China Petroleum Processing and Petrochemical Technology

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

Future Trends and Strategies for Sustainable Energy Management

Pawan Kumar Sharma, Dharm Veer Arya, Shashank Gupta & Anuj Baliyan
Department of Mathematics, Bareilly College, Bareilly, Uttar Pradesh, 243 001, India
pksharma1170@gmail.com, *dvarya1857@gmail.com*, *shashank.gupta875@gmail.com* & *abaliyan4599@gmail.com*

Abstract- *Global energy production and consumption have been growing steadily since the beginning of the twentieth century. Further, renewable energy production and consumption have reached 7900 TWh and 11102 TWh respectively up to 2021. Such increment in consumption in comparison to production causes more demand which forces us to search new economical and viable trends and strategies for the energy imbalance. Indian domestic coal and lignite consumption increased since 2020 onwards due the economic upturn and high natural gas prices. Simultaneously, developed countries have shifted their investments towards renewable energy sources in an effort to combat the climate crisis, due to their lower carbon emissions. Consequently, global electricity generation rate from renewable sources has risen significantly compared to non-renewable sources. In the pursuit of sustainable energy management, economic analysis of power storage technologies conducted by industrial energy management systems emphasizes the need for stable and sustainable technology development. Technical analysis of photovoltaic solar energy highlights its potential to shape future trends in economic and sustainable development through the widespread installation of PV systems. Indian energy scene has undergone a drastic change in recent decades through strategic planning processes. This review study critically compares two key technologies, Li-ion batteries and hydrogen fuel cells technologies for integration with PV-based systems for sustainable development. Computational results indicate the superiority of Li-ion battery storage, with the cost of electrolyzers emerging as a critical factor in improving system performance. These findings emphasize the importance of adopting innovative strategies and technologies for sustainable energy management in a changing global energy landscape.*

Keywords- Electric vehicles, Hydrogen battery, Lithium-ion battery, PV cell

1. INTRODUCTION

All facets of life and matter within the universe are set in motion by energy; it is, therefore, the fundamental force behind all activities and can be defined as the capacity for performing work. In ancient times, energy was harnessed in three primary forms: human power, animal power and heat. The necessity for human power has historically been a driving force behind slavery throughout known history. As time progressed, the labour of muscles transitioned to machines primarily powered by fossil fuels (coal, oil, gas) and nuclear energy, leading to a surge in energy demand. Unfortunately, this has accelerated the depletion of fossil and nuclear resources and their utilization has proven detrimental to earth's environment, evident in global climate change and resulting disasters like rain, floods, deforestation and glaciers melting; Owing to which, there has been a growing emphasis on shifting towards renewable and sustainable energy sources such as solar, wind, biomass, hydropower and geothermal as shown in Fig. 1 and Table 1.

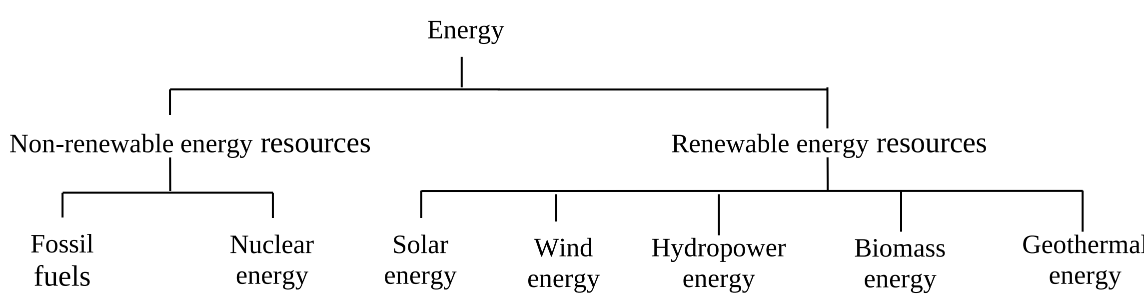

Fig. 1: Classification of energy resources

Renewable energy sources are natural resources that can be naturally replenished over time, offering a sustainable and environmentally friendly alternative to traditional fossil fuels. Among renewable energy resources solar PV systems represent the fastest growing resource for electric power generation [1]. These sources play a significant role in diversifying our energy mix and reducing greenhouse gas emissions. They provide us with energy in various forms, including electricity, heat, and fuels. These renewable sources bring several advantages, such as reduced environmental impact, long-term sustainability and the creation of job opportunities, all of which contribute to a more resilient and eco-friendly energy future. Research and development efforts in this sector focus on improving efficiency, sustainability, affordability, energy economics and product quality.

Table 1: Historical development of renewable energy

Inventions	Year	Inventions	Year
Hydroelectric power	200 BC	Wind turbines used commercially	1927
Wind energy	1590	Dam technology	1935
Hydrogen fuel	1838	Solar goes to space	1958
Solar energy	1839	Li-ion battery	1970
First solar energy system	1860	One whole village goes to solar	1978
Solar cells to generate energy	1876	Solar project	1996
Wind turbines	1887	Ivanpah	2013
Photoelectric effect	1905	Chadrayaan-3 at south pole of moon	2023

The difference in the proportion of renewable energy within the installed capacity as opposed to its actual electricity generation can be described to variables such as fluctuations in sunshine hours and wind patterns, which directly impact the extent to which the installed capacity is utilized. In September 2021, the United Kingdom government made a substantial commitment of US$ 1.2 billion towards green projects and initiatives focused on renewable energy in India. This commitment is aimed at supporting India's ambitious goal of achieving 450 GW of renewable energy capacity by the year 2030. Additionally, the exploration and development of renewable energy heavily involve offshore wind technology and the production of green hydrogen. In the Union Budget for the fiscal year 2022-23, the Indian government introduced significant measures to promote sustainable energy practices. These included the issuance of sovereign green bonds and the granting of infrastructure status to energy storage systems, which encompass grid-scale battery systems. In 2022, the estimated power consumption reached approximately 1895 TWh and the government allocated 19500 crores for the Production-Linked Incentive (PLI) Scheme, designed to stimulate the manufacturing of high-efficiency solar modules. Furthermore, Energy Efficiency Services Limited (EES) is actively collaborating with private-sector energy service companies to scale up its Building Energy Efficiency Programme (BEEP).

2. GENERATION AND CONSUMPTION OF ENERGY

Energy serves as a crucial input for agriculture, construction, industrial production and economic growth, with per capita consumption acting as an indicator of national progress. India has experienced the fastest growth in renewable energy capacity addition among large economies in the last nine years, with renewable energy capacity growing by 2.9 times and solar energy expanding by over 18 times. Approximately 30% of the total outlay of the Indian economy's five- year plan has been allocated to the energy sector, making it sensible to integrate energy planning into economic planning.

Energy planning involves considering various factors such as technological, social, economic, environmental, demographic and organizational aspects. A system analytic approach and modelling techniques are crucial in planning, which can be classified into three steps: technology appraisal, development of a mathematical framework for the energy economy system and implementation and management, providing feedback for action on both the energy supply and demand sectors.

Following source https://www.statista.com, the variation in global production and consumption of renewable energy from 2009 onwards may be demonstrated as shown in Fig. 2. Developed countries are investing more in renewable energy than fossil fuels to mitigate climate crisis due to lower carbon emissions [2]. Therefore, share of renewable energy rate increased rapidly as compared to non-renewable energy rate in global electricity generation after 2010 as shown in Fig. 3. The data has been taken from “Energy Statistics Pocketbook 2022”.

