International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Applications of Rechargeable Lithium - Ion Battery in Electric Vehicles: A Review

Zachary Bosire Omariba[1], Stephen Mageto Gichana[2]

[1]Department of Computer Science, Egerton University

[2]Department of Computer Science, Meru University of Science and Technology

Abstract: ***With the evolution of rechargeable lithium - ion batteries (LIBs) and their subsequent application in electric vehicles (EVs), there is a shift by individuals, organizations, and governments in the way they plan, develop, and enact their strategies on transportation technology. This is because modern EVs powered by rechargeable LIBs not only presents new opportunities, but also a set of issues and challenges, that need to be resolved. The rising emissions from fossil fuel powered vehicles, has accelerated demand for newer transportation solutions that are environment friendly. This has made many countries to take proactive measures by enact laws and come up with policies in relation to the adoption of EVs that are powered by rechargeable batteries, as a way of responding to climate change. It is for this reason that this study presents the different issues and challenges surrounding the implementation of battery powered EVs. The main concentration area will be the different proactive measures that organizations and governments can embrace as a way to respond to climatic change, thus creating an emission free environment. Also this paper will look at the drivers and barriers related to the adoption of EVs powered by LIBs to help decision and policy makers to make informed choices in regard to climatic change.***

Keywords: Lithium - ion battery, Electric Vehicles, power requirements, lithium - ion - battery technology

1. Introduction

An electric vehicle (EV) refers to different types of vehicles which includes plug - in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), extended - range battery electric vehicles (E - REVs) and battery electric vehicles (BEVs) [1]. Because of these development of EVs, it has led to continuous growth of the vehicle electrification in the transport industry. The storage in the form of batteries has traditionally been the dominant source of power in EVs. A lot of progress has been made on batteries as well as in other energy storage devices such as micro - fuel cells, micro - heat engines, and capacitors. However of them all the batteries and in particular the lithium - ion batteries (LIBs) are the dominant source of power in the transport industry due to their miniaturization, high capacity, good temperature sensitivity, and less weight [2]. In order to survive for longer periods of time on a single battery charge, an EV should exhibit low power consumption. In this paper, the progress of LIBs technology will be evaluated, followed by the EVs technology. The expectations, opportunities, and challenges of battery power EVs is also examined. This paper discusses about the LIB technology in Section 2, and the EVs technology in Section 3. In Section 4, the battery powered EVs readiness and expectations is discussed, while the drivers and barriers of EVs adoption is discussed in Section 5. The challenges and open research issues of batteries application in EVS is given in Section6, with Section 7 providing the conclusion.

a) LIB technology

LIBs have emerged as a promising energy storage solution for electric vehicles**.** The lifespan of LIBs in EVs applications will largely depend on the progress of battery technology as well as usage patterns at the IoT device level. Long battery lifespan will have a benefit of reducing the need for second, or even third battery replacement [3] [4] [5] when capacity drops by a given percentage of the original rated value, thereby reducing the cost of operating EVs. Zhang et al [6] notes that there are many aspects to the process of developing a battery management system, such as requirement analysis, modelling and simulation, control strategy research, and on - line hardware test, which all need a capable model to identify the characteristics of the LIBs. This means that the LIBs technology is still under development, as more reliable and safer batteries have not been produced yet. Although literature [7] states that LIB technology is migrating from the portable electronics domain to larger - scale applications, the common denominator in the LIB technology is improvements in specific energy, power, safety, and reliability [8]. This means that the demand for better batteries is driven by many industries, and rechargeable LIBs has emerged as the dominant energy storage source for consumer electronics, automotive, aerospace, and stationary storage applications.

There are many diverse range of batteries today which are available for powering various applications. TABLE I shows the range of applications which are powered by these diverse range of batteries together with the required typical energy levels for these applications.

Table I: Battery Ranges and Applications

Battery type	Energy level	Applications
Miniature batteries	100 mWH - 2Wh	Electric watches, Calculators, Implanted medical devices
Batteries for portable equipment	2Wh - 100Wh	Consumer electronics (e. g. Flashlights, toys, power tools, portable radio and TV, mobile phones, camcorders, laptop computers, memory refreshing, instruments, cordless devices, wireless peripherals, emergency beacons)
Starting Lighting and Ignition (SLI) batteries	100 - 600 Wh	Cars, Trucks, Buses, Lawn mowers, Wheel chairs, Robots

Vehicle traction batteries	20 - 630 kWh	Electric vehicles (EVs), Hybrid electric vehicles (HEVs), Plug - in hybrid electric vehicles (PHEVs), Fork lift trucks, Milk floats, Locomotives
Stationary batteries	250Wh - 5 mWh	Emergency power, Local energy storage, Remote relay stations, Communication base stations, Uninterruptible power supplies (UPS)
Military and Aerospace	Wide range	Satellites, Munitions, Robots, Emergency power, communications
Special purpose	3 MWh	Submarines
Load levelling batteries	5 - 100 MWh	Spinning reserve, Peak shaving, Load levelling

b) Electric Vehicle's Technology

IoT is an emerging technology, encompassing a wide spectrum of applications related to industrial control, smart campus [9] [10], smart metering, smart transport, smart home automation, smart agriculture, smart eHealth and so on [11] [12] [13], wherein the devices involved run long hours under strict energy constraints. This IoT technology can be deployed in any field as it is an enabler of reaching out into the real world of physical objects [14]. Technologies like Radio Frequency Identification (RFID), short - range wireless communications, real - time localization, long - range (LORA) networks, and sensor networks becoming increasingly pervasive, making the IoT a reality.

The IoT system contains four main components which includes the sensing components, connectivity or communication components, data processing and cloud component, and the user services or interface and applications [15]. The sensor component in IoT includes sensors, actuators, and devices. The Sensors in IoT determines the physical quality of objects and compute it into a value which is further read by another user or device. This means that the sensors aid in the collection of real time or very minute data from the surrounding environment. The actuators are used to switch off/on another device or equipment by force when need arises thus, triggering various devices into operation based on the data dynamics. On the other hand the IoT devices, or any other things in the IoT, are non - standard computing devices categorised as consumer, enterprise, and industrial devices that connect wirelessly to a network and have the ability to transmit data.

