address the growing demand for efficient, reliable, and sustainable energy solutions. IoT-enabled devices, such as smart meters, sensors, and connected infrastructure, provide granular visibility into energy flows, allowing for precise management and forecasting. These devices collect vast amounts of data on energy usage patterns, environmental conditions, and equipment performance, which are then processed and analyzed to enhance decision-making processes.

One of the key benefits of IoT in the energy sector is its ability to improve energy efficiency. By continuously monitoring energy consumption and identifying inefficiencies, IoT systems can suggest and implement corrective measures, reducing wastage and lowering costs. For instance, smart grids utilize IoT technologies to balance supply and demand dynamically, ensuring optimal distribution of electricity and minimizing losses.

Furthermore, IoT contributes to the development of renewable energy sources by enabling better integration and management of distributed energy resources (DERs) such as solar panels and wind turbines. IoT devices can monitor the performance and health of these assets in real-time, predict maintenance needs, and optimize their operation to maximize output. This capability is crucial in transitioning to a more sustainable energy landscape, where renewable sources play a significant role [1-12].

The implementation of IoT in the energy sector also enhances reliability and resilience. Predictive maintenance, powered by data analytics and IoT sensors, allows for early detection of potential equipment failures, reducing downtime and preventing costly outages. Additionally, IoT facilitates the creation of more resilient energy systems by enabling real-time response to disruptions, such as natural disasters or cyber-attacks, through automated controls and quick rerouting of power [12-25].

Moreover, IoT is pivotal in empowering consumers to play a more active role in energy management. Smart home technologies, connected appliances, and mobile applications provide users with detailed insights into their energy consumption, enabling them to make informed decisions and adopt energy-saving behaviors [26-29]. This consumer empowerment leads to a more decentralized and participatory energy market, where demand-side management becomes more effective.

2. Internet of Things (IoT)
The Internet of Things (IoT) is a developing technology that utilises the Internet to establish communication among physical items or "things" [30]. Physical devices encompass a wide range of objects, such as household appliances and machinery used in industrial settings. By utilising suitable sensors and communication networks, these devices can collect useful data and facilitate the provision of a wide range of services for individuals. Controlling the energy usage of buildings in a smart manner allows for a reduction in energy expenses [31]. The Internet of Things (IoT) has a diverse array of applications, including but not limited to manufacturing, logistics, and the construction industry [32]. The Internet of Things (IoT) is extensively utilized in several fields such as environmental monitoring, healthcare systems and services, energy

management in buildings, and drone-based services [33,34,35,36].

The initial phase in developing IoT systems involves selecting the proper components, such as sensor devices, communication protocols, data storage, and calculation methods, that are suitable for the desired application. For instance, an Internet of Things (IoT) platform designed to regulate the heating, cooling, and air conditioning (HVAC) system in a building necessitates the use of appropriate environmental sensors and communication technology [37]. Figure 1 depicts the distinct constituents of an Internet of Things (IoT) platform [38]. IoT devices, which are integral parts of IoT platforms, can take the shape of sensors, actuators, IoT gateways, or any device that participates in the process of collecting, transmitting, and processing data. An IoT gateway device facilitates the transfer of data into the IoT system and enables two-way communication between the device and the gateway, as well as between the gateway and the cloud.

The communication protocols, which form the third component of the IoT platform, facilitate the exchange of data between devices and the controllers or decision-making centers. IoT platforms provide the option to choose from various communication technologies, each with its own distinct capabilities, based on the specific requirements of the application. Some examples of these technologies are Wi-Fi, Bluetooth, ZigBee [39], as well as cellular technologies as LTE-4G and 5G networks [40]. The data storage is a crucial component of the IoT platform that facilitates the organization and control of data acquired from the sensors.

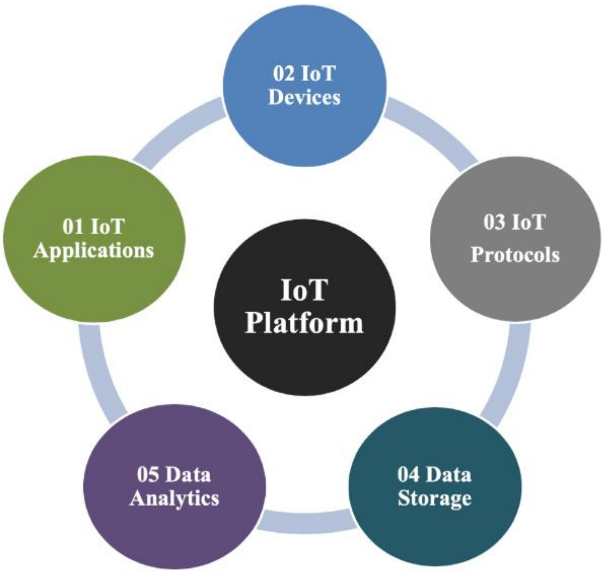

Fig. 1: Components of an IoT platform

The data collected from the gadgets is inherently substantial. This requires the development of a well-organized data storage system that can be located either on cloud servers or at the edge of an IoT network. An integral part of IoT platforms, the fifth component consists of stored data that is utilized for analytical reasons. Data analytics can be conducted offline after data storage or in the form of real-time analytics. Data analytics is conducted to inform decision-making regarding the functioning of the application. Data analytics can be conducted either offline or in real-time, depending on the requirements. In offline analytics, data is initially gathered and subsequently displayed on-site using visualization tools. Real-time analytics utilize cloud or edge servers to offer visualization, such as data analytics [41].

