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***Research Article** (Open Access)*

GREEN CHEMISTRY INITIATIVES IN INDIAN INDUSTRIES

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ABSTRACT
This research examines the effects of renewable energy adoption and energy efficiency initiatives on numerous Indian businesses, focussing on government restrictions and industry-driven efforts. Energy audits, waste heat recovery, and renewable energy sources including wind, solar, and biomass are examined in this research to analyse India's sustainability landscape. The research used quantitative and qualitative methodologies to evaluate renewable energy projects, energy-saving technologies, and conservation activities. Hypothesis testing reveals that government regulations and corporate activity have fostered green chemistry and sustainable practices. This study helps us understand India's renewable energy industry's opportunities and dangers, and we can notice a favourable trend towards energy efficiency and integration. The research recommends using more renewable energy, especially small hydro and alternative fuels, and boosting energy efficiency in crucial industries to meet long-term sustainability goals.

Keywords: *Green Chemistry Renewable Energy, Energy Efficiency, Sustainability*

INTRODUCTION
Sustainable chemistry, or "green chemistry," is an emerging field that aims to reduce the production and use of harmful chemicals through product and process design. Natural resource conservation, efficiency maximisation, and pollution reduction are the grand objectives of this revolutionary field. In India, a nation rapidly developing into an industrial superpower, green chemistry has exploded in popularity due to environmental concerns, stringent rules, and economic need. A thriving industrial sector is essential to India's economic development. Sadly, this growth has often been accompanied by increasing waste generation, decreased resource availability, and air and water pollution. The chemical industry has long been a prominent pollutant in India due to the energy and harmful substances it utilises; nonetheless, it is now an essential aspect of the country's industrial landscape. Green chemistry initiatives should be put into place to address these hurdles. By following the principles of waste reduction, atom economy, and safer chemical usage, industries may reduce their environmental effect without compromising revenues. The transition to green chemistry is not only good for the earth, but it also gives Indian companies an opportunity to grow sustainably and compete internationally. In the 1990s, the concept of "green chemistry" emerged in response to the growing need for sustainable corporate practices and ecologically friendly production processes. To meet the rising demand for eco-friendly products and to adhere to stringent environmental regulations, industries worldwide began using green chemistry principles. India began looking at the potential industrial applications of green chemistry as a result of these global trends. The government and businesses in India have been putting more effort into sustainable practices in the past few years. State environmental laws and government programs such as the "National Action Plan on Climate Change" have facilitated the application of green chemistry. Indian businesses have been able to successfully adopt green chemical practices because to world wide alliances and collaborations that have facilitated the sharing of information and expertise.

Environmentally Friendly Chemical Principles in an Indian Setting
The twelve tenets of green chemistry centre on the elimination of waste, the enhancement of the atom economy, and the use of renewable, non-toxic materials in chemical processes in order to make them safer and more environmentally friendly. It promotes less harmful chemicals and derivatives, more efficient use

of energy, and safer syntheses. The use of catalytic reagents, the degradation of products, and the avoidance of contamination are all emphasised in these concepts. Integrating these ideas, Indian firms are redesigning production processes towards sustainability, notably in the pharmaceutical, agrochemical, textile, and petrochemical sectors.

Rules and Policies Enacted by the Government

By eliminating waste, enhancing the atom economy, and using non-toxic, renewable feedstocks, green chemistry—which is founded on twelve principles—strives to make chemical processes safer and more sustainable. It places an emphasis on developing goods that break down into harmless compounds, using energy-efficient processes, and using safer solvents and catalytic reagents. Pharmaceutical, agrochemical, textile, and petrochemical companies in India are among those using these concepts and revolutionising production methods. In addition to CSR obligations that promote investments in sustainable solutions, the government's laws like the Environmental Protection Act, Hazardous Waste Rules, and the Make in India drive lend credence to green chemistry.

Green Chemistry Initiatives spearheaded by the Industry

The twelve tenets of green chemistry include the following: the use of renewable feed stocks, the reduction of waste, the improvement of the atom economy, and the use of non-toxic compounds. It promotes procedures that employ catalytic reagents and are both safe and energy efficient. Pharmaceutical, textile, agrochemical, and petrochemical companies in India are among those embracing these practices to better the environment. Environmental Protection Act, National Green Tribunal, and Make in India are a few of the government programs that lend assistance to green chemistry in India. In an effort to enhance productivity, decrease waste, and create environmentally friendly products, established companies like as Cipla, UPL Limited, Dr. Reddy's Laboratories, and a number of startups are embracing green chemistry principles.