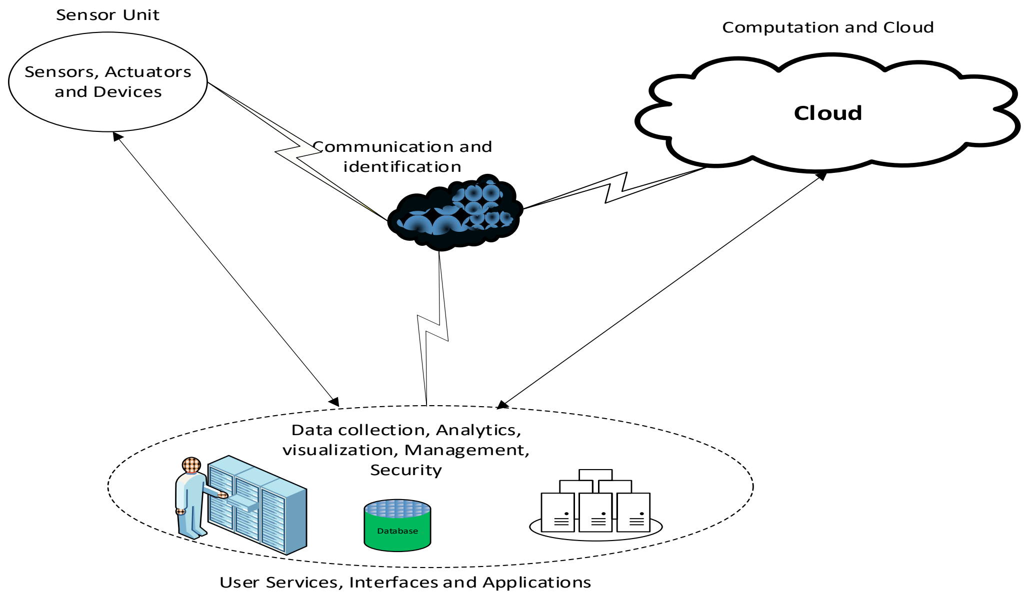

Figure 1: Structure of Internet - of - Things (IoT)

The communication and identification component contains IoT communication protocols such as MQTT, CoAP, AMQP, and DDS are used to connect various IoT objects to send data to management system, and provides authentication and performance gains in networks and operations of sensors, actuators and devices. It assists in the detection of returned faults of the processes, by ensuring that each object acquires a unique identifier. The technologies and protocols used to connect sensors and devices to the internet include Wi - Fi, ZigBee, Bluetooth, LoRaWAN, near field communication (NFC), LTE, cellular, and z - wave

The data processing and cloud component performs all the computations or data manipulations. This includes the collection, storage, and processing of data. All IoT platforms are essentially cloud based, and hence collect, store and process data in the cloud. They support all communication technologies, and transport protocols. On the other hand the services and application component performs the actual data collection, analytics, transmission, visualizing, management, and security.

c) Power requirements of Electric Vehicles

There are currently a number of power sources for IoT applications [16], which includes: storage, distribution, and harvesting as shown in Table 1.

Table 2: Power sources for internet - of - things (IoT)

Harvesting	Storage	Distribution
Wind [16] [17] [18]	Micro - heat engines	Electromagnetic (RF) [19] [20] [21]
Solar [22] [23]	Micro - fuel cells	Wires
Kinetic [19] [23]	Supercapacitors [17]	
Mechanical [17]	Batteries [24] [25]	
Piezoelectric tiles [26]		

The power availability for IoT devices is a big issue for many IoT applications. For example consider the high control tracker in a smart farm to enable the user track the humidity or temperature in a green house, and since there are no clearly wired connections the device must communicate wirelessly while relying on internal power source. There are several sources of power for IoT devices which are classified as: kinetic, thermal, radiant, and biochemical of which the mechanical and radiant are the most prominent.

The Radio - frequency identification (RFID) is a spectral form of Radio - frequency energy harvesting in which power, as well as information, is obtained from a specific source rather than random ambient RF energy. RF energy can be used to tickle charge or to operate consumer electronics such as wearable medical sensors, headsets, and other small IoT devices. An RFID base station has a scanning antenna which transmits RF signals over a relatively short distance. This communicates with the transponder built into a passive RFID tag [27]and provides the transponder with the energy necessary to wake up, read, and communicate in response. Therefore RFID systems can use radio signal generated by an RFID reader to power themselves and for communication. There are active RFID tags with batteries that operate at a greater distance, but passive tags have a virtually unlimited lifespan. The applications of RF energy includes among others, credit cards, asset tracking, and real time location monitoring systems.

The wind energy harvesting is among the other prominent energy sources that powers IoT devices because it does not pollute the environment and is cheap. More research is being conducted to actualize further the application of wind energy in IoT devices. The windmills and turbines are commonly used to get energy from the fluids, but these kinds windmills and turbines are commonly used to get energy from the fluids, but these kinds of systems cannot be scaled down in a centimetre - sized device, as is necessary for typical IoT systems cannot be scaled down in a centimetre - sized device, as is necessary for typical IoT applications, applications, especially in low - wind speed [17]. However to protect the IoT devices, the wind - induced vibration piezoelectric energy harvesters must be packaged when they are used to power a wireless sensor node in real applications [18].

Despite the fact that some IoT devices may not need to collect data regularly, in many harvesting applications the ambient energy may be insufficient to support the devices with its processing and communication needs. Because of this the rechargeable batteries and supercapacitors becomes handy to be used as storage mediums to suitably collect the energy for harvesting devices output [24]. The supercapacitors are high capacity device with higher capacity, but lower voltage limits than other capacitors. It accepts and delivers charge faster than batteries, but it is prone to excessive self - discharging that leads to wastage of harvested energy. On the other hand the rechargeable batteries is preferred and LIBs is the popular one for powering IoT devices because of its rich benefits. Since some renewable energies have some disadvantages in producing energy such as a solar power cannot produce energy at night, it is recommended that all energy sources can be integrated into a system known as a smart micro - grid. This smart micro - grid also needs battery system as a backup energy that will deliver its stored energy when the main energy producer does not produce energy [25]. However despite all these developments, research is ongoing to deliver cheap, safer, high - density, and more - reliable, and longer lasting LIBs.

