E3S Web of Conferences **540**, 11005 (2024) https://doi.org/10.1051/e3sconf/202454011005
ICPES 2023

Sustainable Mobility and Environmental Impacts of Green Batteries: A Comprehensive Review

Abhishek S S[1*], Gopalam Rahul Malik[1], Devadath T Suresh[1], Anudev B, and Geena Prasad[2*]

1Department of Electrical and Electronics Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, India
2Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, India

Abstract: The comprehensive study explores the vital role of the batteries in sustainable development. It evaluates the performance of batteries in both internal combustion engine (ICE) and Electric Vehicles (EVs) while emphasizing the environmental benefits of Green Batteries. The study also explores the battery maintenance and recycling practices for everyday automotive use. Based on lithium-ion battery data, it underscores the urgent need for effective recycling solutions and the rising battery recycling sector. The environmental impacts of battery production, especially for EVs, are recognised, emphasising the importance of transition to renewable energy sources. A comparison between fossil and non-fossil fuels demonstrates the potential benefits of cleaner energy sources. The study also compares the performance of conventional batteries with green batteries, and ultimately recommends the adoption of green batteries powered by renewable energy as a sustainable solution.

Keywords – Batteries, Fossil Fuels, Electric Vehicles, Sustainable Development,Renewable Energy

Contact Author: abhiabhishek111sangeetha@gmail.com, geena@am.amrita.edu

1. Introduction

Promoting non-fossil fuels becomes more important when we consider the energy used and pollutants produced during battery production. The potential for cleaner energy is demonstrated through a comparison of the capabilities of fossil and non-fossil fuels. The benefits of environmentally friendly solutions are evident through a performance comparison of conventional and green batteries. With a focus on green batteries, which are lauded for their environmentally friendly qualities, this study sets out on a thorough journey, dissecting the performance characteristics of batteries, from their use in conventional internal combustion engine (ICE) vehicles to their transformative role in electric vehicles (EVs). Daily battery use cannot be denied inside the complex web of mobility. To meet our rising energy needs, it is crucial to comprehend battery lifespan and the nuances of recycling. In the middle of this, forecasts for the battery recycling market that are influenced by the booming lithium-ion battery recycling business highlight the increasing demand for eco-friendly battery disposal techniques. However, because EVs include resource-intensive processes and resource extraction, the creation of batteries itself creates environmental issues. The paradox of batteries is that they can provide emissions-free transportation while still degrading the environment through their energy-intensive production processes. This contradiction highlights how urgent it is to switch to renewable energy sources to fuel these batteries. A comparative analysis that contrasts the capabilities of fossil and non-fossil fuels in the goal of sustainability highlights the potential benefits of cleaner energy options. As we explore the world of battery technology, a performance assessment is made, contrasting conventional batteries with environmentally friendly alternatives. As this research progresses, a compelling conclusion becomes clear: green batteries, powered by renewable energy, stand out as the beacon of hope in our quest for a more sustainable future marked by diminished environmental impact and cleaner transportation. The switch to green batteries not only fits with our overarching objectives of sustainable development, but also provides a clear path to a future that is cleaner, greener, and more responsible for both technology and transportation. Table 1 depicts the comparison of existing EV batteries with the green battery [3, 11, 16]

Table 1. Comparison of exiting EV batteries v/s green batteries

Green Batteries	**Traditional EV Batteries**
Utilizes cutting-edge production techniques that require reduced energy consumption and result in decreased carbon emissions during the battery manufacturing process	Use older battery techniques resulting in increased energy consumption and the potential for higher greenhouse gas emissions during the manufacturing process
Efficient recycling processes to recover valuable materials from used batteries and some green batteries are designed for second-life application before recycling	Even though recycling programs are existing for traditional batteries, they are not advanced or widespread