REVIEW OF LITERATURE

Arushi Kapoor (2021) Examined the serious environmental problems produced by the pharmaceutical business, which the Indian Ministry of Environment has classified as a "red category." Using Integrated Structural Modelling and MICMAC Analysis, the study uncovered 10 significant hurdles that the pharmaceutical industry faces when trying to use green technologies. The most important obstacles were found to be those related to finance, regulations, and the economy. Kapoor emphasised that there is a severe shortage of cohesive information in this area and urged concentrated efforts to fill this gap while simultaneously promoting green technologies in the sector.

Vesela Veleva (2018) Has out a benchmarking research to assess the level of green chemistry implementation in the pharmaceutical supply chain of India. Although there has been little implementation, the results show that generic pharmaceutical businesses and API makers are very interested in green chemistry. Only 20% of businesses used green chemistry metrics, meaning that the majority depended on wastewater treatment and disposal rather than source reduction. Key drivers were cost reductions and environmental restrictions, whereas regulatory concerns and time limitations were highlighted as important hurdles. The report included specific recommendations on how to address these obstacles and boost the sector's adoption of green chemistry.

Ganapati D. Yadav (2006) Brought attention to the pressing need to safeguard the environment from the growing threat of chemical contamination. The author brought attention to the urgent need for businesses and government agencies to work together to advance green chemistry through the elimination or significant reduction of harmful compounds. An important venue for encouraging discussion and launching campaigns towards eco-friendly chemical processes was the holding of national and worldwide symposiums. In order to create and implement green chemistry methods in India, Yadav pushed for a concerted effort by scholarly, business, government, and NGOs.

Mihir K. Chaudhuri (2003) Brought attention to the worldwide significance of green chemistry by referencing programs such as the US Presidential Green Chemistry Challenge Awards, which were

established in 1995. Examples of practical applications include the atom economy proposed by Barry Trost and new developments such as carbon dioxide (CO2) as a blowing agent and hydrogen peroxide (H2O2) oxidant activators. Although India is not leading the pack in clearly defined green chemistry initiatives, Chaudhuri did note that some progress has been achieved. The study highlighted the necessity for a consortium strategy to promote green practices in India and urged academics, technocrats, and politicians to work together proactively to incorporate green chemistry into school curricula.

M. Kidwai (2001) Reiterated the critical importance of preventing chemical pollution and urged institutions and businesses to work together to create safer chemical procedures. In order to promote scientific discourse and develop ecologically sustainable practices, Kidwai emphasised the value of symposiums and called for joint action by universities, businesses, and governments.

Objectives of the Study

1. To examine the role of government policies in promoting green chemistry in India.
2. To evaluate industry initiatives focusing on waste reduction and safer chemical processes.

HYPOTHESIS

H1: There is a significant influence of government policies on the adoption of green chemistry in India.
H2: There is a significant impact of industry initiatives on the implementation of green chemistry principles.

MATERIALS AND METHODS

The interviews, surveys, and case studies that made up the study's primary data were supplemented by secondary data culled from publications and reports. A mixed-methods technique was used for the research. It offers a comprehensive understanding of the topic by combining qualitative research on energy efficiency barriers with quantitative analysis to assess the impact of renewable energy on performance.

Data Analysis

Hypothesis Testing:

Hypothesis	Null Hypothesis (H_0)	Alternative Hypothesis (H_1)	Test Statistic	Significance Level (α)	Decision Rule
H1	In India, government measures do not affect green chemical uptake.	There is a significant influence of government policies on the adoption of green chemistry in India.	t-test or F-test (depending on data type)	0.05	Reject H_0 if p-value < 0.05
H2	Industry initiatives do not significantly impact the implementation of green chemistry principles.	There is a significant impact of industry initiatives on the implementation of green chemistry principles.	t-test or F-test (depending on data type)	0.05	Reject H_0 if p-value < 0.05

The impact of corporate and governmental initiatives on the adoption of green chemistry in India is examined through the use of p-values in hypothesis testing. Renewable energy and energy efficiency initiatives in India are spearheaded by the Ministry of New and Renewable Energy and the Bureau of Energy Efficiency. These initiatives centre on solar power, wind power, biomass, waste heat recovery, and energy audits. Although wind and solar power have come a long way, there is still a lot of untapped potential in alternative fuels and small hydropower. Biomass, biogas, and biofuels should replace fossil fuels as an organization's top sustainability priority.