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

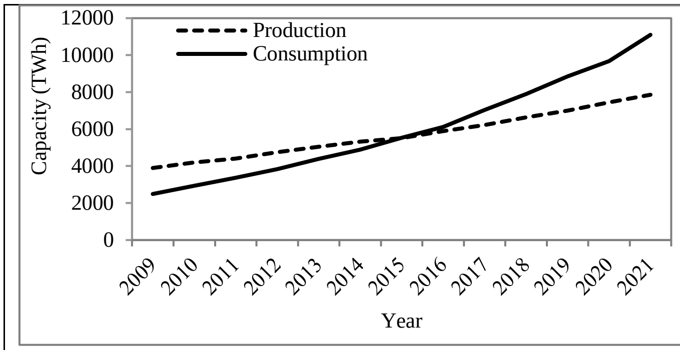

Fig. 2: Global production & consumption of renewable energy

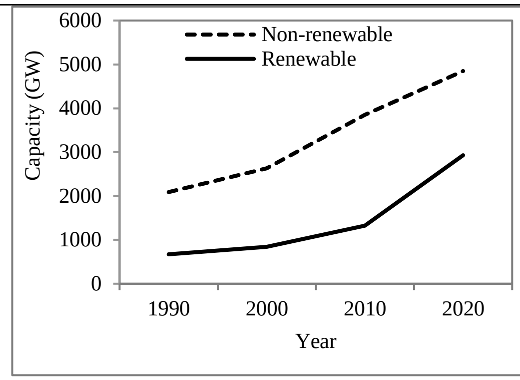

Fig. 3: Global electricity generation

Following source https://www.yearbook.enerdata.net, Indian domestic coal and lignite consumption increased since 2020 onwards due the economic upturn and high natural gas prices as well as due to the high demand and poor average quality of coal and lignite in India as depicted in Fig. 4. Following source https://www.powermin.gov.in, total electricity generation of India increased from 2009-10 to 2019-20 but decreased in 2020-21 due to covid-19 pandemic and increased rapidly from 2021-22 onwards due to increase in its consumption after to get relief from lockdown as shown in Fig. 5.

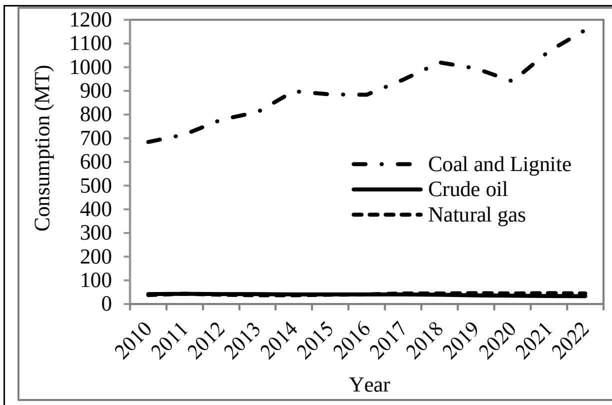

Fig. 4: Indian domestic consumption by sources

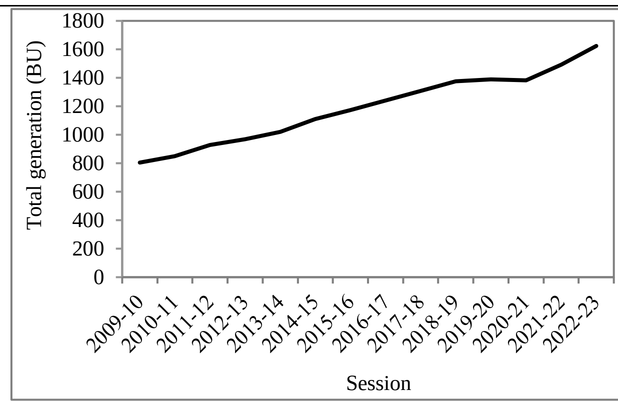

Fig. 5: Total electricity generation in India

Following source https://www.powermin.gov.in, Fig. 6 shows that India has done much to bridge energy supply demand gap since 2009-10 to 2021-22.

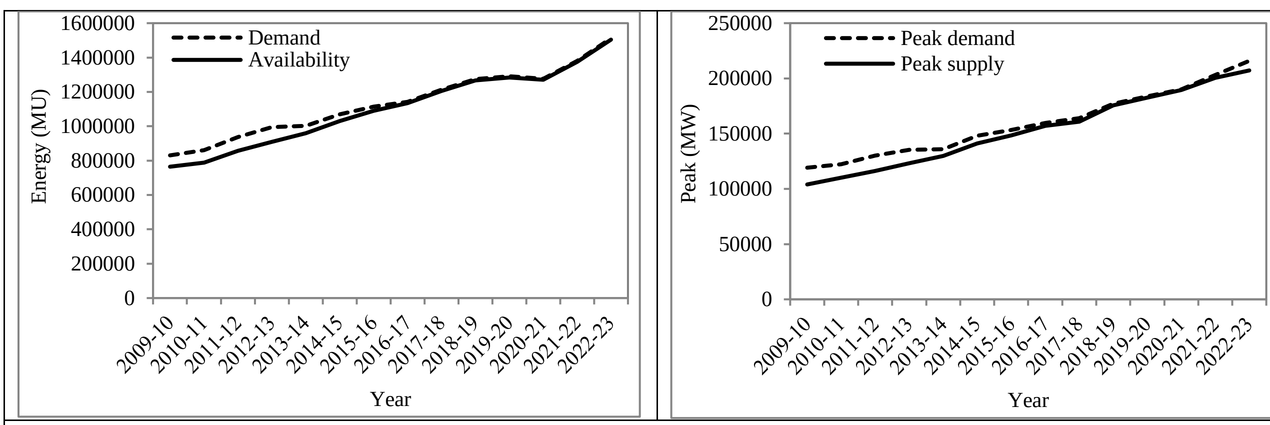

Fig. 6: The power supply position in India

3. INNOVATION IN POWER GENERATION

Hydrogen, lithium and PV systems show promise in providing power for both residential and commercial sectors. These sources not only mitigate environmental concerns but also enhance energy security by reducing dependence on finite fossil fuels. Ongoing advancements in technology continue to improve the efficiency and affordability of energy systems, making them increasingly integral to global efforts to address climate change and ensure a sustainable energy future. Solar photovoltaic energy is the leading type of renewable energy for power generation. The conversion of solar radiation into electricity is made possible through the photovoltaic effect, which was initially observed by Becquerel [3] in 1839. This sector is experiencing rapid global growth to overcome the mismatch between production and load. Battery is the most widely employed storage method to mitigate the above mismatch such as:

3.1 Solar PV Systems

To sustain this momentum, significant advancements have been made in areas such as material selection, energy efficiency in manufacturing processes, device design, production technologies and novel concepts to improve the overall efficiency of the system. Solar photovoltaic arrays are networks of many electrical generators, i.e., solar cells, interconnected to provide required terminal voltage and current ratings. Following N.K. Gautam and N.D. Kaushika [4], the explicit mathematical analysis based on randomly generated parameters of solar cell characteristics has been studied. The current-voltage relationship for a single diode solar cell can be given as follows:

$$I - I_{scc} + I_{scc}\left(\frac{1-\gamma}{e^{P}-1}\right)\left[e^{P\left(\frac{V+IR_s}{V_0}\right)} - 1\right] + \gamma I_{scc}\left(\frac{V+IR_s}{V_0}\right) = 0; P = \frac{eV_0}{NkT}, \gamma = \frac{V_0}{R_{sh}I_{scc}} \tag{1}$$