The solar cell technology can be used to power IoT devices [18] indefinitely, whereas the solar panels [22] are used to power larger IoT devices as well. However it proves to be less efficient may be at night and if the IoT devices are required to transmit data on a regular basis. The kinetic energy harvesting [19] is another technology used to obtain IoT energy from everyday activities, and thus can be the best option to power IoT devices. The kinetic (motion) energy can be harvested by a wireless node within an IoT form factor and on developing energy allocation algorithms for such nodes. Current research is focused on various methods for estimating harvested energy from acceleration traces [23] [28]. The energy availability associated with specific human activities like relaxing, walking, cycling, running will provide some form of energy to IoT devices which has for long not been in focused on. This technology is based on the technology known as reverse electro - wetting. Decreasing size and power requirements of carrying electronics devices make it possible to replace portable batteries with systems that capture energy from human locomotion [29]. But since we have high and very low levels of kinetic energy, both can be used to power smart IoT devices depending on the energy needs.

d) Battery power consumption in EVs

Whether an IoT device is powered by internal or external battery, or an electronic system's external supply, a measurement solution for determining the IoT device's power consumption must support a power - supply range from millivolts to several volts or more. Harvesting energy from all other available sources could permanently supply the node with the required power, thus providing the most promising solution to the power supply problem [28]. With the growing number of IoT devices, the power consumption has been an item of concern and a key research problem. It necessitates that the use of artificial intelligence (AI) technologies to detect the abnormal behaviours and react to it instantly. The maximum power management of the IoT devices is one of the major design issue of any IoT devices. To determine the power consumption of many IoT devices requires capability to measure power use across its different voltages. There are a number of software and hardware that are used that measure the IoT device power consumption under any different operating conditions. For example a radio communication tester (RTC) makes it possible to measure and analyse the power consumption of an IoT device while operating under different network connected conditions. Any of these measurement solution for characterizing IoT device power consumption needs therefore to be able to measure a wide dynamic range of current levels, which may run from Nano - amps to several amps. The battery provided stable energy supply, but if causes a replacement cost due to a limited capacity and lifetime of the battery [30]. Since the IoT devices can be operating under various modes like active/working, idle or dormant, and sleep/inactive mode [31], it is realized that low current levels of some IoT designs in sleep mode may be simply beyond the measurement limit of most instruments, especially when high measurement accuracy is needed at those low current levels. The sensor nodes consume more power in active mode than in sleeping mode, thus state - of the - art microcontrollers can stay in sleep power - saving mode with sub micro - amp sleep current [32].

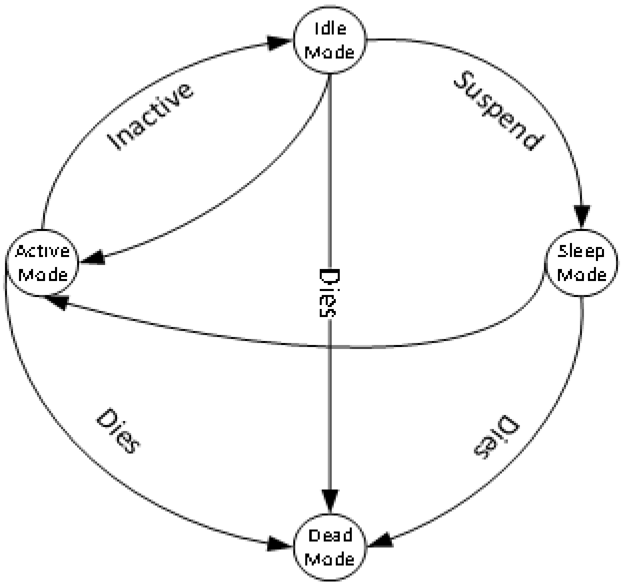

Figure 2: Operation modes of EVs

The IoT devices as shown in Figure 3, operates under four modes: active, idle, sleep, and dead mode. However the latter mode is very dangerous and hence IoT devices requires regular maintenance, and on the event one device or component is un - operational it requires to be changed immediately, otherwise it becomes very risky. During the active mode the device is fully functional or working and consumes power depending on the tasks performed. In the idle stage the device consumes less power since there exists no running activities, thus minimum energy usage. In the sleep state all processes are suspended or the components are switched off, hence no power usage. Finally in the dead state, there are no tasks executed, maybe due to battery power failure or device malfunction. The energy consumed in low power mode is influenced by sleep duration [30], and consequently the energy consumed in high power mode is influenced by the active duration of the IoT devices. The IoT devices should be configured in a way that they use low - power mode to reduce the device’s energy consumption during idle time. Consequently IoT devices energy consumption is reduced to alleviate the problems caused by independent power supplies. To mitigate the problem of independent power sources, it is necessary to minimize the energy consumption of IoT devices. Reducing energy consumption in battery - based IoT devices can increase battery lifetime and reduce replacement costs [30], as well as reduced power failure and energy losses. Pressure in energy consumption can be addressed at primarily three levels: hardware and infrastructures in general; systems software; and data management. At the hardware and infrastructures it is useful to distinguish between work to produce energy - efficient chips or devices and work at a level that considers infrastructures built with multiple such chips or devices [33]. Also the system software has to be managed mostly resource management, to ensure that resources are made in a way that they are light weight so as to consume less energy. Data management involves the design and deployment of policies, architectures, and procedures allowing the accurate management of the full data lifecycle. As shown in Figure 3, the projected market share of LIBs used in handsets from 2012 - 2020 in million (US$), is likely to keep soaring high. If other devices that use batteries are considered based on these statistics, it means that LIBs are under pressure as the technology is improving.