3. ENABLING TECHNOLOGIES

The Internet of Things (IoT) is a paradigm where objects and elements within a system are equipped with sensors, actuators, and processors, enabling them to communicate and provide meaningful services. In IoT systems, sensors collect data, which is routed through gateways to control centers or the cloud for storage, processing, analytics, and decision-making. Once a decision is made, a corresponding command is sent back to the actuator in response to the sensed data. Given the variety of sensor and actuator devices, communication technologies, and data computing approaches, this section discusses the existing technologies enabling IoT. Additionally, examples from literature on their application in the energy sector are provided.

3.1 Sensor Devices

Sensors are crucial drivers of IoT, collecting and transmitting data in real-time, thus enhancing the effectiveness and functionality of IoT systems [42]. Different sensors are developed for various applications, such as agriculture, environmental monitoring, healthcare, and public safety [44]. In the energy sector, sensors are employed in energy production, transmission, and distribution to create cost and energy savings. They enable smart energy management systems, real-time energy optimization, and new approaches for energy load management. Research trends focus on developing sensor applications to improve load shaping, consumer awareness, and renewable energy production [45].

Temperature Sensors: These sensors detect heating and cooling fluctuations, which are vital in converting mechanical energy into electrical energy in power generation. They also optimize system performance by managing ventilation and cooling systems in residential areas [46, 42].

Humidity Sensors: Used to measure air moisture and humidity, these sensors are critical in wind energy production, especially for offshore turbines. They monitor moisture levels to ensure optimal turbine operation and reduce energy costs [47].

Light Sensors: These sensors measure luminance or brightness and are used to control lighting levels automatically. They help reduce energy consumption in buildings by adjusting indoor and outdoor lighting based on ambient light levels [48, 49, 19].

Passive Infrared (PIR) Sensors: Also known as motion sensors, PIR sensors detect infrared radiation from surrounding objects. They reduce energy consumption in buildings by controlling lighting and air conditioning systems based on occupancy [50, 48].

Proximity Sensors: These sensors detect nearby objects without physical contact and are used in wind energy production. Applications include blade pitch control, yaw position monitoring, and rotor speed monitoring, enhancing the longevity and reliability of wind turbines [51, 52].

3.2 Actuators

Actuators convert energy into motion, taking electrical input from automation systems and acting on devices and machines within IoT systems [53]. They produce various motion patterns such as linear, oscillatory, or rotational motions. Actuators are categorized based on their energy sources:

Pneumatic Actuators: These use compressed air to generate motion and are ideal for processes requiring quick and precise responses without needing large motive force.

Hydraulic Actuators: Utilizing liquid for motion, these actuators are suitable for industrial processes that require high speed and large forces.

Thermal Actuators: These actuators convert thermal energy into kinetic energy. Typically, they consist of a temperature-sensing material that changes volume with temperature, used in industrial processes where temperature-based motion is needed.

Electric Actuators: These actuators convert electrical energy into kinetic energy, either in a linear or rotary motion, and are commonly used in energy-efficient control systems in power plants [54, 55].

In the energy sector, pneumatic actuators control valves in power plants, while electric actuators enhance energy efficiency and control various operations [55]. Specific actuators, like LINAK electric actuators, minimize energy waste in wind turbines and solar panels. Literature also highlights IoT applications using actuators, such as wireless sensor and actuator networks to reduce overall energy consumption through optimized device and machine operations [56].

3.3 Comparison of Various Wireless Technologies

This table provides a detailed comparison of different wireless technologies based on various parameters:

LoRA: Suitable for long-range, low-power applications like smart buildings. Features include robustness against interference and low data rate.

NB-IoT: Ideal for smart grid communication with low power usage and deep indoor penetration.

LTE-M: Used for smart meters, offering high data rates, mobility support, and security.

Sigfox: Applied in smart buildings for low data rate applications with ultra-narrowband communication and long battery life.

Weightless: Flexibly used for smart meters, providing high reliability and frequency flexibility.

Bluetooth: Common in smart home appliances, characterized by short range, high data rate, and ease of integration.

Zigbee: Employed in renewable energy systems for smart metering, known for mesh networking, low power, and scalability.

Satellite: Used in solar and wind power plants for global coverage, though it has high latency and installation costs.

Technology	Range	Data Rate	Battery Life (Power Usage)	Security	Installation Cost	Example Applications	Key Features
LoRA	≤50 km	0.3–38.4 kbps	Very low (8–10 years)	High	Low	Smart buildings (smart lighting)	Long range, low power, robust against interference
NB-IoT	≤50 km	≤100 kbps	High (1–2 years)	High	Low	Smart grid communication	Low power, wide area, deep indoor penetration
LTE-M	≤200 km	0.2–1 Mbps	Low (7–8 years)	High	Moderate	Smart meter	High data rate, mobility support, secure
Sigfox	≤50 km	100 bps	Low (7–8 years)	High	Moderate	Smart buildings (electric plugs)	Ultra-narrowband, long battery life, low data rate
Weightless	≤5 km	100 kbps	Very long	High	Low	Smart meter	Flexibility in frequency, high reliability
Bluetooth	≤50 m	1 Mbps	Low (few months)	Low	Low	Smart home appliances	Short range, high data rate, easy integration
Zigbee	≤100 m	250 kbps	Very low (5–10 years)	High	Low	Smart metering in renewable energy systems	Mesh networking, low power, scalable
Satellite	Very long (>1500 km)	100 kbps	Low	High	Costly	Solar and wind power plants	Global coverage, high latency, reliable