Similarly, for cell(m, n),

$$I_{mn} = (I_{scc})_{mn} - (I_{scc})_{mn}\left(\frac{1-\sigma_{mn}}{e^{P_{mn}}-1}\right)\left[e^{P_{mn}\left(\frac{V_{mn}+I_{mn}R_S}{(V_0)_{mn}}\right)} - 1\right] + \sigma_{mn}((I_{scc})_{mn})_{mn}\left(\frac{V_{mn}+I_{mn}R_S}{(V_0)_{mn}}\right) \tag{2}$$

The electrical characteristics of series-parallel, total-cross-tied and bridge-linked arrays can be investigated using the mathematical network analysis approach. The current I_{mn} for given voltage V_{mn}, the iterative formula for Newton-Raphson method is given as follows:

$$(I_{mn})_{i+1} = (I_{mn})_i - \frac{f(V_{mn}, I_{mn})}{\frac{\partial f(V_{mn}, I_{mn})}{\partial I_{mn}}} \tag{3}$$

For Newton-Raphson method, the initial value $(I_{mn})_0$ can be found by using Bisection method.

Computational results show that superiority of bridge-linked type solar cells interconnecting network over series-parallel and total-crossed-tied networks in coping with the effects of electrical mismatches. Solar PV technology has been widely embraced in many parts of the world as solar energy is abundant and available virtually everywhere on the Earth's surface [5]. Following source https://www.statista.com, from 2010 to 2021, the cost of installing solar PV system decreased consistently on a global scale. This reduction in costs was primarily attributed to the increased availability of materials, which in turn lowered production expenses.

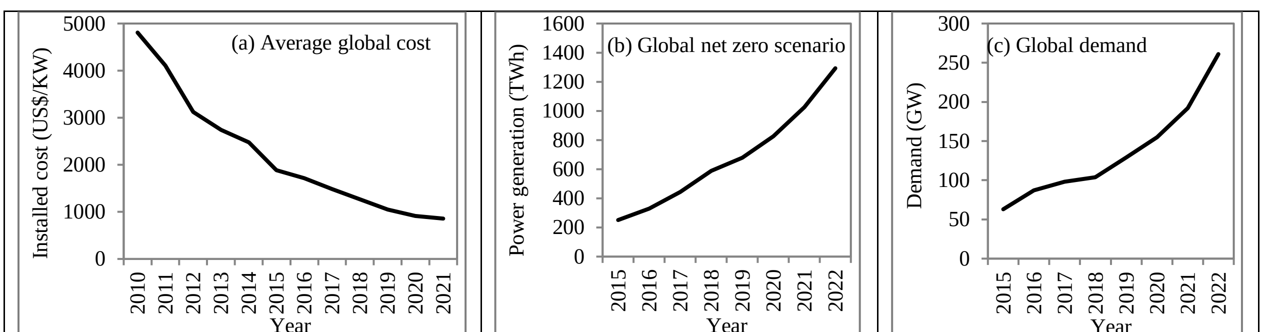

Fig. 7: For solar PV systems

As of 2021, the average installed cost of solar PV system had reached approximately 857 US$/KW as shown in Fig. 7a. After 2010, the rapid decline in the average installed cost of global solar PV system has increased the number of such installations which leads to a rapid increase in solar power generation in net zero scenario as shown in Fig. 7b.

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

Following source https://www.statista.com, after 2015, the demand of global solar PV increased due to higher retail electricity prices & growing policy support to help consumers to save money on their electricity bills as shown in Fig. 7c.

According to data from the International Energy Agency (IEA), as shown in Fig. 8, the global distribution of cumulative power capacity across various technologies is depicted. Notably, the share of solar PV cells has been consistently on the rise since 2010. In the previous year, it witnessed a substantial increase, accounting for 45% of the total global investment in electricity generation. This is three times greater than the investment made in fossil fuel technologies, owing to policy support and increasing competitiveness within the solar PV sector. In 2021, both developed and developing countries gave high priority to the expansion of solar PV capacity. This decision was driven by a growing environmental consciousness concerning the depletion of non-renewable resources and the emissions of pollution, as visually represented in Fig. 9.

According to information sourced from the Ministry of New and Renewable Energy at https://www.mnre.gov.in, during the period from 2013-14 to 2017-18, India's off-grid solar PV applications program was focused on providing solar PV-based solutions in areas where reliable grid power was lacking. This initiative is depicted in Fig. 10.