Reduced environmental impact, which includes reduced usage of water, emissions, and hazardous waste generation	Traditional EV batteries have a larger environmental footprint in terms of emissions and waste
Renewable Energy integration	Traditional battery production facilities do not prioritize renewable energy to some extent
Improves safety by eliminating or reduce the use of hazardous materials	Less safety and have a higher environmental impact due to the materials they contain
Examples: Solid-State, Lithium-Sulphur	Examples: Nickel-metal-hydride, lead-acid

2. Battery

Lithium-ion Battery

Researchers analysed eleven distinct lithium-ion battery packs made of diverse materials in a study aiming at completely evaluating the environmental impact of lithium-ion battery packs during their use stage. They developed a multilevel index evaluation system based on battery environmental parameters using the life cycle assessment method and the entropy weight approach for environmental load quantification. According to the study's findings, the Li-S battery had the least environmental impact throughout the use stage of the several lithium-ion batteries analysed, indicating its significantly cleaner profile within the Li-ion family [12].

However, the overall finding emphasises that lithium-ion batteries, as a group, have environmental consequences. Notably, the composition of the power structure in each location was found to connect with various environmental variables. For example, coal power generation within the regional power structure can have an impact on numerous indicators, such as the CF, EF, AP, and EP generated by the battery packs during operation. Similarly, nuclear power generation can have an impact on the water footprint of battery packs, whereas natural gas power generation can have an impact on the abiotic depletion potential (ADP) during operation.

The researchers stressed that when considering the environmental impact holistically, the green property index should not be simply dependent on the region's principal power sources. Other parameters, such as mass energy density, are important. During the operational phase, the battery pack with the highest environmental characteristic index was identified as Li-S, while the battery pack with the lowest green characteristic index was identified as LMO/NMC-C. The mass energy density factor is responsible for this result. Even with the same capacity, battery packs with higher mass energy density result in smaller pack weights and, as a result, lower energy consumption for transportation throughout the use stage, leading to a greener profile [1].

The environmental effects of lithium-ion (Li-ion) batteries are becoming more apparent, with significant issues covering numerous elements of their production and use. Notably, the greenhouse gas (GHG) emissions connected with Li-ion battery production for automobiles,

 https://doi.org/10.1051/e3sconf/202454011005

particularly when recycling is considered throughout the battery's life cycle, are still under inquiry and inspection. Furthermore, the increased demand for important elements such as nickel (Ni), cobalt, lithium, and manganese, which are essential components of Li-ion batteries, has increased mining activity. Unfortunately, these mining operations frequently take place in arid locations, which raises problems due to their water-intensive nature, increasing the environmental impact of water use in these mining areas. Within the Li-ion battery sector, there is an increasing emphasis on solutions such as closed-loop recycling systems to solve some of these environmental concerns and promote sustainability [2, 13].

Green Battery

'Green batteries' are batteries or battery technologies that prioritise environmental sustainability and minimise their environmental impact throughout their lifecycle, from raw material extraction and production to usage and disposal. Green batteries are created with the intention of lowering greenhouse gas emissions, decreasing pollution, saving resources, and encouraging sustainability [7]. Currently, lithium-ion batteries (LIB) are one of the cutting-edge technologies capable of meeting the majority of these critical needs at a fair cost. Aside from performance and costs, the environmental impact, i.e., the battery's and the battery cell's sustainability over the entire life cycle—that is, from raw material extraction and battery material production to cell and battery pack production, battery utilisation, and possibilities for second life usage and recycling—receives increasing attention. Various approaches for the creation of 'greener' batteries are introduced in this overview, with a focus on the entire battery life cycle and the LIB technology. Alternative battery technologies are reviewed critically in terms of sustainability and competitiveness [8].