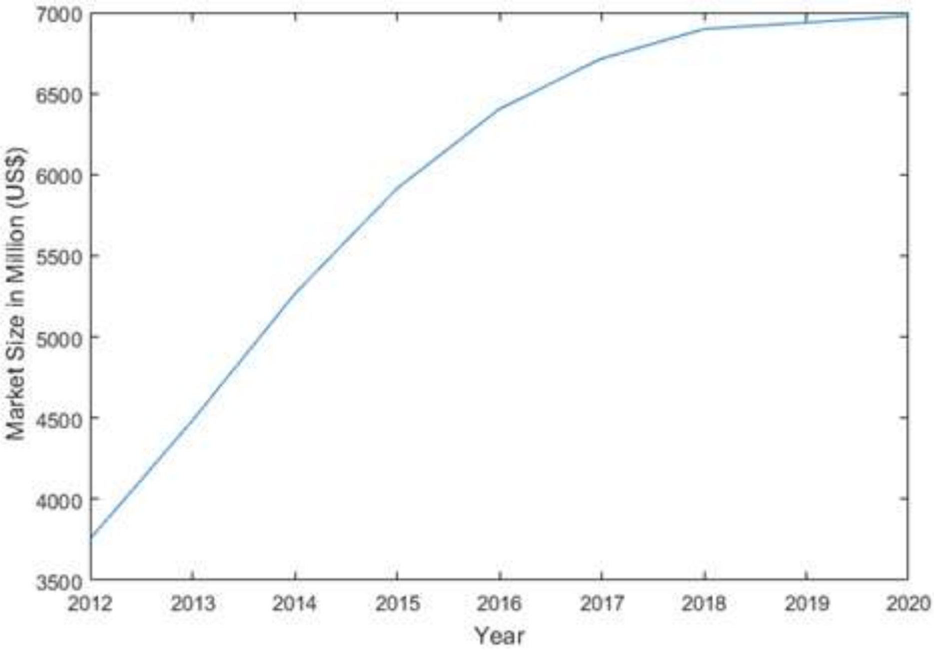

Figure 3: Projected market for LIBs used in EVs from 2012 - 2020

e) EVs battery option

The battery is the main power option for IoT and LIBs are playing a key role in the IoT industry. The main challenge of deploying IoT battery - powered sensing systems is managing the maintenance of batteries [24]. Due to this reason, practitioners often employ prediction techniques to approximate the battery lifetime of the deployed devices [24]. If L_h is the battery lifetime, C is the battery nominal capacity, and Q_h is the IoT device charge consumption per unit hour, then the battery lifetime can be evaluated as:

$$L_h = \frac{C}{Q_h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (1)$$

IoT depends on independent power sources, and as such if a failure occurs in the power source the running task fails automatically. This call for restarting the task again when the power resumes thus leading to energy wastage during task restart and failure. This problem can be moderated by minimizing the power consumption of IoT devices [30]. Further according to literature [34], offloading the data between IoT edge devices and smart devices like phones/devices/gateways for completing a task in an efficient energy and communication way will aid in utilizing the energy used by the devices thus improving the battery life. Also it is crucial for IoT software to leverage the low power modes of the hardware and put the device to a sleep mode for as long as possible [35] to conserve energy. Further integration of renewable energy into interconnected energy systems [36]is another key energy option which will yield to not only cutting on costs but also to clean the environment. Therefore the IoT devices should be designed to achieve long term maintenance free monitoring and use of IoT nodes that use energy preserving and efficient Radio frequency (RF) technology.

f) Electric Vehicle's Adoption

Battery prognostics is still considered relatively immature as compared to diagnostics, thus more focus is on developing prognostic methods rather than evaluating and comparing their performances [2]. Consequently, there is a need for dedicated attention towards developing standard methods to evaluate prognostic performance from a viewpoint of how post - prognostic reasoning will be integrated into the health management decision making process [37].

g) Battery Powered EVs Readiness and Expectations

There is increasingly common battery - powered devices in use and in the market today. Some of these devices comes with common and some variant expectations some of which may be domain or industry specific as to where these devices are used. The main expectations that these battery - powered devices comes with that are a consideration to the manufacturers production list includes:

- Increasing mobility
- Higher data demands
- Larger, colour, touch - based displays
- "Always - connected" applications
- Complex interaction: SW apps, FW, HW
- Competitive advantage – huge business impact, especially in medical and Industrial IoT
- Life safety, medical applications growing
- Invasive, expensive battery changes
- Disruption: patient & health care professional

To ensure that the IoT battery - powered devices meet their expectations effort has to be put in place to ensure that these devices achieves: high bandwidth to capture fast turn - ons; seamless ranging for highly dynamic signals; RF detection; fast setup and data collection

h) Drivers and Barriers of EVs Adoption

There are many opportunities for prognostics and health management of LIBs, but they have been met with various challenges in equal measure. In this study these opportunities and challenges from LIBs perspective are analysed from four perspectives namely: technological, financial/cost, security, and environmental. Table 2 provides a summary of these opportunities and challenges of LIBs.

Table 3: Drivers and Barriers and Solutions of Battery Powered EVs Adoption

Drivers	*Barriers*	*Solution*	*References*
• Existence of recycling technologies • Growth in demand for LIB • Intelligent cost management • Cost savings • Battery state monitoring system • 3R - principle: Recycle, reuse, reduce • Mitigated emissions • Integration of renewable energies	• Consumer attitudes and perception • Lack of incentives • Purchase price • Range limitation • Diminishing charge infrastructure	• Performance of higher power, larger energy capacity • RUL Prediction, SOH diagnosis, Aging • Enduring adverse circumstances • Development of low weight battery • Reliability • Degradation uncertainties • Lower cost • Battery degradation costs More safety assurance • Disposing waste batteries • How to reduce production of new batteries • Consumer awareness	[47 - 54] [55 - 58] [59 - 63] [4] [38] [39] [40]

The LIB technology is considered as one of the most promising for the near future by a majority of literary sources [41]. However a lot has to be done to ensure that batteries of higher power performance, larger energy capacity are realized, as well as improving the batteries to endure adverse circumstances. Consequently the prediction of RUL, monitoring of battery aging, and SOH diagnosis requires technologies that are accurate in order to avoid catastrophic failures. This is explained by the way it has caught the market share in commercialization in consumer electronics such as cell phones, laptops, video cameras, digital cameras, power tools, and other portable electronic devices [42]. LIBs have many advantages which include [43] [44] [45] [42] [46] [47] light weight, high energy density, low self - density, no maintenance, faster recharge, and customization. However this technology faces some challenges like reliability, degradation uncertainties, enduring adverse environment and remaining useful life prediction.