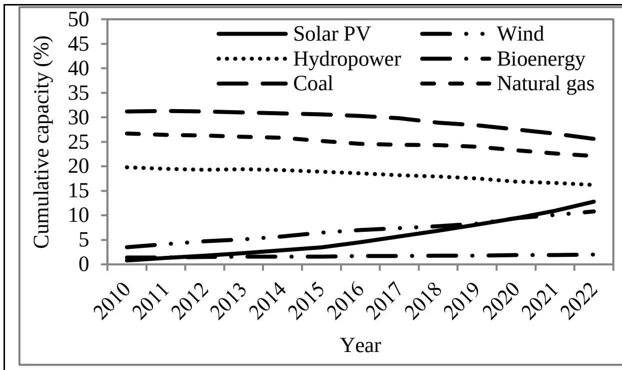

Fig. 8: Global energy collection with different sectors

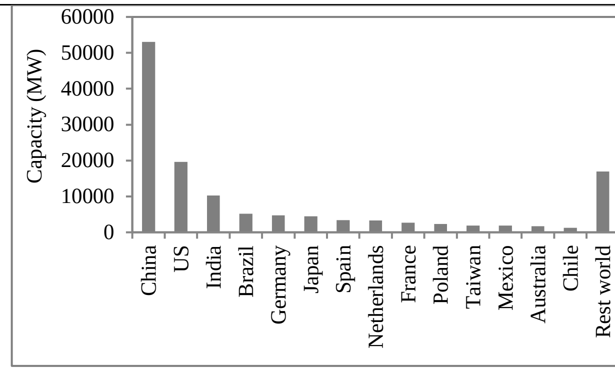

Fig. 9: Solar PV generation capacity in 2021

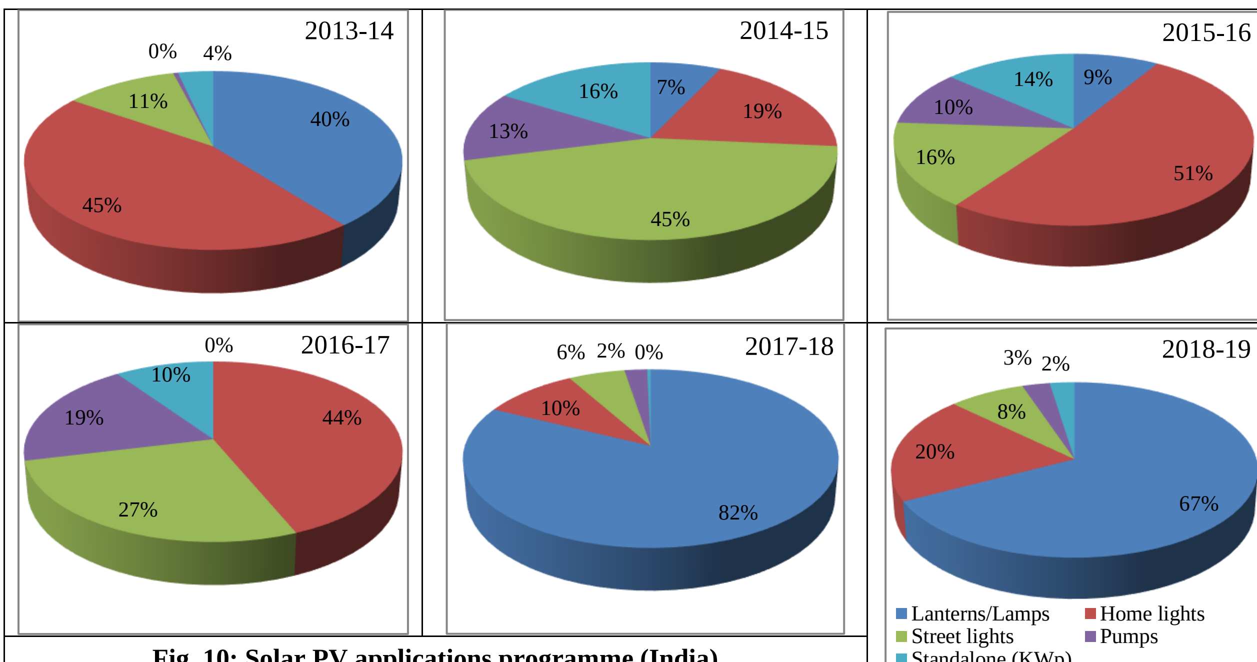

Fig. 10: Solar PV applications programme (India)

3.2 Li-ion Battery

Lithium is a crucial metal for green storage and development technologies. It can be found in various regions of the world such as Australia, Chile, China, Argentina, Brazil, Zimbabwe, Portugal, Bolivia and the United States.

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

According to the source https://www.statista.com/statistics/, Australia is the leading producer and biggest supplier of the world as demonstrated in Table 2. Further, Fig. 11 shows that Bolivia and Argentina have the greatest lithium reserves. Bolivia and Argentina have 21 million tons and 19 million tonnes of reserves of lithium respectively. Australia primarily extracts lithium from hard rock mines. Lithium is very crucial for Indian economy as renewable energy source to reduce imports, self-reliance, battery manufacturing, clean energy targets and economic benefits for Jammu & Kashmir, digital revolution. But currently, India has to face many challenges to extract lithium as water consumption (approximately 1.9 million liters/metric tonnes), environment degradation, lack of expertise, feasibility study, impact on Himalayas, high investments etc. Currently, less than 1% of lithium is recycled due to the lack of a significant incentive to develop a lithium recycling industry [6]. However, with rising demand for lithium resources, the need to recover lithium before it's wasted in disposal will become crucial. In India, the discovery of lithium deposits first occurred in the Salal-Haiman area of the Reasi District in Jammu & Kashmir. Subsequently, significant reserves of lithium were also found in Rajasthan's Nagaur district, specifically in the Renvat hill of Degana. In more details, according to data provided by the District Administration Reasi, the lithium-bearing land spans a total of 18,913 Kanals and 17 Marlas, comprising 3,929 Kanals of private land, 269 Kanal and 7 Marla of state-owned land, and 14,715 Kanals and 10 Marlas of forest land.

Table 2: Lithium mine production by country

Country	Production (tonnes)				
	2018	**2019**	**2020**	**2021**	**2022**
Australia	51,000	45,000	39,700	55,000	61,000
Chile	16,000	19,300	21,500	26,000	39,000
China	8,000	10,800	13,300	14,000	19,000
Argentina	6,200	6,300	5,900	6,200	6,200
Brazil	600	2,400	1,420	1,500	2,200
Zimbabwe	1,600	1,200	417	1,200	800
Portugal	800	900	348	900	600

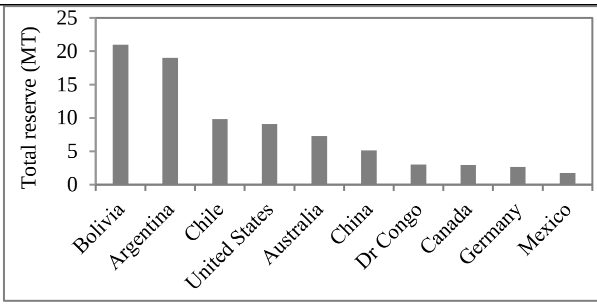

Fig. 11: Lithium reserve of various country

The Geological Survey of India (GSI) has identified substantial lithium deposits in the Degana region, which is historically known for supplying tungsten minerals to the country. GSI and mining authorities have asserted that the lithium reserves in Rajasthan have the potential to meet approximately 80% of India's total demand for this critical metal. This breakthrough could reduce India's reliance on China as a lithium source, establishing India as the world's 7th largest lithium resource, with sufficient capacity to meet domestic demand. This discovery underscores the significance of industrial energy management as a partial solution to the challenge of decoupling GDP growth from increased commercial energy consumption. It also highlights the need for technological advancements in decentralized energy and power systems.

The applications of lithium vary as per its use. In form of lithium carbonate, it is used as a medication to treat mental illness. Further, it is used in manufacturing of lightweight alloys for the aeronautics industry. Lithium hypochlorite is used as a disinfectant in swimming pools and as a reagent for some chemical reactions. Lithium is also used as a tracer in soil and water contamination studies because it mimics the movement of metals in the soil solution and water body closely and can be used to accurately predict residence time. Lithium batteries are a broad category that includes various types of lithium-based chemistries, while Li-ion batteries are a specific subset of lithium batteries that use Li-ion technology to store and release electrical energy. Li-ion batteries are widely used in portable electronic devices and electric vehicles due to their high energy density and rechargeable capabilities. The difference between lithium battery and Li-ion battery has been demonstrated in Table 3.

Table 3: Difference between lithium & lithium-ion battery

Lithium battery	**Lithium-ion battery**
Non-rechargeable	rechargeable
Less efficiency	High efficiency
High-energy intensity	Less-energy intensity
Capacity is lost	Less capacity is lost
Smaller & lighter batteries	Larger & better weight capacity
Metallic as electrode material is used	Lithium cobalt oxide, lithium iron sulphate is used
Used in cameras, clocks & small electronics devices	Used in smartphones, laptops, electric vehicles, etc.

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

Lithium is a soft, silvery-white alkali and non-ferrous metal that plays a vital role in electric vehicle batteries and various other industries, with the surging demand for lithium resources being driven by the EV market. Table 4 represents the imported quantities and cost of lithium & Li-ion for three continuous sessions. Imported quantities are decreasing continuously while their costs are fluctuating during given financial years. Table 5 & 6 represent the factors influencing lithium and inflation/shortages of lithium respectively.