4. IOT IN THE ENERGY SECTOR

Today, the energy sector remains heavily reliant on fossil fuels, which account for nearly 80% of the world's final energy consumption. The excessive extraction and combustion of these fuels lead to severe environmental, health, and economic consequences, including air pollution and climate change. To mitigate these adverse effects, improving energy efficiency—using less energy to deliver the same service—and increasing the deployment of renewable energy sources are crucial strategies

4.1 Role of IoT in Energy Generation

In the power sector, the automation of industrial processes and supervisory control and data acquisition (SCADA) systems has been prominent since the 1990s. These early IoT applications contributed significantly to monitoring and controlling equipment and processes, reducing risks of production losses and blackouts. Today, IoT is vital in addressing the challenges faced by aging power plants, such as reliability, efficiency, environmental impacts, and maintenance issues. Many power sector assets are over 40 years old, expensive, and not easily replaceable. IoT helps mitigate these challenges by using sensors to monitor equipment for failures or efficiency drops, triggering maintenance alerts. This enhances system reliability and efficiency while lowering maintenance costs.

For example, an IoT-enabled power plant can save approximately USD 230 million over its lifetime, and existing plants of similar size can save up to USD 50 million when retrofitted with IoT systems. This is due to the improved monitoring and predictive maintenance capabilities offered by IoT technology.

The integration of variable renewable energy (VRE) sources like wind and solar introduces the "intermittency challenge," where matching energy generation with demand becomes difficult. IoT provides solutions for balancing energy supply and demand, facilitating higher shares of clean energy integration and reducing greenhouse gas (GHG) emissions. Machine learning algorithms can optimize the balance of various supply and demand technologies, enhancing the efficiency of energy use.

For instance, artificial intelligence can manage the power output from thermal power plants alongside in-house renewable sources, such as aggregating outputs from numerous small-scale solar PV panels.

Recent data indicates significant growth in the adoption of smart meters and other IoT technologies in the energy sector. Europe, for example, saw a 47% penetration of smart electricity meters by the end of 2023, with countries like France, Spain, and Italy leading nationwide rollouts. Germany has set ambitious targets to complete its smart meter rollout by 2032, despite currently lagging behind with only 4% deployment.

In the Middle East and Africa, Saudi Arabia and the UAE are leading the way, with Saudi Arabia deploying approximately 11 million smart meters and the UAE expected to complete its rollout by 2029. Latin America, however, has been slower in adoption due to regulatory delays, though countries like Uruguay aim to complete their rollouts by 2026.

Technological advances in IoT, including improvements in chips, connectivity, security, and artificial intelligence, are driving down costs and enabling more efficient devices. These innovations are opening up new applications and markets, transforming industries by embedding connectivity into traditional products and processes.

In summary, the IoT landscape in energy generation is rapidly evolving, with significant advancements in smart metering and predictive maintenance technologies. These innovations are crucial for enhancing the efficiency, reliability, and sustainability of power systems worldwide

4.2 IoT in Smart Grids

Smart Grid" signifies a modern era of electricity management that leverages information technology to enhance the generation, delivery, and consumption of electricity. Smart grids have been proposed as a viable solution to mitigate electrical energy waste by addressing the challenges faced by traditional power grids, such as efficiency, stability, security, power quality, and the continuously growing demand for electrical energy [46, 47]. A typical smart grid topology, as illustrated in Fig. 3, includes sectors for power flow and power systems. These sectors are interconnected through the processes of power production, transmission, distribution, and presumption, enabling them to independently consume or generate electrical power.

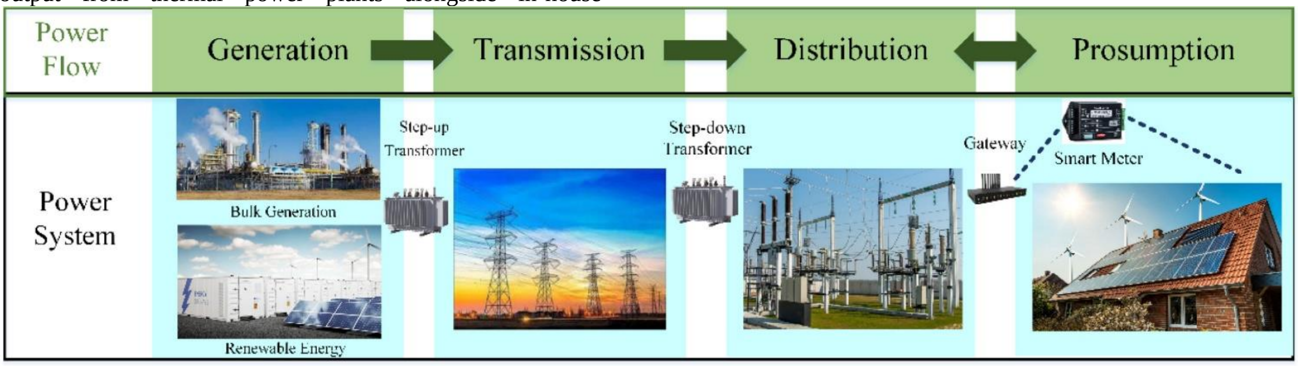

Fig. 2: Representing SG architecture for power flow and power systems [48]

In conventional grid systems, the absence of real-time monitoring requires end users to report abnormal events and service interruptions. In contrast, Smart Grids (SG) utilize IoT technology with unique IP addresses to monitor all grid components in real time. IoT technology plays a crucial role in identifying SG data, network structure, procedures, data storage security, and measurements [49]. It can be integrated into all SG components, including power production, transmission, distribution, and consumption [50, 51].