In the recent past LIB costs have been reduced significantly by almost 65% from 2010 [48]. Several countries are working around the clock to see how best they can substitute fossil based powered energies for technological option of greener/renewable energy to further cut on the cost as well as to conserve the environment [2]. Manufacturers are working on how to employ intelligent cost management methods in - order to produce low cost LIB. This is partly achieved by recycling of used LIBs, which could have gone into a waste dumped in a landfill. However the development LIBs and its certification of safety critical applications are very expensive.

These costs can be reduced by encapsulating safety - critical components, and safety measures can be restricted to the respective parts [49]. Accounting for the battery aging is crucial as the cost of LIBs has a crucial significant impact on overall system cost. The modelled battery degradation cost includes the impacts of the battery temperature, the average SOC, and the DOD on fading the LIB capacity [50]. But the general costs of batteries reduced tremendously from 1000$/kWh in 2008, to 268$/kWh in 2015, which is a 73% reduction in 7 years [51]. If this trend continues, in the future it looks promising to consumers of IoT, but if alternative measures to sources of energies are not sought, then the meagre resources for the manufacture of LIBs will be depleted.

The safety of LIBs is paramount to ensure confidence and widespread adoption of IoT in our society, as they are a proven technology for powering electronic and automotive applications and their continuous use in the future is undeniable. For enhanced security and more accurate SOC estimation, the parameter values of equivalent circuit model (ECMs) should be continually updated since surface temperature measurements alone might not be sufficient to ensure safe battery operation [52]. During cycling, cells within a pack exhibit non - uniform properties which may lead to some unbalances (e. g. voltage variations between cells) that may trigger a safety hazard [53]. When IoT devices are used outdoors changes in temperature and load can cause performance degradation in LIBs. Battery degradation may lead to leakage, insulation damage, and partial short - circuit. If there is no online detection of degradation, further battery usage will cause serious situations such as spontaneous combustion and explosions, especially if the current state of health has not been assessed in a timely fashion, or the future battery health state has not been estimated [54]. The main thermal safety issues of LIBs to be addressed are overheating, combustion, and explosion and cycle life. To avoid any catastrophic incidences caused by degradation of LIBs and to predictively maintain the safety of IoT devices, carrying out research on RUL prognostics of LIBSs is of great importance [55] [54] [53] [56].

The use of LIB will be the next big thing as many governments are fighting against production and sale of vehicles powered only by fossil fuels in favour of cleaner vehicles. This is in a bid to clean up the country's air, or in fighting against global warming. There are several opportunities in relation to environmental aspects in the use production and sale of green energy to the fight global warming. Several environmental opportunities that exist include but are not limited to: *3R - principle: recycle, reuse, and reduce; mitigated emissions; integration of renewable energies.*

Consequently the LIB consumers requires awareness on taking part on the 3R - principle, since many consumers prefer new batteries, making spent batteries to have little potential for reuse ending up being dumped along with other urban solid waste. Taking into account the importance of key parameters for the environmental performance of LIBs, research efforts should not only focus on energy density but also on maximizing cycle life and charge/discharge efficiency [57]. The application of the 3R - principle to LIBs will bring savings quantified in terms of energy and cumulative energy extracted from the natural environment [58]. It will be seen how material or cell recovery from existing cells will be another source of future materials for LIBs [59]. Therefore the 3R rule for reuse, recycle, and reduce should be employed purposely to reduce the extinction of the rare iron ores, and this will go along line in the conservation of the environment. Current research is coiled towards these principles to improve on the technologies around it.

i) Challenges and open research issues of Batteries in EVs

The management and maintenance of batteries is one of the key challenges of deploying IoT battery - powered sensing systems. Due to this challenge commonly the practitioners often employ prediction techniques to approximate the battery lifetime of the deployed devices [24]. Reka and Dragicevic [60] outlines three major challenges namely data leakage, cyber - attacks, and unpredictable or unreliable internet connectivity, of which Lopez et al. [61]agrees that raising user awareness and promoting privacy sensitive behaviours is a major open research concern. According to them when data is in wrong hands then calamity can arise due to its inappropriate usage, and at the same time if there is an internet downtime then the systems will not be working and this can lead to total system shutdown. Another challenge is transferring huge volumes of data efficiently [62] as the number of IoT devices is growing exponentially. This challenge however can be solved by designing of a mobility management model that can help in triggering efficient handover and selecting optimal networks based on multi - criteria decision modelling. Consequently a reliable system architecture which integrates green IoT with 5G network can speed the process as it requires to communicate with other heterogeneous networks efficiently with minimum energy requirements.

Due to the existence of a myriad of challenges, according to the literature [12] [63], the following open research issues of IoT exist: data confidentiality, security and privacy; scalability and interoperability; data, operation, resource and energy management; functionality safety and fault tolerance; availability, reliability, mobility and other QoS criteria; standardization activities, architecture and protocols;

identification and networking addressing. These open research issues for batteries and IoT can be summarized as:

Design trade - offs

Managing the maintenance of batteries is one of the greatest challenge of deploying the IoT battery - powered sensing systems [24]. It is envisioned that to offer best result the IoT devices deployable should be low - power ones, which is still a challenge too. However this challenge can be addressed by measuring the sleep current and the active current separately, using two different shunt resistors: a large shunt resistor for measuring the sleep current with high accuracy, and a small shunt resistor for measuring the active current without resetting the board. At present the major limitation of measuring current is that the major device under use needs to be attached to the battery. Another challenge and research issue is that still IoT networks are limited in scope, with majorly less than 10 nodes in a network that can vary widely in power consumption depending on the application [16]. During design of batteries the following should be considered: battery type &capacity, processing power, component size &quality, cost, Firmware behaviour in the MCU, functionality, features, performance, connectivity, and user experience.