Table 4: Imported quantities and cost of lithium & Li-ion for three continuous sessions

Session	2018-19		2019-20		2020-21	
	Quantity (Thousand numbers)	Value (Rs. Crores)	Quantity (Thousand numbers)	Value (Rs. Crores)	Quantity (Thousand numbers)	Value (Rs. Crores)
Lithium (HS Code: 85065000)	85,224	202	72,376	147	71,392	173
Lithium-ion (HS Code: 85076000)	6,27,353	8,574	5,39,428	8,819	5,16,733	8,811

Table 5: Factors influencing lithium

For demand	For supply
Electric vehicle (EV) adoption	Geographical distribution
Consumer electronics	Production capacity
Energy storage systems	Technological advancements
Industrial applications	Environmental regulations
Urbanization and infrastructure	Price fluctuations
Technological advancements	Trade policies
Government policies and incentives	Recycling efforts
Recycling efforts	New discoveries

Table 6: Inflation & shortages of lithium

Causes	Impact
Growing electric vehicle market	Increased battery cost
Energy storage systems & Market demand	Price volatility
Electronic devices and gadgets	Increased battery cost
Government policies and regulations	Social & geopolitical effect
Political stability & Price fluctuations	Increased battery cost

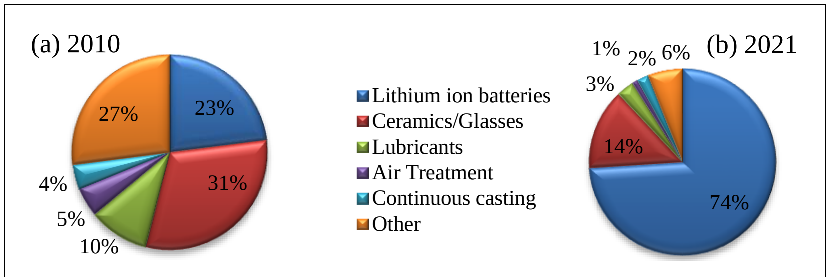

Fig. 12: percentage change in global Lithium consumption

Li-ion batteries, EVs, ceramics/glasses, lubricants, pharmaceutical, air treatment, polymers, aluminum-lithium alloys are the main industrial applications of lithium. Lithium consumption increased globally because of the surge in EV adoption and renewable energy storage since 2010 to 2021 as shown in Fig. 12.

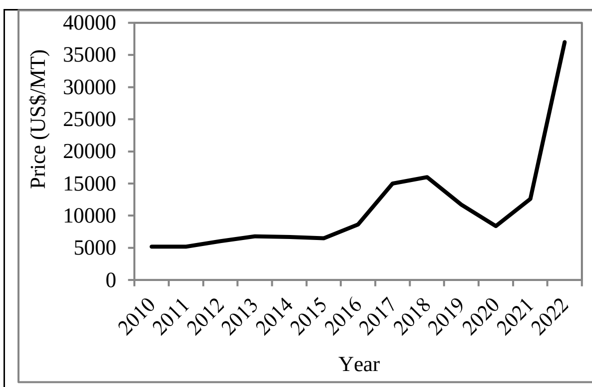

Fig. 13: Average lithium carbonate price

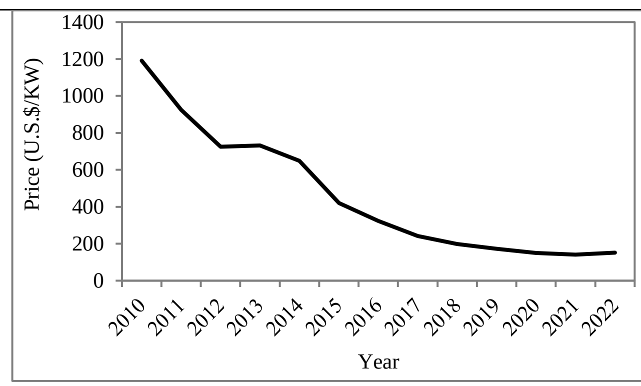

Fig. 14: Average cost of volume weighted Li-ion battery

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

Fig. 13 represents the variation in average lithium carbonate price for last 13 years, where better growth in price has been seen in 2016-18 and faster growth in 2021. The average Li-ion battery price has decreased due to the increase in worldwide lithium production, decreasing logistics costs, and an increase in the number of units of Li-ion batteries produced by manufacturing industries. But due to increase in demand of volume weighted Li-ion battery and in average production cost of lithium carbonate, the average price of Li-ion battery increased by 7% in 2022 instead of 2021 as shown in Fig. 14.

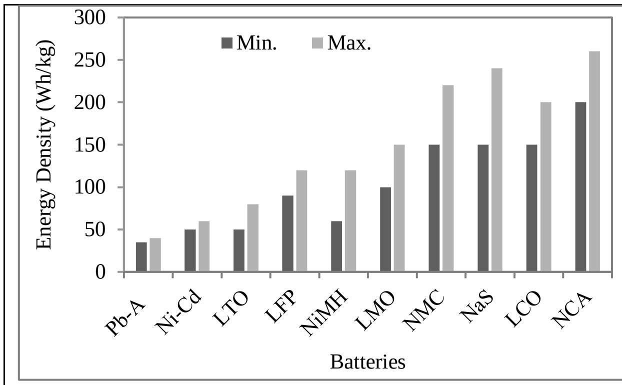

Fig. 15: Energy density comparison

Table 7: Total average cost (million US$) to build a Li-ion battery factory

Startup costs	Min.	Max.
Equipment purchase & installation	6.0	8.0
Raw material sourcing & acquisition	1.0	3.0
Research & development expenses	2.0	4.0
Infrastructure & facility construction	10	15.0
Employee training & hiring costs	0.5	1.0
Legal & regulatory compliance costs	0.5	1.5
Marketing & advertising expenditures	1.0	2.0
IT system & software implementation costs	0.5	1.0
Initial inventory & working capital expenditures	5.0	7.0
Total	26.5	42.5

Following the source https://batteryuniversity.com, the specific energy density of lead acid (Pb-A), nickel-cadmium (Ni-Cd), Li-titanate (LTO), Li-iron phosphate (LFP), nickel-metal hydride (NiMH), Li-ion manganese oxide (LMO), nickel manganese cobalt (NMC), sodium sulphur (NaS), Li-cobalt (LCO) and Li-nickel cobalt aluminum oxide (NCA) has compared as shown in Fig. 15. A Li-aluminum (NCA) stand out for its high capacity, but this advantage is specific to energy storage [7]. In terms of specific power and thermal stability, Li-manganese (LMO) and Li-phosphate (LFP) outperform other systems.
The country requires up to 903 GWh of energy storage to decarbonize its mobility and power sectors by 2030 and Li-ion batteries will meet the majority of this demand. The Li-ion battery industry is a rapid growing sector, driven by the increasing demand for energy-efficient and sustainable technologies. Following source https://finmodelslab.com, according to Markets and Markets, the global market size for lithium-ion batteries is projected to reach $94.4 billion by 2025, with a compound annual growth rate (CAGR) of 16.2% from 2020 to 2025. This growth is being driven by increased demand for electric vehicles and the widespread adoption of renewable energy sources. The average cost required in setting up the Li-ion battery factory ranges from 26.5 US$ to 42.5 US$ as shown in Table 7.

3.3 Hydrogen Battery

Hydrogen batteries (Hydrogen fuel cells) are the devices that generate electricity through a chemical reaction between hydrogen and oxygen. These cells can be used in various applications e.g., transportation (cars and buses), backup power systems and stationary power generation. Hydrogen fuel cell vehicles possess high potential to reduce emissions related to the transportation sector. Several countries (Japan, South Korea, Germany, China, United States and Norway) have been actively using hydrogen fuel cells and investing in hydrogen technology. The global hydrogen fuel cell vehicle market size was valued at $0.92 billion in 2021, and is projected to reach $43.2 billion by 2031, growing at a CAGR of 45.5% from 2022 to 2031. Hydrogen fuel cell technology was in its early stages of development and adoption in the Indian market. The Indian government had expressed interest in promoting hydrogen as a clean energy source and had initiated some projects and policies related to hydrogen fuel cells. The aim of National Hydrogen Mission is to promote the production, storage, and use of green hydrogen as a clean and sustainable energy source. Several researchers are working on pilot projects known as "Green Energy Technology and Future Trends of Acceptance" and research initiatives in progress. Hydrogen has been explored for various industrial applications like steel etc., which have high carbon emissions.