IoT technology has been employed to supervise and maintain energy production and consumption, manage energy storage, handle distributed power plants, and monitor renewable energy sources (RESs) [52, 53]. Additionally, IoT can monitor transmission lines and substations [52, 53]. For end-user applications, IoT is used in smart homes, to manage the charging and discharging of electric vehicle (EV) batteries, and for load control and energy management.

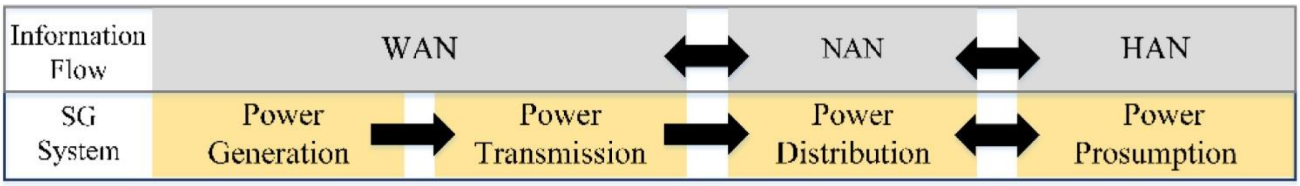

Fig. 3: Typical smart grid architecture.

A typical IoT-assisted smart grid topology is shown in Fig. 3 that comprises power production, transmission, distribution and presumption as well. Additionally, it has three networks for proper energy management and control. These are: Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN).

4.3 Smart Buildings

Energy consumption in urban areas can be categorized into residential buildings (domestic use), commercial services (shops, offices, schools), and transportation. In the residential sector, domestic energy consumption includes lighting, appliances, domestic hot water, cooking, refrigeration, heating, ventilation, and air conditioning (HVAC). HVAC systems typically account for around half of a building's energy consumption. Thus, managing HVAC systems effectively is crucial for reducing electricity consumption.

With technological advancements, IoT devices are increasingly significant in controlling energy losses in HVAC systems. For instance, wireless thermostats can be strategically placed based on occupancy patterns to detect unoccupied spaces. When an unoccupied zone is identified, actions can be taken to reduce energy consumption, such as decreasing HVAC operations in those areas. This targeted approach can lead to substantial reductions in energy usage and minimize losses.

5. FUTURE TRENDS

Applying current IoT systems for providing energy efficient solutions in the energy sector has many advantages highlighted in previous sections. However, for deploying IoT in the energy domain, new solutions and trends are needed to improve the performance of IoT and overcome the associated challenges. In this section, we present the Blockchain technology and Green-IoT as two approaches that can help to tackle some of the challenges.

5.1 Blockchain and IoT

Current IoT systems mostly rely on centralized cloud systems [54, 55]. In most IoT applications, thousands of IoT devices and machines need to be connected, which is hard to synchronize. Moreover, due to the centralized and server-client nature of IoT when server is vulnerable, all the connected objects are easy to be hacked and compromised, which result in security concerns for the system and privacy issues for users [56]. Fortunately, Blockchain can be a solution for this challenge [57].

Blockchain provides a decentralized and democratized platform with no need for third party’s intervention. The consensus platform of blockchain requires every IoT node proves that it pursues the same goal as others. Verified transactions is also stored in the form of a block, which is linked to the previous one in a way information can never be erased. Moreover, the history of every single transaction at every node can be recorded and is accessible by everyone. Therefore, any member in blockchain becomes aware of any changes in each block immediately [58,59,60]. Moreover, due to the distributed ledger of blockchain, even thousands of IoT devices can be synchronized easily. The consensus algorithms of blockchain based on peer-to-peer networks can provide a secure distributed database [56]. Therefore, decentralized and private-by-design IoT that can guarantee the privacy can be promised by blockchain [61].

More importantly, blockchain can store and share software updates between objects. There are innocuousness checking nodes that approve the accuracy of update information as a new node and guarantee its protection from any threats, once an update added to the blockchain as a valid block, it is impossible to erase or change it. Therefore, IoT-based platforms can be provided with updates availability and innocuousness through blockchain [62].

In the energy sector, the application of blockchain will accelerate the IoT effectiveness by providing a decentralized platform for distributed power generation and storage systems enhancing energy security and efficiency. Real and high-qualified data can be exchanged freely between devices and people can directly have access to energy information without the involvement of any third party. Neighbors can simply trade energy with one another. Therefore, without involvement of authorities, not only trust will be enhanced among people, but also many costs of this connection to the centralized grids can be saved. Another advantage is that by monitoring the usage statistics of an area, Blockchain enables the energy distribution to remotely control energy flow to that particular area. Furthermore, blockchain-based IoT systems helps in the diagnosis and maintenance of equipment within smart grid [57].

Currently, the direct application of blockchain technology in an IoT-based system is impossible due to lack of enough computational resources, insufficient bandwidth and the need to preserve power. However, cloud and fog computing platforms can ease the way for blockchain services in IoT [63].