Long - life and reliability

One of the biggest challenges in battery reliability is the detection of trace contamination in assembled cells. Often, contamination issues are not highlighted until after failures have been observed. Any cell or battery that has an open recall for issues regarding contamination should be considered defective for safety reasons [5]. When contamination particles result in internal short circuits, rapid self - discharge of the cell or battery is observed which further can cause harm to the IoT devices of lower their efficiency. Long life and reliability is a must to meet the total cost of ownership expectations of most IoT applications minimizing replacement and sensor servicing needs while increasing reliability and user confidence for industrial, commercial and residential applications. The IoT architecture contains three layers where, lower layers are responsible for event related aggregation, middle layers are responsible for storing and retrieving information produced by higher level and lower level layers, while the higher level layer is responsible for query related data. The major challenge is energy efficiency and reliability in lower level layers because devices and communication channels used in lower layers are lower power edge devices like sensors devices and lower power radio links. In the higher layer the challenge is data management and processing because they handle a huge chunk of data, while in middle layer the challenge is controlling the temperature dissipated for storage devices [64]. LIBs should offer longevity, quality, and autonomous operation required of any type of sensor application. This poses a grey are for research in batteries and IoT in relation to extending device lifetime [64] by balanced energy utilization and reliable data transfer are major concern in IoT technology.

New and disruptive battery technologies

The LIBs technology is facing competition from new disruptive battery technologies that may make it to pave way for high - performance batteries, unless more is done to keep improving it. These technologies include silicon - based batteries, paper - polymer battery, magnesium battery, potassium - ion battery, room - temperature sodium sulfur battery, proton battery, Nickel - Zinc battery, aluminium - ion battery, graphite - ion battery, and many more technologies. These technologies places LIBs at the edge of research and development to maintain a competitive niche in the market and make it a sole market player.

Privacy and security

Security and privacy is a major concern despite the numerous benefits that IoT comes with. This ranges from the security of the IoT devices, and data privacy of the information stored, transmitted, shared or information application [63] [65]. This calls for suitable remedial measures which can be done with the advancement of technology by bringing in new authentication schemes, encryption methods, public key infrastructure (PKI) and also by creating standardized application program interfaces [60].

2. Conclusion

In this paper, the application of rechargeable lithium - ion batteries for use in EVs have been investigated showing beneficial properties of lithium - ion in the terms of energy density, power density and rate capabilities. Lithium - ion (Li - ion) rechargeable batteries are used as one of the major energy storage components EVs. Reliability of Li - ion batteries used in these devices has been recognized as of high importance from a broad range of stakeholders, including EV manufacturers, regulatory agencies, and governments.

3. Conflict of Interest

The Authors declare no conflict of interest regarding the publication of this paper.

References

[1] I. Vassileva and J. Campillo, “Adoption barriers for electric vehicles : Experiences from early adopters in Sweden, ” *Energy*, vol.120, pp.632–641, 2017.

[2] Z. Omariba, L. Zhang, and D. Sun, “Review on Health Management System for Lithium - Ion Batteries of Electric Vehicles, ” *Electronics*, vol.7, no.5, p.72, 2018.

[3] K. Richa, C. W. Babbitt, G. Gaustad, and X. Wang, “A future perspective on lithium - ion battery waste flows from electric vehicles, ” *Resour. Conserv. Recycl.*, vol.83, no.2014, pp.63–76, 2014.

[4] F. Gu, J. Guo, X. Yao, P. A. Summers, S. D. Widijatmoko, and P. Hall, “An investigation of the current status of recycling spent lithium - ion batteries from consumer electronics in China, ” *J. Clean. Prod.*, vol.161, pp.765–780, 2017.

[5] N. Williard, C. Hendricks, B. Sood, J. S. Chung, and M. Pecht, “Evaluation of batteries for safe air transport, ” *Energies*, vol.9, no.5, pp.1–13, 2016.

[6] L. Zhang, H. Peng, Z. Ning, Z. Mu, and C. Sun, “Comparative Research on RC Equivalent Circuit

Models for Lithium - Ion Batteries of Electric Vehicles, " *Appl. Sci.*, vol.7, no.10, p.1002, 2017.

[7] K. B. Hatzell, A. Sharma, and H. K. Fathy, "A survey of long - term health modeling, estimation, and control of Lithium - ion batteries: Challenges and opportunities, " *2012 Am. Control Conf.*, pp.584–591, 2014.

[8] B. Scrosati and J. Garche, "Lithium Batteries : Status, Prospects and Future, " *J. Power Sources*, no.195, pp.2419–2430, 2010.

[9] M. R. . Veeramanickam and M. Mohanapriya, "IOT enabled Futurus Smart Campus with effective E - Learning : i - Campus, " *GSTF J. Eng. Technol.*, vol.3, no.4, pp.81–87, 2016.

[10] M. W. Sari, P. W. Ciptadi, and R. H. Hardyanto, "Study of Smart Campus Development Using Internet of Things Technology, " *IOP Conf. Ser. Mater. Sci. Eng.*, vol.190, no.012032, 2017.

[11] A. Hussain, "Energy Consumption of Wireless IoT Nodes Amen Hussain, " Norwegian Uniersity of Science and Technology, 2017.

[12] G. Lampropoulos, K. Siakas, and T. Anastasiadis, "Internet of Things (IoT) in Industry : Contemporary Application Domains, Innovative Technologies and Intelligent Manufacturing, " *Int. J. Adv. Sci. Res. Eng.*, vol.4, no.10, pp.109–118, 2018.

[13] Rupa, R. Kumari, N. Bhagchandani, and A. Mathur, "Smart Garbage Management System Using Internet of Things (IOT) For Urban Areas, " *IOSR J. Eng.*, vol.08, no.5, pp.78–84, 2018.

[14] K. M. Sadique, R. Rahmani, and P. Johannesson, "Towards Security on Internet of Things : Applications and Challenges in Technology, " *Procedia Comput. Sci.*, vol.141, pp.199–206, 2018.