Table 8 represents the comparative study between hydrogen battery and Li-ion battery. Hydrogen batteries store energy by converting hydrogen gas into electricity, offering low energy density and faces challenges in storage and transportation. Li batteries including lithium-ion and lithium-polymer, store energy chemically and are more

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

commonly used due to their lighter weight, ease of recharging and established infrastructure, making them the preferred choice for portable electronics and electric vehicles.

Table 8: Comparative study of hydrogen and Li-ion battery

Parameter	Lithium Battery	Hydrogen Battery
Energy Density	Higher energy density	Lower energy density
Efficiency	Highly efficient	Good efficiency
Charging/Refueling	Recharged by plugging	Refueled with compressed hydrogen gas
Environmental Impact	Primarily related to the mining and disposal of lithium, cobalt, and other materials	Clean energy carrier
Infrastructure	Charging infrastructure more widespread and established	Hydrogen refueling requires significant investment.
Application	Portable electronics, EVs, and renewable energy storage systems.	Hydrogen-powered vehicles (e.g., cars, buses, and trucks) and backup power systems.

Storage of green electricity is identified as one of the most important research problems in energy system applications. Practical and effective energy storage can help increase the contribution of renewable energy to the global energy mix and can also lead to a sustainable energy future. In this order Fig. 16 illustrates the benefits of hydrogen batteries, highlighting their potential to significantly contribute to the realization of a pollution-free environment.

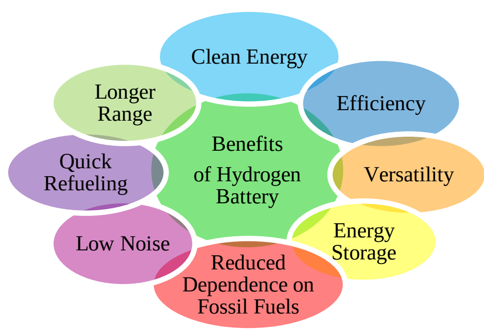

Fig. 16: Benefits of Hydrogen Battery

According to the source https://www.statista.com, Fig. 17 illustrates that there were approximately 136 charging points available for hydrogen fuel for EVs. Furthermore, Table 9 reveals that China boasts the largest number of hydrogen fuel stations worldwide. Japan is the prominent supplier of hydrogen automotive fuel.

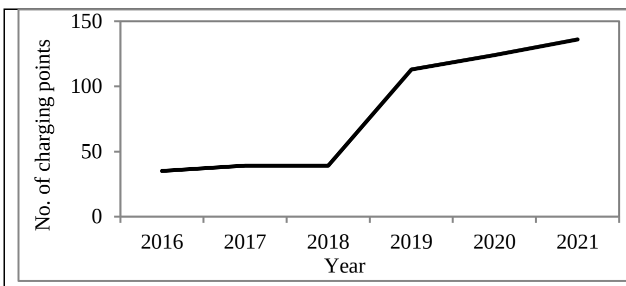

Fig. 17: No. of hydrogen fuel cell EV charging points in the European Union

Table 9: No. of hydrogen fueling station for road vehicle worldwide as 2022 by country

S.R.	Country	No. of hydrogen fuel stations
1	China	250
2	Japan	161
3	South Korea	141
4	Germany	93
5	United States	54
6	France	21
7	Switzerland	13
8	Netherland	11
9	Canada	9
10	India	3

3.4 Sodium Battery

Due to India having a large coastline, also has large reserves. Lithium is about 100 times more expensive than sodium. Lithium is 80 thousand dollars per ton, while sodium is 800 dollars per ton. Sodium-ion batteries are of lower cost, stationary energy storage, compatible, environmentally friendly, less energy density and cycle life than Li-ion batteries. Even though Sodium ion batteries are less efficient than Li-ion batteries, they are still much better than

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

lead-acid batteries. Faradion claims that its batteries can store 160 watt-hours of energy per kilogram. This is almost equivalent to lithium batteries with Li-ion phosphate technology. Consequently, continuous research is needed for significant use of Sodium ion batteries which can be used in economical cars, buses, trucks, tractors or elsewhere.

4. Efficiency Determination

Battery capacity at different discharge rates can be evaluated by Peukert's equation

$$I_A = I_N \times \left(\frac{C}{C_N}\right)^{k_p};\ where\ I_N = \frac{C_N}{Capacity\ rate\ (in\ hours)} \tag{4}$$

The Peukert's exponent k_p is specific to each battery chemistry and typically for common lead-acid batteries, $1 \leq k_p \leq 1.4$. A lower k_p value indicates less capacity loss at higher discharge rates. The rate of chemical reactions in batteries due to temperature can be expressed by Arrhenius equation as:

$$K = F \times e^{\left(-\frac{E_A}{RT}\right)} \tag{5}$$

For a Li-ion battery, take $T = 298\ K (25°C), R = 8.314 \frac{J}{mol\ K}, E_A = 30000\ \frac{J}{mol}, F = 10^{12}$ (a typical value for battery reactions), we have $K \approx 1.48 \times 10^5$. Higher temperatures increase the rate of capacity fade, while lower temperatures decrease it.
The efficiency of a battery is calculated by the formula as:

$$\eta = \left(\frac{Output\ energy\ during\ discharge\ cycle}{Input\ energy\ during\ charging\ cycle}\right) \times 100\% \tag{6}$$

where,

$$Input\ energy\ = \int C_P\, dt\ \ (in\ Wh)\quad \&\quad Output\ energy = \int D_P\, dt\ (in\ Wh) \tag{7}$$

$$C_P = C_I \times C_V \qquad \& \qquad D_P = D_I \times D_V \tag{8}$$

Further, the battery efficiency can vary based on factors like charging and discharging rates, temperature and the specific chemistry of the battery.

5. Innovation in Electric Vehicle

Following source https://www.livemint.com/news/india/ev-industry-in-india, India, a rapidly growing economy, aspires to be a manufacturing hub for electric vehicles under the 'Make in India' initiative as shown in Fig. 18. This represents the potential for substantial growth, with reported market projections far exceeding recent sales of electric vehicle in India. Following the source https://www.statista.com, the highest growth is attained by 2-wheeler sale in 2019 and declined by 18% in 2020 due to economic slowdown and nationwide lockdown as shown in Fig. 19.