5.2 Green IoT

The energy consumption of IoT devices is an important challenge, especially in large-scale deployment of these technologies in near future. To run billions of devices that will be connected to the Internet significant amount of energy is required. The big number of IoT devices will also produce a great deal of electronic waste [64]. To tackle these challenges, a low-carbon and efficient communication networks are needed. Fortunately, these necessities has led to the appearance of the green IoT (G-IoT) [65, 66]. The key component of G-IoT is its energy-efficient characteristics throughout the life cycle, i.e., design, production, deployment, and ultimately disposal.

G-IoT cycle can be applied in different IoT technologies. For example, in radio frequency identification (RFID) tags. To decrease the amount of material in each RFID tag, which is difficult to be recycled, the size of RFID tags are reduced [67-76]. Green M2M communications is another example, which enables adjusting power transmission the minimum level, facilitates more efficient communication protocols using algorithmic and distributed computing techniques [77-80]. In wireless sensor networks also the sensors nodes can be in the sleep mode and just work when necessary. In addition, radio optimization techniques, such as, modulation optimization or cooperative communication can be applied to reduce the power consumption of the nodes. Moreover, energy-efficient routing techniques, such as, cluster architectures or multi-path routing can provide efficient solutions [130,131]. In conclusion, the above-mentioned approaches and examples can reduce the energy needs of IoT systems.

6. CONCLUSIONS

Energy systems are on the threshold of a new transition era. Large-scale deployment of VRE in distributed energy systems and the need for efficient use of energy calls for system-wide, integrated approaches to minimize the socio-economic-environmental impacts of energy systems. In this respect, modern technologies such as IoT can help the energy sector transform from a central, hierarchical supply chain to a decentralized, smart, and optimized system. In this paper, we review the role of IoT in the energy sector in general, and in the context of smart grids particularly.

We classify different use cases of IoT in each section of the energy supply chain, from generation through energy grids to end use sectors. The advantages of IoT-based energy management systems in increasing energy efficiency and integrating renewable energy are discussed and the findings are summarized. We discuss different components of an IoT system, including enabling communication and sensor technologies with respect to their application in the energy sector, for example, sensors of temperature, humidity, light, speed, passive infrared, and proximity. We discuss cloud computing and data analytic platforms, which are data analysis and visualization tools that can be employed for different smart applications in the energy sector, from buildings to smart cities.

7. REFERENCES

[1] Stearns, P.N. Reconceptualizing the Industrial Revolution. J. Interdiscip. Hist. 2011, 42, 442–443.

[2] Mokyr, J. The second industrial revolution, 1870–1914. In Storia dell'Economia Mondiale; Citeseer, 1998; pp. 219–245. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.481.2996&rep=rep1&type=pdf (accessed on 30 August 2024).

[3] Jensen, M. The Modern Industrial Revolution, Exit, and the Failure of Internal Control Systems. J. Financ. 1993, 48, 831–880.

[4] Kagermann, H.; Helbig, J.; Hellinger, A.; Wahlster, W. Recommendations for Implementing the Strategic Initiative Industrie 4.0: Securing the Future of German Manufacturing Industry; Final Report of the Industrie 4.0 Working Group; Forschungsunion: Frankfurt/Main, Germany, 2013.

[5] Witchalls, C.; Chambers, J. The Internet of Things Business Index: A Quiet Revolution Gathers Pace; The Economist Intelligence Unit: London, UK, 2013; pp. 58–66.

[6] Datta, S.K.; Bonnet, C. MEC and IoT Based Automatic Agent Reconfiguration in Industry 4.0. In Proceedings of the 2018 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS), Indore, India, 16–19 December 2018; pp. 1–5.

[7] Shrouf, F.; Ordieres, J.; Miragliotta, G. Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm. In Proceedings of the 2014 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Selangor Darul Ehsan, Malaysia, 9–12 December 2014; pp. 697–701.

[8] Bandyopadhyay, D.; Sen, J. Internet of Things: Applications and Challenges in Technology and Standardization. Wirel. Pers. Commun. 2011, 58, 49–69.

[9] International Energy Agency (IEA). Global Energy & CO2 Status Report. 2019. Available online: https://www.iea.org/geco/

[10] Intergovernmental Panel for Climate Change (IPCC). Global Warning of 1.5 °C: Summary for Policymakers. 2018. Available online: https://www.ipcc.ch/sr15/chapter/spm/

[11] Zakeri, B.; Syri, S.; Rinne, S. Higher renewable energy integration into the existing energy system of Finland–Is there any maximum limit? Energy 2015, 92, 244–259.

[12] Connolly, D.; Lund, H.; Mathiesen, B. Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union. Renew. Sustain. Energy Rev. 2016, 60, 1634–1653.

[13] Grubler, A.; Wilson, C.; Bento, N.; Boza-Kiss, B.; Krey, V.; McCollum, D.L.; Rao, N.D.; Riahi, K.; Rogelj, J.; De Stercke, S.; et al. A low energy demand scenario for meeting the 1.5 C target and sustainable development goals without negative emission technologies. Nat. Energy 2018, 3, 515–527.

[14] UN. Special Edition: Progress towards the Sustainable Development Goals; UN: New York, NY, USA, 2019.

[15] Tan, Y.S.; Ng, Y.T.; Low, J.S.C. Internet-of-things enabled real-time monitoring of energy efficiency on manufacturing shop floors. Procedia CIRP 2017, 61, 376–381.