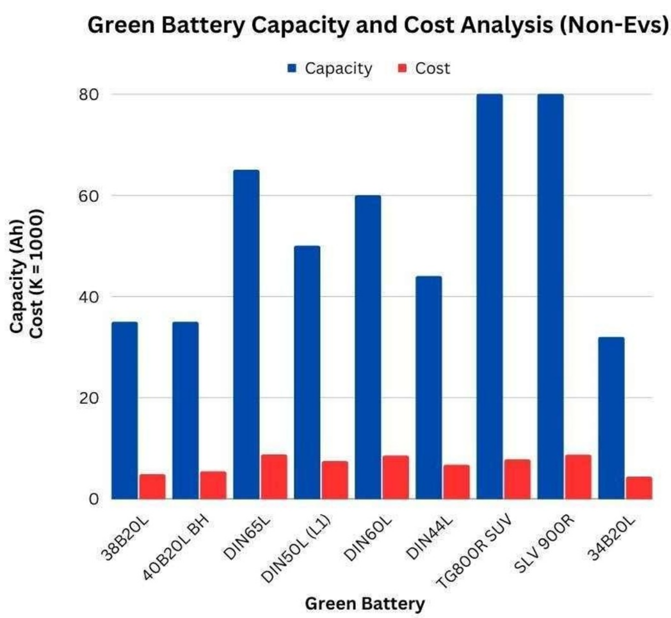

Figure.1 Bar graph of TATA green battery comparison for non-electric vehicles Figure 1 shows an overview of numerous TATA green batteries designed for conventional, non-electric cars is given in the above bar graph. To accommodate the requirements and financial constraints of various customers, these batteries are offered in a range of capacities and pricing points. The graph shows nine different battery models with capacities ranging from 32Ah to 80Ah. Additionally, it lists the pricing of each device in

 https://doi.org/10.1051/e3sconf/202454011005

Indian Rupees (Rs), which ranges from Rs 4,428 for the affordable Premio 34B20L to Rs 8,836 for the robust Premio DIN65L. When buying a battery for their non-electric vehicles, consumers can utilize this graphic representation to balance capacity and cost based on theirneeds and financial constraints [4, 10].