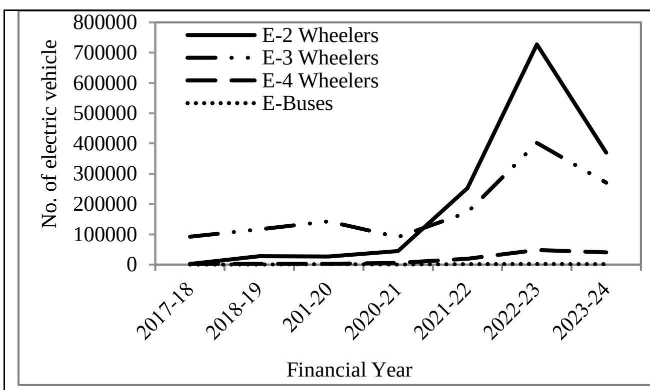

Fig. 18: No. of electric vehicle in India

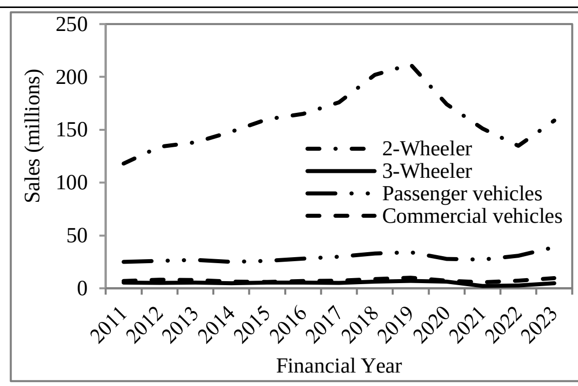

Fig. 19: Sales of automobiles in India

According to the source https://www.statista.com, China has the highest estimated global demand of Li-ion battery exhibited in Fig. 20. China's extensive manufacturing capacity and ability to offer lithium products at

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

competitive prices have propelled the nation to a dominant position in global lithium production. China's status as the largest consumer of lithium is attributed to its rapidly growing electronics and EV industries.

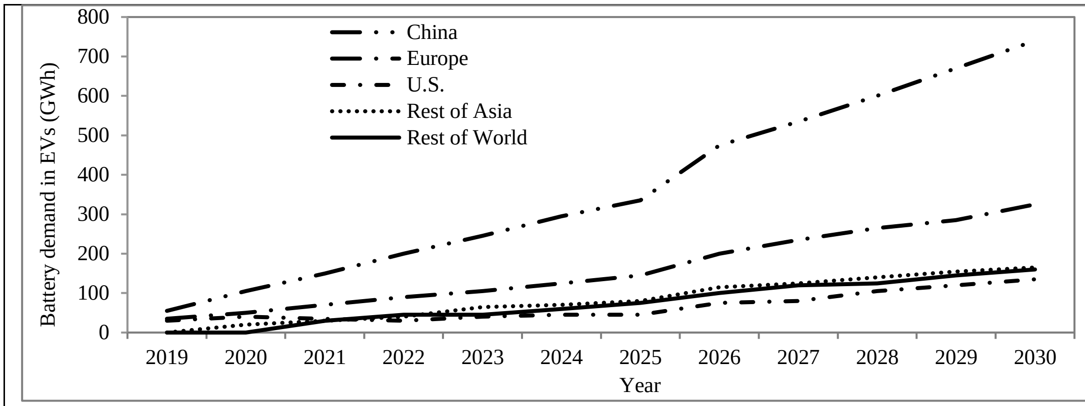

Fig. 20: Estimate global Li-ion battery demand in EVs

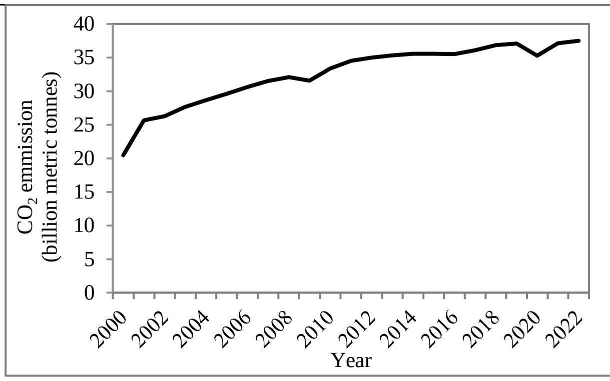

Fig. 21: Annual CO_2 emission worldwide

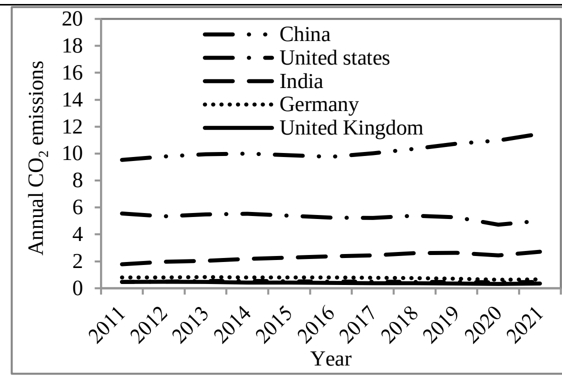

Fig. 22: CO_2 emissions from fossil fuels & industry

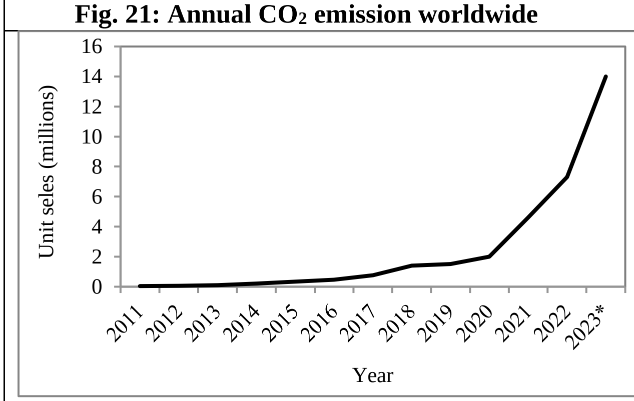

Fig. 23: Global Battery-EVs sales

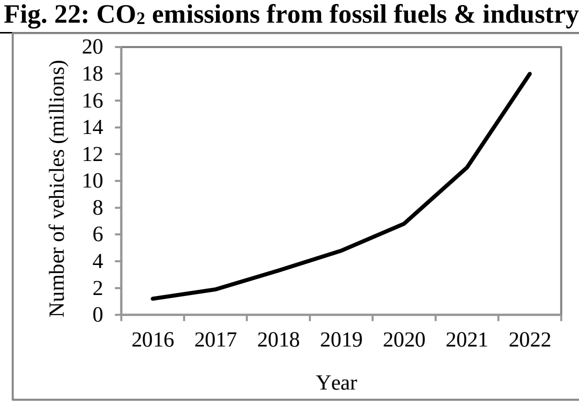

Fig. 24: Global count of used battery-EVs

Following source https://www.statista.com/global -co2-emissions/, Fig. 21 shows that there is increase in the CO_2 emission from 2000-2008 and then decreased in the emission has been noticed due to the rise of renewable in the power sectors in the next two year. After 2010 the carbon emission increased due to the increased in the demand of automobiles. According to the source www.ourworldindata.org/co2-emissions/, Fig. 22 shows that most CO_2 emission generated by fossil fuels and industry has been made by China as compared to other countries and then followed by United States which pollutes the environment. Following source https://www.statista.com/global-battery-electric-vehicle-sale/, Fig. 23 represents battery-electric vehicle sales are projected to reach 14 million in 2023, up from about 7.3 million in 2022. BEV sales have increased due to several factors, including increasing consumer interest in more sustainable transport and government regulation to curb direct transportation emissions. According to the source https://www.statista.com/, Fig. 24 shows that the use of electric vehicles around the world

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2713-2725

has been increasing continuously since 2016.