[16] Bhattacharyya, S.C. Energy Economics: Concepts, Issues, Markets and Governance; Springer: Berlin/Heidelberg, Germany, 2011.

[17] Tamilselvan, K.; Thangaraj, P. Pods—A novel intelligent energy efficient and dynamic frequency scalings for multi-core embedded architectures in an IoT environment. Microprocess. Microsyst. 2020, 72, 102907.

[18] Zhou, K.; Yang, S.; Shao, Z. Energy Internet: The business perspective. Appl. Energy 2016, 178, 212–222.

[19] Motlagh, N.H.; Khajavi, S.H.; Jaribion, A.; Holmstrom, J. An IoT-based automation system for older homes: A use case for lighting system. In Proceedings of the 2018 IEEE 11th Conference on Service-Oriented Computing and Applications (SOCA), Paris, France, 19–22 November 2018; pp. 1–6.

[20] Da Xu, L.; He, W.; Li, S. Internet of Things in Industries: A Survey. IEEE Trans. Ind. Inform. 2014, 10, 2233–2243.

[21] Talari, S.; Shafie-Khah, M.; Siano, P.; Loia, V.; Tommasetti, A.; Catalão, J. A review of smart cities based on the internet of things concept. Energies 2017, 10, 421.

[22] Ibarra-Esquer, J.; González-Navarro, F.; Flores-Rios, B.; Burtseva, L.; Astorga-Vargas, M. Tracking the evolution

of the internet of things concept across different application domains. Sensors 2017, 17, 1379.

[23] Swan, M. Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0. J. Sens. Actuator Netw. 2012, 1, 217–253.

[24] Gupta, A.; Jha, R.K. A survey of 5G network: Architecture and emerging technologies. IEEE Access 2015, 3, 1206–1232.

[25] Stojkoska, B.L.R.; Trivodaliev, K.V. A review of Internet of Things for smart home: Challenges and solutions. J. Clean. Prod. 2017, 140, 1454–1464.

[26] Hui, H.; Ding, Y.; Shi, Q.; Li, F.; Song, Y.; Yan, J. 5G network-based Internet of Things for demand response in smart grid: A survey on application potential. Appl. Energy 2020, 257, 113972.

[27] Petroșanu, D.M.; Căruțașu, G.; Căruțașu, N.L.; Pîrjan, A. A Review of the Recent Developments in Integrating Machine Learning Models with Sensor Devices in the Smart Buildings Sector with a View to Attaining Enhanced Sensing, Energy Efficiency, and Optimal Building Management. Energies 2019, 12, 4745.

[28] Luo, X.G.; Zhang, H.B.; Zhang, Z.L.; Yu, Y.; Li, K. A New Framework of Intelligent Public Transportation System Based on the Internet of Things. IEEE Access 2019, 7, 55290–55304.

[29] Khatua, P.K.; Ramachandaramurthy, V.K.; Kasinathan, P.; Yong, J.Y.; Pasupuleti, J.; Rajagopalan, A. Application and Assessment of Internet of Things toward the Sustainability of Energy Systems: Challenges and Issues. Sustain. Cities Soc. 2019, 101957.

[30] Haseeb, K.; Almogren, A.; Islam, N.; Ud Din, I.; Jan, Z. An Energy-Efficient and Secure Routing Protocol for Intrusion Avoidance in IoT-Based WSN. Energies **2019**, 12, 4174.

[31] Zouinkhi, A.; Ayadi, H.; Val, T.; Boussaid, B.; Abdelkrim, M.N. Auto-management of energy in IoT networks. Int. J. Commun. Syst. **2019**, 33, e4168.

[32] Höller, J.; Tsiatsis, V.; Mulligan, C.; Avesand, S.; Karnouskos, S.; Boyle, D. From Machine-to-Machine to the Internet of Things: Introduction to a New Age of Intelligence; Elsevier: Amsterdam, The Netherlands, 2014.

[33] Atzori, L.; Iera, A.; Morabito, G. The Internet of Things: A survey. Comput. Netw. **2010**, 54, 2787–2805.

[34] Hui, T.K.; Sherratt, R.S.; Sánchez, D.D. Major requirements for building Smart Homes in Smart Cities based on Internet of Things technologies. Future Gener. Comput. Syst. **2017**, 76, 358–369.

[35] Evans, D. The Internet of Things: How the Next Evolution of the Internet is Changing Everything. CISCO White Pap. **2011**, 1, 1–11.

[36] Motlagh, N.H.; Bagaa, M.; Taleb, T. Energy and Delay Aware Task Assignment Mechanism for UAV-Based IoT Platform. IEEE Internet Things J. **2019**, 6, 6523–6536.

[37] Ramamurthy, A.; Jain, P. The Internet of Things in the Power Sector: Opportunities in Asia and the Pacific; Asian Development Bank: Mandaluyong, Philippines, 2017.

[38] Jia, M.; Komeily, A.; Wang, Y.; Srinivasan, R.S. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. Autom. Constr. **2019**, 101, 111–126.

[39] Karunarathne, G.R.; Kulawansa, K.T.; Firdhous, M.M. Wireless Communication Technologies in Internet of Things: A Critical Evaluation. In Proceedings of the 2018 International Conference on Intelligent and Innovative Computing Applications (ICONIC), Plaine Magnien, Mauritius, 6–7 December 2018; pp. 1–5.

[40] Li, S.; Da Xu, L.; Zhao, S. 5G Internet of Things: A survey. J. Ind. Inf. Integr. **2018**, 10, 1–9.