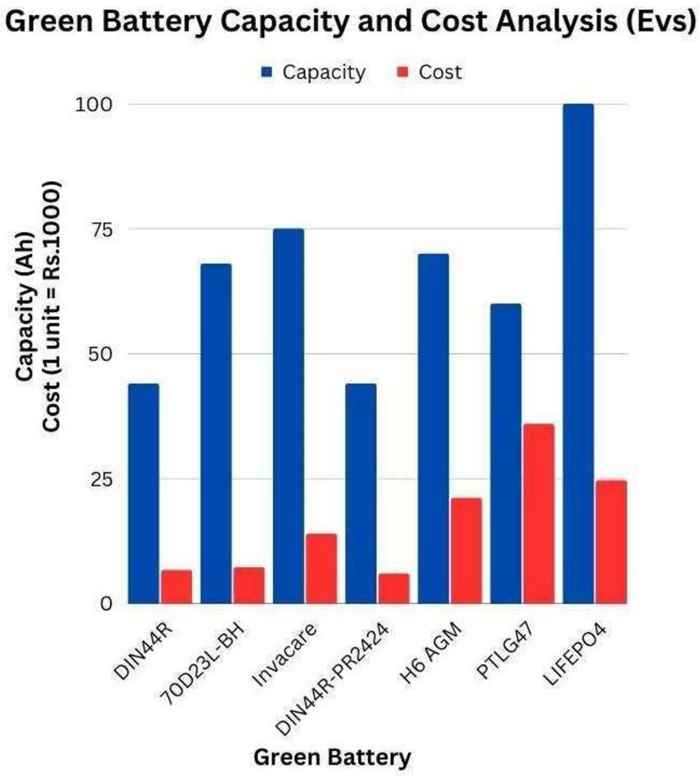

Figure 2. Bar graph for TATA green battery comparison for electric vehicles Figure 2 depicts a comparison of electric vehicle batteries, showing their capacity and associated prices. These batteries, purchased from a variety of manufacturers, provide a range of solutions to meet the unique needs of EV customers. The highlighted models come in a variety of capacities ranging from 44Ah to 100Ah, with prices in Indian Rupees (Rs). Notably, the Premio DIN44R (TATA Green) is a cost-effective option with a 44Ah capacity priced at Rs 6,810, making it a good value. In comparison, EV owners looking for bigger capacity batteries can look into the Invacare, which has a 75Ah capacity, or the LIFEPO4 (BYD), which has a 100Ah capacity but is more expensive. The H6 AGM (EP/D) and PTLG47 (BCI) models are more expensive, with prices starting at Rs 21,200 and going up to Rs 36,000, reflecting enhanced features and capabilities. This detailed bar graph enables prospective EV customers to make informed selections by balancing battery capacity and cost concerns in accordance with their unique EV performance needs and budget limits [4].

 https://doi.org/10.1051/e3sconf/202454011005

3. Consumption of Energy

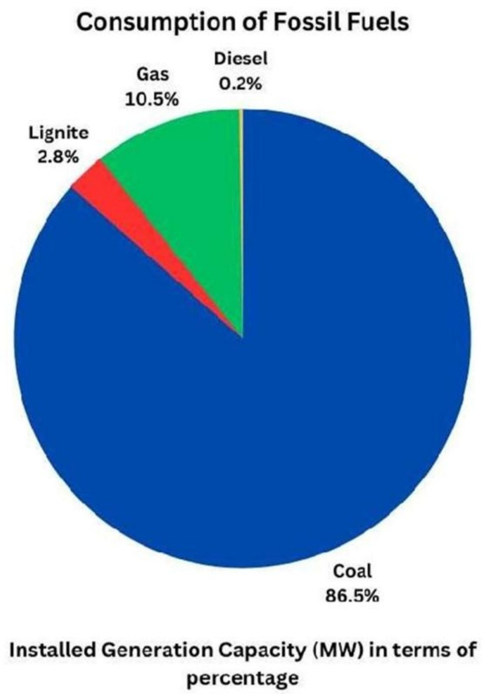

Figure 3. Pie-chart of environmental impact of fossil fuel-powered electricity generation in India

Manufacturing of batteries using fossil fuels have an impact on the environment that goes beyond production lines, which surely worsen the environment. The source of electricity used to power batteries in vehicles is crucial in determining how truly environmentally friendly they are in countries like India where the switch to electric mobility is gaining pace. According to information on installed generation capacity (measured in megawatts, MW), coal, petroleum, diesel, and lignite account for a significant portion of India's electrical production. With 205,235 MW, coal has the most installed capacity, making up 49.1% of the total. Petrol is second with 24,824 MW, followed by diesel with 589 MW, and lignite with 6,620 MW. In total, these fossil fuels make up 56.8% of India's 237,269 MW installed generating capacity. This highlights the important need for EVs to be powered by cleaner and more sustainable electricity sources, as the environmental impact is directly linked to the energy sources that charge their batteries [5].