Table 1: All government/private projects in India's renewable energy

Source	Capacity (MW)
Wind Energy	23,444
Small Hydro	4,055.36
Biomass	1,410.20
Biomass from Cogeneration	3,008.35
Solar	3,743.97

Indian renewable energy sources include wind power 23,444 MW, small hydro 4,055.36 MW, and biomass 1,410.20 MW. Biomass from cogeneration adds 3,008.35 MW, highlighting waste-to-energy alternatives. Solar energy can expand above 3,743.97 MW. This indicates that India is serious about fulfilling its energy needs and reducing its dependence on non-renewable sources by using a range of renewable resources.

Table: 2 Sector-wide energy savings trends

Sector	Common Trends
Power	Boiler efficiency audits, regenerative burners, motor VFDs, pump and compressor efficiency, and solar energy use are priorities. Governments promote renewables.
Iron & Steel	Conserve energy (waste heat recovery, air preheating, fuel replacement). Renewable energy is growing.
Oil & Gas	Conservation (gas flaring, power factor improvement, corrective devices) and renewable energy are balanced.
Information Technology	Certifications for building energy conservation (lighting, HVAC, DG sets), with a focus on renewable energy usage shortly.
Automobile	Renewable energy integration and energy conservation (waste heat recovery, VFDs, efficient oil use) increase.
Cement	Energy conservation (WHRs, air preheaters, kilns, motor VFDs) and renewable energy are expanding.
Pharmaceuticals	High emphasis on energy saving (HVAC, lights, compressors), with renewable energy slowly added.
Chemicals	HVAC and compressor energy saving and renewable energy adoption.
Hospitality	Certified hotel energy conservation (lighting, HVAC, DG sets), with future focus on renewable energy.
Heavy Engineering	VFD-powered motors, cooling towers, pumps, and PFCs save energy and increase renewable energy.
Financial	Office building lighting, HVAC, and DG certifications conserve energy and promote renewable energy.
Construction	Certifications for energy-efficient lighting, HVAC, and DG systems, with a future focus on renewable energy.
Coal Mining	Big ambitions for renewable energy and energy saving (conveyors, cranes, continuous mining).
Aluminum	Energy conservation (conveyors, cranes, motors) and renewable energy integration are priorities.
Railways	Balanced renewable energy and energy conservation (power factor adjustment, regenerative braking, fuel injection, traction, non-traction).

Indian firms use waste heat recovery, variable frequency motors, and energy-efficient building technologies to conserve energy. Solar power is growing in heavy engineering, electricity, iron and steel, and oil and

gas. Many companies are preserving energy for renewable energy. These include pharmaceutical, chemical, lodging, and construction. Energy efficiency and renewable power are helping coal, rail, and aluminium become sustainable.

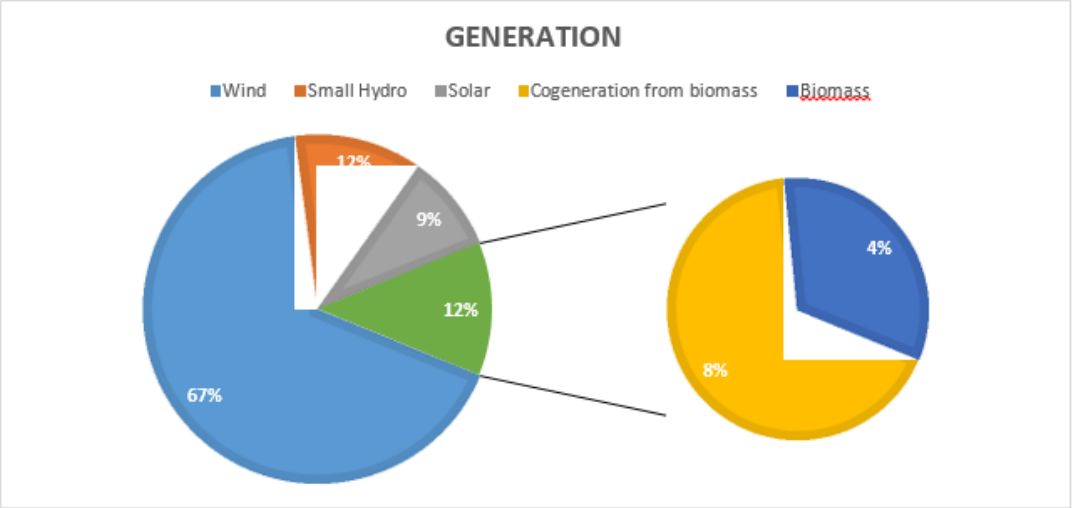

Figure: 1 India's renewable energy capacity percentage. (All government/private initiatives)