5.1 Classification of Electric Vehicle Charging Station and Their Parameter

The capacity of a charging point for electric vehicles can vary widely depending on the type of charger and its power rating. Table 10 shows that Level 1 chargers are known as "trickle chargers" of slowest charging, Level 2 chargers the most common chargers and Level 3 chargers as DC fast chargers or superchargers. The manufacturing cost of EV batteries ranges from $130 to $250 per kWh. Most of the Li-ion batteries cost $10 to $20,000 depending on the device it powers. An electric vehicle battery is the most expensive typically costing $4,760 to $19,200. Table 11 denotes number of publicly available electric vehicle chargers (EVSE) in 2022, by major country and type.

Table 10: Classification of electric vehicle charging station and their parameter

	Equipment Cost (Approx.)	Installation Cost (Approx.)	Charging Power rate	Voltage	Current	Charging Rate (MPH)
Level 1	$200 to $600	$500 to $1500	1.44-1.92 kW	120 V	12-16 A	2-5
Level 2	$600 to $1200	$800 to $2500	55 kW	240 -400 V	80 A	20-30
Level 3	$10,000 to $50,000	$10,000 to $100,000	350 kW	800 V	500 A	100-350

Table 11: Number of EVSE

Country	China	South Korea	United States	Netherlands	France	Germany	United Kingdom	Italy	Japan	Norway
Slow	1,000,000	180,000	1,00,000	1,20,000	74,000	64,000	42,000	31,000	21,000	15,000
Fast	760,000	21,000	28,000	4,300	9,700	13,000	8,600	6,500	8,400	9,100

China had nearly 1.8 million publicly accessible electric vehicle chargers in 2022, accounting the largest public charging infrastructure in the world. The United States ranked third: 100,000 slow chargers and around 28,000 fast chargers were installed across the nation.

5.2 State Wise Operational Public EV Charging Stations (PCS)

In India, there are currently 6,586 operational public EV charging stations, with an additional 419 public EV charging stations in operation along national highways. The Indian government has unveiled plans for the construction of 69,000 EV charging stations across the nation as part of the initial phase of EV infrastructure development, anticipating a demand for 400,000 charging stations by the year 2028.

According to a report by the Confederation of Indian Industry (CII) titled 'Charging Infrastructure for Electric Vehicle,' India is projected to require a minimum of 1.32 million charging stations by the year 2030 to facilitate the swift adoption of electric vehicles (EVs). The data in Table 12 provides an overview of the major states in India that offer public EV charging stations as of 2022.

Table 12: Public EV charging stations in India in 2022

State	PCS	State	PCS
Delhi	1845	Telangana	365
Karnataka	704	Rajasthan	254
Maharashtra	660	Haryana	232
Tamil Nadu	441	Andhra Pradesh	222
Uttar Pradesh	406	Gujarat	195

6. CONCLUSION

India is the third largest producer of electricity in the world during 2022-23, the total electricity generation in the country was 1844 TWh of which 1618 TWh was generated by utilities. Thermal power which is about 71% of electricity consumed is the largest source of power in India. Global renewable energy production is increasing continuously since 2009 and amounted to nearly 7900 TWh in 2021. Similarly global consumption of renewable energy has increased significantly over 2015 to 2021 and nearly reached 11102 TWh in 2021. In 2021, the Indian Li-ion battery market was valued at US$ 2.1 billion. According to IMARC Group, the market is expected to reach US$ 4.7 billion by 2027, exhibiting a CAGR of 15.3% during 2022-2027. India, with around 300 sunny days in most parts of the country, holds high potential for solar energy utilization through solar thermal or solar photovoltaic technology. Over the last four decades, numerous solar energy-based systems and devices have been developed and deployed in India, offering successful solutions for lighting, cooking, water heating, air heating, and electricity generation. The computational results show that Li-ion battery is superior to the hydrogen due to its high energy density and high efficiency. The focus of research is to develop eco-friendly energy systems with enhance efficiency, sustainability, affordability and product quality.

ACKNOWLEDGEMENT

The authors wish to thanks to **Uttar Pradesh Government** to sanction Grant for the project entitled "Energy Economic and Planning for Sustainable Development in Uttar Pradesh" through letter "No**-24/2023/681/ Sattar-4-2023-002-4(59)/2022 Dated 28-03-2023".**

NOMENCLATURE

Name	Symbol	Name	Symbol	Name	Symbol
Actual discharge rate	I_A	Charging current	C_I	Boltzman's constant	k
Nominal discharge current	I_N	Charging voltage	C_V	Electron charge	e
Nominal capacity of the battery (Ah)	C_N	Discharging voltage	D_V	Peukert's exponent	k_p
Instantaneous power during charging	C_P	Current through cell	I	Kilowatts	KW
Instantaneous power during discharging	D_P	Universal gas constant	R	Million tonnes	MT
Short circuit current for cell	I_{scc}	Capacity remaining in the battery	C	Million unit	MU
Open circuit voltage	V_0	Rate constant	K	Gigawatts	GW
Activation energy	E_A	Pre-exponential factor	F	Billion tonnes	BT
Discharging current	D_I	Cell operating temperature	T	Megawatts	MW
Shunt resistance	R_{sh}	Ideality constant	N	Terawatts-hour	TWh
Series resistance	R_s	Voltage at cell	V		

REFERENCES

[1] Jordehi A R, Parameter estimation of solar photovoltaic (PV) cells: A review, Renew Sustain Energy Rev 61 (2016) 354-371.

[2] Gulagi A, Ram M, Bogdanov D, Sarin S, Mensah T N O & Breyer C, The role of renewables for rapid transitioning of the power sector across states in India, Nature Communications 13 (2022) 5499-5517.

[3] Sampaio P G V & Gonzalez M O A, Photovoltaic solar energy: Conceptual framework, Renew Sustain Energy Rev 74 (2017) 590-601.

[4] Gautam N K & Kaushika N D, Network analysis of fault-tolerant solar photovoltaic arrays, Solar energy materials and solar cells 69 (2001) 25-42.

[5] Makki A, Omer S & Sabir H, Advancements in hybrid photovoltaic systems for enhanced solar cells performance, Renew Sustain Energy Rev 41 (2015) 658-684.

[6] Kavanagh L, Keohane J, Cabellos G G, Lloyd A & Cleary J, Global lithium sources-industrial use and future in the electric vehicle industry: a review, Resources 7 (2018) 57-85.

[7] Rajanna B V & Kumar M K, Comparison study of lead-acid and lithium-ion batteries for solar photovoltaic applications, International Journal of Power Electronics and Drive System 12 (2021) 1069-1082.

[8] Tsakiris A, Analysis of hydrogen fuel cell and battery efficiency, Young Energy Researchers Conference Wels/Austria (2019).

[9] Wong K W & Chow W K, Principle for the working of the lithium-ion battery, J Mod Phys 11 (2020) 1743-1750.

[10] Gujarathi P K, Shah V & Lokhande M M, Electric vehicles in India: market analysis with consumer perspective, Policies and Issues, Journal of green Engineering 8(1) (2018) 17-36.

[11] Handwerker M, Wellnitz J & Marzbani H, Comparison of hydrogen powertrains with the battery powered electric vehicle and investigation of small-scale local hydrogen production using renewable energy, Hydrogen 2 (2021) 76-100.

[12] Rastogi A K & Gupta N G, An analysis of Indian automobile industry: slowdown as an opportunity for new development, International journal of research in commerce, IT & management 10(3) (2013) 36-41.