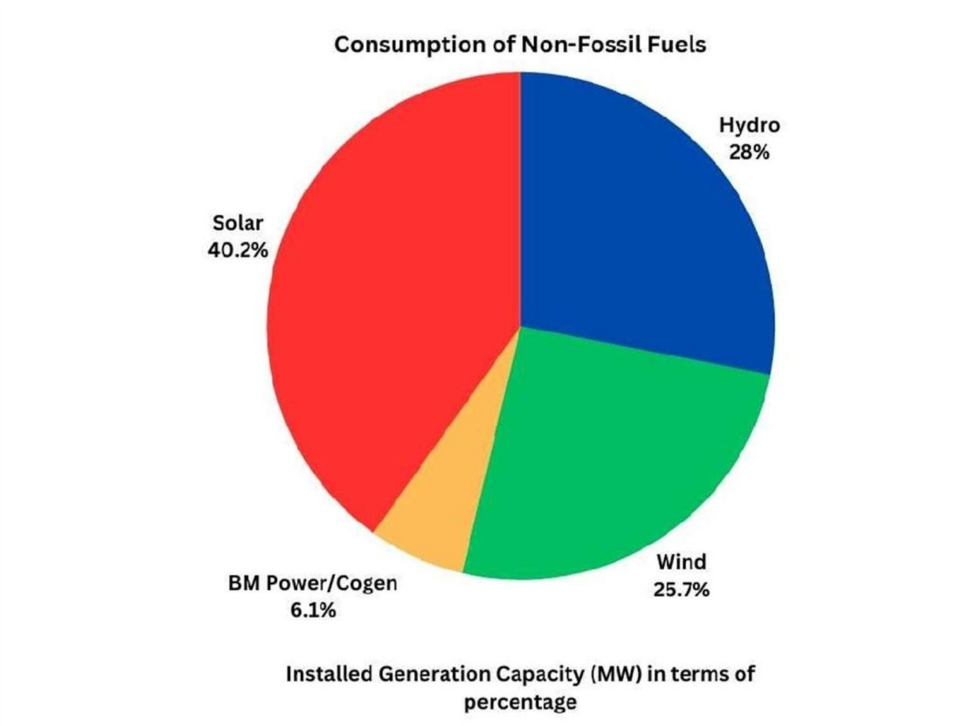

Figure 4 Pie-chart of environmental impact of non-fossil fuel powered electricity generation in India

When it comes to charging or powering batteries, the choice of energy source is critical, especially in the context of sustainability. India has made great progress towards a cleaner and greener energy landscape in terms of non-fossil fuels. The pie chart depicting non-fossil fuel installed power capacity (in megawatts, MW) presents a captivating tale. The installed capacity of hydroelectric power is 46,850 MW, accounting for 11.2% of total non-fossil fuel capacity. Wind energy comes in second with 42,868 MW and a 10.3% share, while solar energy contributes 67,078 MW, accounting for 10.3% of total non-fossil fuel capacity. Furthermore, BM Power/Cogen contributes 10,248 MW, accounting for 2.5% of non-fossil fuel capacity. These non-fossil fuel sources combine to generate an astounding total installed generation capacity of 179,322 MW, accounting for 43.0% of India's total capacity. With a total installed capacity of 417,668 MW combining both fossil fuels and non-fossil fuels, it is clear that non-fossil fuels are carving out a significant share of the energy landscape. This research emphasizes the critical importance of non-fossil fuel sources in the long-term charging and powering of batteries, paving the way for a cleaner, more ecologically responsible future for battery-powered products in India [5, 17].

4. Recycling

Battery recycling is critical to reducing the environmental effect of lithium-ion (Li-ion) batteries, which are widely utilised in a variety of applications such as electric vehicles and consumer gadgets. The United States' Environmental Protection Agency (EPA) has set recycling rules for lithium batteries, emphasising the necessity of appropriate disposal and recycling. Because there are unique recycling methods for single-use and rechargeable batteries, it is best to deliver batteries of all sizes to specialised recycling centres. These facilities allow for the safe breakdown of batteries and the recovery of specific metals that can be reused in a variety of applications. Currently, three major methods for recycling lithium-ion batteries are in use:

Pyrometallurgical Recovery: This method entails pyrolysis, incineration, roasting, and smelting. It is crucial to note, however, that typical industrial techniques frequently fail to recover lithium effectively. The primary focus is now on mining other important metals such as cobalt, nickel, and copper. In terms of materials and capital resources, this approach has a relatively poor recycling efficiency. It also consumes a lot of energy and incorporates gas treatment stages that result in less gas byproducts.

Hydrometallurgical Metals Reclamation: Aqueous solutions are used to recover metals from ores in hydrometallurgy, which is a method widely utilised for copper recovery. It has advantages over traditional smelting, particularly in terms of sulphur dioxide byproduct reduction.