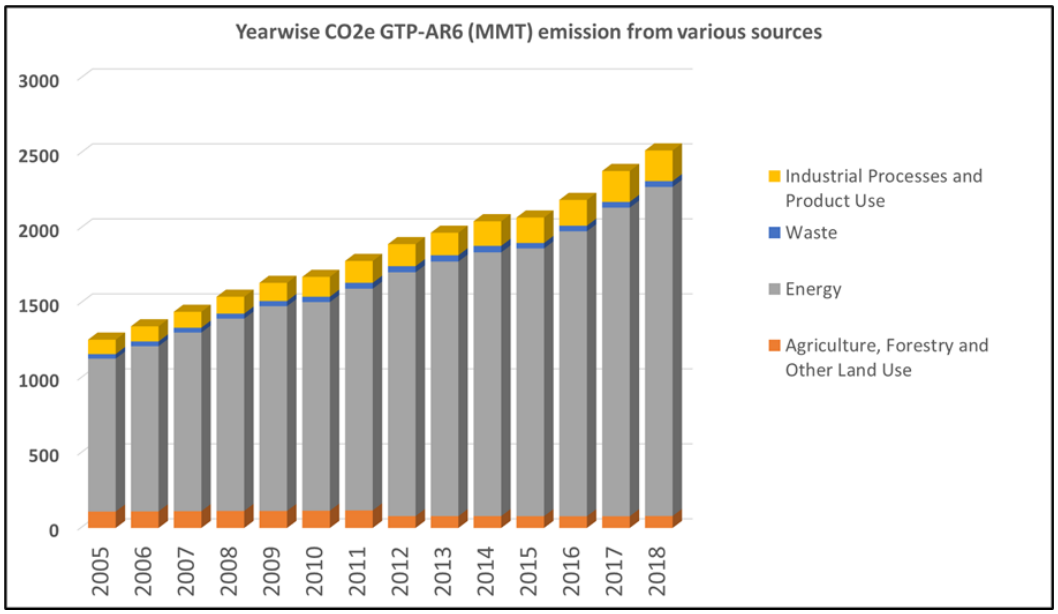

Figure: 2 Indian Carbon Emissions Forecast

Table 3. Highlighted The following are some of India's sustainability projects across industries

Sectors	Renewable Energy Initiatives	Energy Efficiency Initiatives	Adaptation Techniques	Resource Conservation Techniques
Power	NTPC, Tata, Reliance, Adani, and Torrent invest in Wind, Solar, and Small Hydro.	Energy-saving methods such as VFDs, electrostatic precipitators, NOx burners, efficient coal settling, HVAC system improvements.	Strengthening transmission and distribution towers, rainwater harvesting.	Air preheaters, electrostatic precipitators, CO2 scrubbers.
Iron & Steel	Tata Steel, SAIL, Jindal Steel adopt Solar and bio-diesel, promoting renewable energy use.	Regenerative burners, energy-efficient techniques like heat recovery, coal moisture control, and blast furnace gas recycle.	Strengthening infrastructure like blast furnaces, rainwater harvesting.	Slag disposal, blast furnace gas reuse, wastewater treatment, pre-heaters in furnaces.
Oil & Gas	IOCL, ONGC, HPCL investing in solar, wind energy, with ONGC's offshore wind farm project.	Green buildings, energy audits, HVAC monitoring, gas flaring reduction.	Rainwater harvesting, spill prevention, safe oil discharge, pipeline maintenance.	Waste oil recycling, by-product manufacturing.
Information Technology	Infosys, Wipro, TCS invest in solar panels, setting renewable energy consumption targets.	Energy-efficient buildings (LEED certified), DG set maintenance, HVAC monitoring.	Green technology awareness, policy change for e-waste management.	E-waste, paper, food waste management, and energy generation from MSW.
Automobile	Ashok Leyland, Maruti Suzuki, Tata Motors, Mahindra & Mahindra adopt wind and solar energy.	Energy-efficient production employing electric traction, LED lighting, and waste heat recovery.	Water reservoirs, carbon-neutral events, green awareness initiatives.	Oil circulation, water recycling, waste heat recovery.
Cement	ACC, Lafarge, RAMCO invest in wind and biomass for renewable energy.	Preheater, clinker cooler, and kiln efficiency optimisation waste heat recovery.	Green belts, water management, and mill upgrades.	Waste heat recovery, air preheaters, water recycling.