[15] H. Hejazi, H. Rajab, T. Cinkler, and L. Lengyel, "Survey of Platforms for Massive IoT, " in *2018 IEEE International Conference on Future IoT Technologies (Future IoT)*, 2018, pp.1–8.

[16] A. Raj and D. Steingart, "Review — Power Sources for the Internet of Things, " *J. Electrochem. Soc. JES Focus Issue Ubiquitous Sensors Syst. IoT*, vol.165, no.8, pp.3130–3136, 2018.

[17] G. Boccalero, C. Boragno, D. D. Caviglia, and R. Morasso, "FLEHAP : A Wind Powered Supply for Autonomous Sensor Nodes, " *J. Sens. Actuator Networks*, vol.5, no.15, 2016.

[18] C. Zhang, X. He, S. Li, Y. Cheng, and Y. Rao, "A Wind Energy Powered Wireless Temperature Sensor Node, " *Sensors*, vol.15, pp.5020–5031, 2015.

[19] Q. Luo, X. He, S. Jiang, and X. Wang, "Impact - Based Electromagnetic Energy Harvester with, " *Energies*, vol.10, no.1848, 2017.

[20] P. D. Mitcheson, "Energy Harvesting for Human Wearable and Implantable Bio - Sensors, " pp.3432–3436, 2010.

[21] S. Teodora, Z. Sherali, D. G. Mois, and Corneliu Folea Silviu, "Wireless energy harvesting : Empirical results and practical considerations for Internet of Things, " *J. Netw. Comput. Appl.*, vol.121, no. July, pp.149–158, 2018.

[22] M. El Moulat, O. Debauche, S. Mahmoudi, A. B. Lahcen, P. Manneback, and F. Lebeau, "Monitoring System Using Internet of Things For Potential Landslides Landslides, " *Procedia Comput. Sci.*, vol.134, pp.26–34, 2018.

[23] M. Gorlatova, J. Sarik, G. Grebla, M. Cong, I. Kymissis, and G. Zussman, "Movers and Shakers : Kinetic Energy Harvesting for the Internet of Things, " *IEEE J. Sel. Areas Commun.*, vol.33, no.8, pp.1624–1639, 2015.

[24] X. Fafoutis, A. Elsts, A. Vafeas, G. Oikonomou, and R. Piechocki, "On Predicting the Battery Lifetime of IoT Devices : Experiences from the SPHERE Deployments, " in *In RealWSN'18: Workshop on Real - World Embedded Wireless Systems and Networks*, 2018.

[25] K. Friansa, I. N. Haq, B. M. Santi, D. Kurniadi, E. Leksono, and B. Yuliarto, "Development of Battery Monitoring System in Smart Microgrid Based on Internet of Things (IoT), " *Procedia Eng.*, vol.170, pp.482–487, 2017.

[26] E. Elbakush, S. Ibrahim, S. Mustafa, and A. Halawani, "On the Performance of Human Energy Harvesting Technology, " in *2017 IEEE Green Energy and Smart Systems Conference (IGESSC)*, 2017.

[27] M. Bayani, K. Leiton, and M. Loaiza, "INTERNET OF THINGS (IOT) ADVANTAGES ON E - LEARNING IN THE SMART CITIES, " *Int. J. Dev. Res.*, vol.07, no.12, pp.17747–17753, 2017.

[28] E. Ibarra, A. Antonopoulos, S. Member, E. Kartsakli, J. J. P. C. Rodrigues, and C. Verikoukis, "QoS - Aware Energy Management in Body Sensor Nodes Powered by Human Energy Harvesting, " *IEEE Sens. J.*, vol.16, no.2, pp.542–549, 2016.

[29] A. Manjare and S. More, "A Design of Energy Harvesting Step Sole, " in *Proceedings of the 2nd International Conference on Communication and Electronics Systems (ICCES 2017)*, 2017, pp.458–461.

[30] M. Kim, J. Lee, Y. Kim, and Y. H. Song, "An Analysis of Energy Consumption under Various Memory Mappings for FRAM - based IoT Devices, " in *2018 IEEE 4th World Forum on Internet of Things (WF - IoT)*, 2018, pp.574–579.

[31] U. Mahmud, S. Husain, and S. Yang, "Power Profiling of Context Aware Systems : A Contemporary Analysis and Framework for Power Conservation, " *Wirel. Commun. Mob. Comput.*, 2018.

[32] K. Khanchuea and R. Siripokarpirom, "An IoT - enabled Platform for Power Consumption Measurement of Low - Power Wireless Sensor Devices, " in *2018 2nd International Conference on Engineering Innovation (ICEI)*, 2018, pp.57–62.

[33] L. Bittencourt *et al.*, "Internet of Things The Internet of Things, Fog and Cloud continuum : Integration and challenges, " *Internet of Things*, vol.3, no.4, pp.134–155, 2018.

[34] W. S. Ravindra and P. Devi, "Energy balancing between computation and communication in IoT edge devices using data offloading schemes, " in *2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT)*, 2018, pp.22–25.

[35] Y. Bin Zikria, H. Yu, M. K. Afzal, M. H. Rehmani, and O. Hahm, "Internet of Things (IoT): Operating System, Applications and Protocols Design, and Validation Techniques, " *Futur. Gener. Comput. Syst.*,

vol.88, pp.699–706, 2018.

[36] Y. Song, J. Lin, M. Tang, and S. Dong, "An Internet of Energy Things Based on Wireless LPWAN," *Engineering*, vol.3, no.4, pp.460–466, 2017.

[37] A. Saxena, J. Celaya, B. Saha, S. Saha, and K. Goebel, "Metrics for Offline Evaluation of Prognostic Performance, " *Int. J. Progn. Heal. Manag.*, vol.1, no.1, pp.1–20, 2010.

[38] Q. Wang *et al.*, "Environmental impact analysis and process optimization of batteries based on life cycle assessment, " *J. Clean. Prod.*, vol.174, pp.1262–1273, 2018.

[39] L. Li *et al.*, "Process for recycling mixed - cathode materials from spent lithium - ion batteries and kinetics of leaching, " *Waste Manag.*, vol.71, pp.362–371, 2018.