Direct Recycling: While recycling is a more environmentally responsible option, it is sometimes more expensive than traditional raw ore mining. Because of the growing demand for lithium-ion batteries, attempts have been made to develop more efficient recycling systems. However, one big problem is that recycling is not often a design priority when making batteries.

Lithium-ion batteries include potentially dangerous elements such as cobalt, nickel, and manganese, which must be disposed of properly. These metals can harm water sources and ecosystems if they leach out of landfills. Fires in landfills and battery recycling plants have also been connected to improper lithium-ion battery disposal. As a result, some governments require lithium-ion battery recycling. Nonetheless, due to the continuous high cost and immaturity of recycling technologies, the rate of recycling remains very low.

Lithium-ion battery recycling and responsible disposal are critical stages in reducing their environmental impact, ensuring that precious metals are recovered for reuse while eliminating pollution and any risks associated with incorrect disposal. To meet the increased demand for Li-ion batteries, efforts are being made to develop more cost-effective and efficient recycling technologies [6, 18].

Battery Recyling Market

It is expected to grow rapidly, with a market value of around 2.0 trillion Indian Rupees (INR) in 2023. Revenue is expected to reach over 4.0 trillion INR by 2030, representing a solid Compound Annual Growth Rate (CAGR) of 10.5%. This increased trend is predicted to continue throughout the forecast period, which runs from 2023 to 2030, with 2022 serving as the base year. These data show significant market growth, emphasising the growing importance of battery recycling solutions and the environmental imperative of responsibly managing battery waste in the Indian market [9, 14].

5. Conclusion

Batteries play a critical role in moulding our environmental impact, cost-effectiveness, and overall sustainability. Their importance in sustainable development cannot be overstated. It becomes clear that green batteries, created with sustainability in mind, hold considerable advantages when examining the performance of batteries across a variety of applications, notably in the context of internal combustion engine (ICE) vehicles and electric vehicles (EVs).The switch to EVs with green batteries offers a promising replacement for ICE engines, which depend on traditional fuel sources with well-documented environmental effects. The significance of appropriate recycling techniques is highlighted by awareness of the extent of the transportation sector's reliance on batteries, as well as their longevity and end-of-life management. The industry for battery recycling is primed for significant growth,particularly when it comes to lithium-ion batteries.

The market for battery recycling is anticipated to increase significantly, particularly in the case of lithium-ion batteries, underlining the potential financial and environmental advantages of efficient disposal and recycling. Furthermore, given that manufacturing procedures frequently include the consumption of fossil fuels, it is imperative to recognize the environmental impact of battery production for EVs. To lessen this, it is crucial to switch to renewable energy sources, both for the creation of batteries and for charging them. Throughout the battery lifecycle, we may cut emissions by encouraging the use of non-fossil fuels for power generation. Comparing installed capacity for fossil and non-fossil fuels highlights the benefits of cleaner energy sources. In EVs, the performance characteristics of conventional batteries and green batteries are compared, and the preference is clearly in favour of the latter. Green batteries that are fuelled by renewable energy sources become an attractive option in the quest for zero-emission mobility and a more sustainable future. A number of factors, including effective recycling procedures, more environmentally friendly production techniques, and the adoption of green batteries, will determine the future of sustainable transportation and responsible battery use. We may move towards a more sustainable and eco-conscious future by putting an emphasis on ecologically friendly alternatives and embracing renewable energy, lowering our reliance on fossil fuels, and reducing our environmental impact [19].