[41] Watson Internet of Things. Securely Connect with Watson IoT Platform. 2019. Available online: **https://www.ibm.com/internet-of-things/solutions/iot-platform/watson-iot-platform** (accessed on 30 August 2024).

[42] Ehsan Bazgir, Ehteshamul Haque, Md. Maniruzzaman and Rahmanul Hoque, "Skin cancer classification using Inception Network", World Journal of Advanced Research and Reviews, 2024, 21(02), 839–849.

[43] Rahmanul Hoque, Suman Das, Mahmudul Hoque and Ehteshamul Haque, "Breast Cancer Classification using XGBoost", World Journal of Advanced Research and Reviews, 2024, 21(02), 1985–1994

[44] Rahmanul Hoque, Masum Billah, Amit Debnath, S. M. Saokat Hossain and Numair Bin Sharif, "Heart Disease Prediction using SVM", International Journal of Science and Research Archive, 2024, 11(02), 412–420.

[45] Rahmanul Hoque, Md. Maniruzzaman, Daniel Lucky Michael and Mahmudul Hoque, "Empowering blockchain with SmartNIC: Enhancing performance, security, and scalability", World Journal of Advanced Research and Reviews, 2024, 22(01), 151–162

[46] Tonyali S., Cakmak O., Akkaya K., Mahmoud M.M.E.A., Guvenc I. Secure data obfuscation scheme to enable privacy-preserving state estimation in smart grid AMI networks IEEE Internet Things J., 3 (5) (2016), pp. 709-719, 10.1109/JIOT.2015.2510504

[47] Buswig Y.M., Affam A., Albalawi H., Julai N., Hj A., Qays O. Development and modelling of three phase inverter for harmonic improvement using sinusoidal pulse width modulation (SPWM) control technique Int. J. Recent Technol. Eng., 8 (4) (2019), pp. 1897-1902.

[48] Qays, M. O., Ahmad, I., Abu-Siada, A., Hossain, M. L., & Yasmin, F. (2023). Key communication technologies, applications, protocols and future guides for IoT-assisted smart grid systems: A review. Energy Reports, 9, 2440-2452.

[49] Atasoy T., Akinc H.E., Ercin O. An analysis on smart grid applications and grid integration of renewable energy systems in smart cities 2015 Int. Conf. Renew. Energy Res. Appl. ICRERA 2015 (2015), pp. 547-550.

[50] Hu Q., Li F. Hardware design of smart home energy management system with dynamic price response IEEE Trans. Smart Grid, 4 (4) (2013), pp. 1878-1887, 10.1109/TSG.2013.2258181

[51] Viani F., Robol F., Polo A., Rocca P., Oliveri G., Massa A. Wireless architectures for heterogeneous sensing in smart home applications: Concepts and real implementation Proc. IEEE, 101 (11) (2013), pp. 2381-2396, 10.1109/JPROC.2013.2266858

[52] Wu, S.W., 2011. Research on the key technologies of IOT applied on Smart Grid. In: 2011 Int. Conf. Electron. Commun. Control. ICECC 2011 - Proc. pp. 2809–2812.

[53] Wang Y.F., Lin W.M., Zhang T., Ma Y.Y. Research on application and security protection of internet of things in smart grid IET Conf. Publ. vol. 2012 no. 636, CP (2012), 10.1049/CP.2012.2311

[54] Kshetri, N. Can Blockchain Strengthen the Internet of Things? IT Prof. **2017**, 19, 68–72.

[55] Dorri, A.; Kanhere, S.S.; Jurdak, R. Towards an optimized blockchain for IoT. In Proceedings of the Second International Conference on Internet-of-Things Design and Implementation, Pittsburgh, PA, USA, 18–21 April 2017; pp. 173–178.

[56] Huh, S.; Cho, S.; Kim, S. Managing IoT devices using blockchain platform. In Proceedings of the 2017 19th International Conference on Advanced Communication Technology (ICACT), Bongpyeong, Korea, 19–22 February 2017; pp. 464–467.

[57] Alladi, T.; Chamola, V.; Rodrigues, J.J.; Kozlov, S.A. Blockchain in Smart Grids: A Review on Different Use Cases. Sensors **2019**, 19, 4862.

[58] Christidis, K.; Devetsikiotis, M. Blockchains and Smart Contracts for the Internet of Things. IEEE Access **2016**, 4, 2292–2303.

[59] Korpela, K.; Hallikas, J.; Dahlberg, T. Digital Supply Chain Transformation toward Blockchain Integration. In Proceedings of the 50th Hawaii International Conference on Ssystem Sciences, Waikoloa, HI, USA, 4–7 January 2017.

[60] Hawlitschek, F.; Notheisen, B.; Teubner, T. The limits of trust-free systems: A literature review on blockchain technology and trust in the sharing economy. Electron. Commer. Res. Appl. **2018**, 29, 50–63.

[61] Conoscenti, M.; Vetro, A.; De Martin, J.C. Blockchain for the Internet of Things: A systematic literature review. In Proceedings of the 2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA), Agadir, Morocco, 29 November–2 December 2016; pp. 1–6.

[62] Boudguiga, A.; Bouzerna, N.; Granboulan, L.; Olivereau, A.; Quesnel, F.; Roger, A.; Sirdey, R. Towards better availability and accountability for iot updates by means of a blockchain. In Proceedings of the 2017 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW), Paris, France, 26–28 April 2017; pp. 50–58.