[40] A. Sonoc, J. Jeswiet, and V. K. Soo, "Opportunities to improve recycling of automotive lithium ion batteries, " *Procedia CIRP*, vol.29, pp.752–757, 2015.

[41] A. Mahmoudzadeh Andwari, A. Pesiridis, S. Rajoo, R. Martinez - Botas, and V. Esfahanian, "A review of Battery Electric Vehicle technology and readiness levels, " *Renew. Sustain. Energy Rev.*, vol.78, no. March, pp.414–430, 2017.

[42] X. Chen, W. Shen, T. T. Vo, Z. Cao, and A. Kapoor, "An Overview of Lithium - ion Batteries for Electric Vehicles, " pp.230–235, 2012.

[43] E. Raszmann, K. Baker, Y. Shi, and D. Christensen, "Modeling Stationary Lithium - Ion Batteries for Optimization and Predictive Control, " in *IEEE Power and Energy Conference at Illinois (PECI)*, 2017.

[44] L. Li *et al.*, "Economical recycling process for spent lithium - ion batteries and macro - and micro - scale mechanistic study, " *J. Power Sources*, vol.377, no. October 2017, pp.70–79, 2018.

[45] R. Sreejith and K. R. Rajagopal, "An insight into motor and battery selections for three - wheeler electric vehicle, " *1st IEEE Int. Conf. Power Electron. Intell. Control Energy Syst. ICPEICES 2016*, pp.9–14, 2017.

[46] W. Wang and Y. Wu, "An overview of recycling and treatment of spent LiFePO4batteries in China, " *Resour. Conserv. Recycl.*, vol.127, no.100, pp.233–243, 2017.

[47] Y. Gong, Y. Yu, K. Huang, J. Hu, and C. Li, "Evaluation of lithium - ion batteries through the simultaneous consideration of environmental, economic and electrochemical performance indicators, " *J. Clean. Prod.*, vol.170, pp.915–923, 2018.

[48] A. Rahman, M. Rahman, and M. Rashid, "Wireless Battery Management System of Electric Transport, " *IOP Conf. Ser. Mater. Sci. Eng.*, vol.260, no.1, 2017.

[49] M. Akdere *et al.*, "Hardware and Software Framework for an Open Battery Management System in Safety - Critical Applications, " in *IECON 2016—42nd Annual Conference of the IEEE Industrial Electronics Society*, 2016, pp.5507–5512.

[50] M. O. Badawy and Y. Sozer, "Power Flow Management of a Grid Tied PV - Battery System for Electric Vehicles Charging, " *IEEE Trans. Ind. Appl.*, vol.53, no.2, pp.1347–1357, 2017.

[51] P. Cazzola, M. Gorner, J. T. Yi., and W. Yi, "Global EV Outlook 2016 Electric Vehicles Initiative, " *International Energy Agency*, 2016. .

[52] J. Rivera - Barrera, N. Muñoz - Galeano, and H. Sarmiento - Maldonado, *SoC Estimation for Lithium - ion Batteries: Review and Future Challenges*, vol.6, no.4.2017.

[53] V. Ruiz, A. Pfrang, A. Kriston, N. Omar, P. Van Den Bossche, and L. Boon - brett, "A review of international abuse testing standards and regulations for lithium ion batteries in electric and hybrid electric vehicles, " *Renew. Sustain. Energy Rev.*, vol.81, no. April 2017, pp.1427–1452, 2018.

[54] L. Wu, X. Fu, and Y. Guan, "Review of the Remaining Useful Life Prognostics of Vehicle Lithium - Ion Batteries Using Data - Driven Methodologies, " *Appl. Sci.*, vol.6, no.6, p.166, 2016.

[55] F. Zhang, M. M. U. Rehman, R. Zane, and D. Maksimovíc, "Hybrid balancing in a modular battery management system for electric - drive vehicles, " *2017 IEEE Energy Convers. Congr. Expo. ECCE 2017*, vol.2017 - Janua, pp.578–583, 2017.

[56] X. Ye, Y. Zhao, and Z. Quan, "Thermal management system of lithium - ion battery module based on micro heat pipe array, " *Int. J. Energy Res.*, vol.42, no.2, pp.648–655, 2018.

[57] J. F. Peters, M. Baumann, B. Zimmermann, J. Braun, and M. Weil, "The environmental impact of Li - Ion batteries and the role of key parameters – A review, " *Renew. Sustain. Energy Rev.*, vol.67, pp.491–506, 2017.

[58] J. Dewulf *et al.*, "Recycling rechargeable lithium ion batteries: Critical analysis of natural resource savings, " *Resour. Conserv. Recycl.*, vol.54, no.4, pp.229–234, 2010.

[59] E. A. Olivetti, G. Ceder, G. G. Gaustad, and X. Fu, "Lithium - Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals, " *Joule*, vol.1, no.2, pp.229–243, 2017.

[60] S. S. Reka and T. Dragicevic, "Future effectual role of energy delivery : A comprehensive review of Internet of Things and smart grid, " *Renew. Sustain. Energy Rev.*, vol.91, pp.90–108, 2018.

[61] J. Lopez, R. Rios, F. Bao, and G. Wang, "Evolving privacy : From sensors to the Internet of Things, " *Futur. Gener. Comput. Syst.*, vol.75, pp.46–57, 2017.

[62] S. Din, A. Ahmad, A. Paul, and S. Rho, "MGR : Multi - parameter Green Reliable communication for Internet of Things in 5G network, " *J. Parallel Distrib. Comput.*, vol.118, pp.34–45, 2018.

[63] A. Khanna and S. Kaur, "Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture, " *Comput. Electron. Agric. J.*, vol.157, pp.218–231, 2019.

[64] P. Sarwesh, N. S. V Shet, and K. Chandrasekaran, "ETRT – Cross layer model for optimizing transmission range of nodes in low power wireless networks – An Internet of Things Perspective, " *Phys. Commun.*, vol.29, pp.307–318, 2018.

[65] H. Boyes, B. Hallaq, J. Cunningham, and T. Watson, "The industrial internet of things (IIoT): An analysis framework, " *Comput. Ind.*, vol.101, pp.1–12, 2018.