References

[1]. Hongliang Zhang, “Life cycle environmental impact assessment for battery-powered electric vehicles at the global and regional levels”, Received 2023 Apr 12; Accepted 2023 May 13.
[2]. Sakunai, T., Ito, L. & Tokai, A. Environmental impact assessment on production and material supply stages of lithium-ion batteries with increasing demands for electric vehicles. J Mater Cycles Waste Manag 23, 470–479 (2021).
[3]. Epa, U. (2001). United States environmental protection agency. Quality Assurance Guidance Document-Model Quality Assurance Project Plan for the PM Ambient Air, 2, 12.
[4]. Udupa, J., & Sunil, T. (2023). A Study on Brand Awareness of Indian Batteries. LATEST TRENDS IN MULTIDISCIPLINARY RESEARCH & DEVELOPMENT, 87.
[5]. Hemand Chandran, P. T., Ajithkumar, S., & Bahukhandi, K. D. (2022). Environmental Impact of Emerging Electro World with Special Focus on Electrical-Vehicles and Its Impact on Global Environment. In Environmental Pollution and Natural Resource Management (pp. 309-326). Cham: Springer International Publishing.

[6]. Illikainen, S. (2022). Environmental impacts of Lithium-ion batteries (Bachelor's thesis, S. Illikainen).
[7]. Carole Mathieu, “Green Batteries: A Competitive Advantage for Europe’s Electric Vehicle Value Chain?”, Études de l’Ifri, Ifri, April 2021.
[8]. Duehnen, S., Betz, J., Kolek, M., Schmuch, R., Winter, M., & Placke, T. (2020). Toward green battery cells: Perspective on materials and technologies. Small Methods, 4(7), 2000039.
[9]. Fleischmann, J., Hanicke, M., Horetsky, E., Ibrahim, D., Jautelat, S., Linder, M., ... & van de Rijt, A. (2023). Battery 2030: Resilient, sustainable, and circular. McKinsey & Company, 2-18.
[10]. Chian YT et al. A Review on Recent Progress of Batteries for Electric Vehicles. Int J Appl Eng Res. 14(24). 2019: 4441-4461
[11]. Eurobat, 2014, A Review of Battery Technologies for Automotive Applications, (EUROBAT).
[12]. Wang, Ying Hai, Hao Ming Zhang, and Lian Soon Peh. "Research on Power Consumption of Lithium-Ion Battery Protection Circuit." In Advanced Materials Research, vol. 1049, pp. 582-585. Trans Tech Publications, 2014.
[13]. Christen, Rouven, Gerhard Rizzo, Alfred Gadola, and Max Stöck. "Test method for thermal characterization of Li-ion cells and verification of cooling concepts." Batteries 3, no. 1 (2017): 3.
[14]. Ajith, S., Harivishnu, B., Vinesh, T. K., Sooraj, S., & Prasad, G. (2017). Automated gas pollution detection system. 2nd International Conference for Convergence in Technology (I2CT), (pp. 483-486). IEEE.
[15]. Abhijit, T., Sahay, M., & Gupta, K. K. (2017). Renewable Energy Growth Pattern and Correlation with CO2 Emissions in BRICS Nations. IEEE.
[16]. Poornesh, K., Nivya, K. P., & Sireesha, K. (2020, September). A comparative study on electric vehicle and internal combustion engine vehicles. In 2020 International Conference on Smart Electronics and Communication (ICOSEC) (pp. 1179-1183). IEEE.
[17]. Amrita, Panda, R. C., & Dhandabani, L. (2021, March). A Novel Hybrid Renewable Power Platform: A Sustainable Innovation. In European, Asian, Middle Eastern, NorthAfrican Conference on Management & Information Systems (pp. 218-225). Cham: Springer International Publishing.
[18]. Kayakool, F. A., Gangaja, B., Nair, S., & Santhanagopalan, D. (2021). Li-based all-carbon dual-ion batteries using graphite recycled from spent Li-ion batteries. Sustainable Materials and Technologies, 28, e00262.
[19]. Thiruvonasundari, D., & Deepa, K. (2021). Evaluation and Comparative Study of Cell Balancing Methods for Lithium-Ion Batteries Used in Electric Vehicles. International Journalof Renewable Energy Development, 10(3).