[63] Samaniego, M.; Deters, R. Blockchain as a Service for IoT. In Proceedings of the 2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), Chengdu, China, 15–18 December 2016; pp. 433–436.

[64] Zhu, C.; Leung, V.C.M.; Shu, L.; Ngai, E.C. Green Internet of Things for Smart World. IEEE Access **2015**, 3, 2151–2162.

[65] Abedin, S.F.; Alam, M.G.R.; Haw, R.; Hong, C.S. A system model for energy efficient green-IoT network. In Proceedings of the 2015 International Conference on Information Networking (ICOIN), Siem Reap, Cambodia, 12–14 January 2015; pp. 177–182.

[66] Nguyen, D.; Dow, C.; Hwang, S. An Efficient Traffic Congestion Monitoring System on Internet of Vehicles. Wirel. Commun. Mob. Comput. **2018**, 2018.

[67] Namboodiri, V.; Gao, L. Energy-Aware Tag Anticollision Protocols for RFID Systems. IEEE Trans. Mob. Comput. **2010**, 9, 44–59.

[68] ExtraKowsher, M., Tahabilder, A., Sanjid, M. Z. I., Prottasha, N. J., Uddin, M. S., Hossain, M. A., & Jilani, M. A. K. (2021). LSTM-ANN & BiLSTM-ANN: Hybrid deep learning models for enhanced classification accuracy. Procedia Computer Science, 193, 131-140.

[69] Moon, N. N., Hossain, R. A., Jahan, I., Shakil, S., Uddin, S., Hassan, M., & Nur, F. N. (2022). Predicting the mental health of rural Bangladeshi children in coronavirus disease 2019. International Journal of Electrical and Computer Engineering, 12(5), 5501-10.

[70] Javed Mehedi Shamrat, F. M., Ghosh, P., Tasnim, Z., Khan, A. A., Uddin, M. S., & Chowdhury, T. R. (2022). Human Face recognition using eigenface, SURF method. In Pervasive Computing and Social Networking: Proceedings of ICPCSN 2021 (pp. 73-88). Springer Singapore.

[71] Javed Mehedi Shamrat, F. M., Tasnim, Z., Chowdhury, T. R., Shema, R., Uddin, M. S., & Sultana, Z. (2022). Multiple cascading algorithms to evaluate performance of face detection. In Pervasive Computing and Social Networking: Proceedings of ICPCSN 2021 (pp. 89-102). Springer Singapore.

[72] Hoque, K., Hossain, M. B., Sami, A., Das, D., Kadir, A., & Rahman, M. A. (2024). Technological trends in 5G networks for IoT-enabled smart healthcare: A review. International Journal of Science and Research Archive, 12(2), 1399-1410.

[73] Maniruzzaman, M., Sami, A., Hoque, R., & Mandal, P. (2024). Pneumonia prediction using deep learning in chest X-ray Images. International Journal of Science and Research Archive, 12(1), 767-773.

[74] Hasan, A. S. M., & Ibrahim, A. A. (2022, October). Improved WBAN EH_ MAC Protocol based on Energy Harvesting and Wake up-Sleep Duty Cycling Technique. In 2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT) (pp. 478-483). IEEE.

[75] Fahmudur Rahman, Denesh Das, Anhar Sami, Priya Podder, Daniel Lucky Michael, "Liver cirrhosis prediction using logistic regression, naïve bayes and KNN", International Journal of Science and Research Archive, 2024, 12(01), 2411–2420.

[76] Li, T.; Wu, S.S.; Chen, S.; Yang, M.C.K. Generalized Energy-Efficient Algorithms for the RFID Estimation Problem. IEEE/ACM Trans. Netw. 2012, 20, 1978–1990.

[77] Xu, X.; Gu, L.;Wang, J.; Xing, G.; Cheung, S. Read More with Less: An Adaptive Approach to Energy-Efficient RFID Systems. IEEE J. Sel. Areas Commun. 2011, 29, 1684–1697.

[78] Klair, D.K.; Chin, K.; Raad, R. A Survey and Tutorial of RFID Anti-Collision Protocols. IEEE Commun. Surv. Tutor. 2010, 12, 400–421.

[79] Lee, C.; Kim, D.; Kim, J. An Energy Efficient Active RFID Protocol to Avoid Overhearing Problem. IEEE Sens. J. 2014, 14, 15–24.

[80] Amit Deb Nath, Rahmanul Hoque, Md. Masum Billah, Numair Bin Sharif, Mahmudul Hoque . Distributed Parallel and Cloud Computing: A Review. International

Journal of Computer Applications. 186, 16 (Apr 2024), 25-32.

[81] Imran Hussain Mahdy, Partha Protim Roy and Rafiqul Bari Kabir, "Assessing climate change impacts with downscaling techniques: A case study", International Journal of Science and Research Archive, 2024, 12(02), 1645–1652.

[82] Imran Hussain Mahdy, Mujibur Rahman, Fatema Islam Meem and Partha Protim Roy, "Comparative study between observed and numerical downscaled data of surface air temperature", World Journal of Advanced Research and Reviews, 2024, 23(01), 2019–2034.

[83] Rahman, M., Ishaque, F., Hossain, M. A., Mahdy, I. H., & Roy, P. P. (2021). Impact of industrialization and urbanization on water quality of Surma River of Sylhet City. Desalination and water treatment, 235, 333-345.