Sectors	**Renewable Energy Initiatives**	**Energy Efficiency Initiatives**	**Adaptation Techniques**	**Resource Conservation Techniques**
Pharmaceuticals	Dr. Reddy's Lab implements solar; others plan renewable energy consumption increases.	Energy and water audits, green buildings, HVAC, solvent recovery.	Ensuring production continuity during crises, proper raw material storage.	Wastewater treatment, recycling, and reducing toxicity in chemical processes.
Chemicals	Tata Chemicals, Aditya Birla Carbon invest in wind and solar energy projects.	Improved catalyst usage, enhanced spray technology, energy-efficient pumps and fans with VFDs.	Rainwater harvesting, safe chemical storage, and reusing hazardous waste.	Water filtration, high safety standards for chemical handling.
Hospitality	ITC, Taj Hotels use wind and solar energy.	LEED-certified buildings, energy-efficient lighting, HVAC monitoring.	Water storage, green building certifications, earthquake-resistant infrastructure.	Waste food, clothes, and rubbish sent to Waste to Energy plants.
Heavy Engineering	Bharat Forge, BHEL, Thermax adopt biofuels, solar, and waste-to-energy technologies.	Energy-efficient pumps, cooling towers, welding inverters, and waste heat recovery devices.	Improving infrastructure, water reservoirs, and carbon-neutral events.	Reusing waste heat and scrap.
Financial	YES Bank, ICICI Bank, HSBC support clean energy projects and CDM initiatives.	Energy-efficient systems in offices, HVAC monitoring, DG set inspection, lighting upgrades.	Promoting environmental awareness, water conservation efforts.	Paper waste recycling and reusing for future purposes.
Construction	Construction companies invest in renewable energy sources for their projects.	Energy efficiency in buildings, using energy-efficient lighting, improved HVAC systems, and external walls optimization.	Earthquake-resistant foundations, adapting to changing soil features.	Recycling raw materials, reusing construction scraps, reducing material waste.

Renewable energy, energy efficiency, and resource conservation are significant Indian policies, according to studies. Industries such as cement, IT, cars, iron and steel, and oil and gas have embraced energy-saving practices and renewable energy sources, while power providers have been investing in wind, solar, and hydro. Energy efficiency and resource conservation measures like water management and recycling are also implemented in the building, pharmaceutical, chemical, and hospitality industries.

Table: 4 Indian Sectors' Energy, Adaptation, and Resource Conservation Initiatives

Sector	Renewable Energy	Energy Efficiency	Adaptation	Resource Conservation
Power	NTPC uses solar, small hydro, biomass, biodiesel, MSW. Private companies like Tata, Reliance, and Adani fund solar, wind, and small hydro.	Save energy with upgraded HVAC, motor drives, flue gas conditioning, pump, fan, blower and electrostatic precipitators for emission control.	Strengthening of infrastructure: transmission & distribution lines, boilers, cooling towers. Rainwater harvesting and proper storage house maintenance.	Using air preheaters, electrostatic precipitators, CO2 scrubbers, regenerators.
Iron & Steel	Tata Steel, SAIL, and Jindal Steel adopting solar, biodiesel, and pushing solar technology.	Hot strip mill lean gas, coke dry quenching, sinter plant heat recovery, blast furnace gas recycling.	Strengthening of infrastructure: transmission & distribution lines, blast furnaces, rainwater harvesting.	Slag, blast furnace gas and dust reuse; wastewater; furnace pre-heaters.
Oil & Gas	IOCL, ONGC, HPCL investing in solar and wind energy, including offshore wind farm.	Energy conservation techniques: green buildings, energy audits, HVAC systems monitoring, reducing gas flaring.	Adaptations include rainwater collecting, carbon-neutral events, rig infrastructure reinforcing, pipeline maintenance.	Spill prevention, safe discharge of oil, water recycling, by-product manufacture.
Information Technology	Infosys, Wipro, TCS adopting solar energy, planning to increase renewable consumption.	LEED-certified buildings, HVAC monitoring, DG set maintenance, energy-efficient lighting.	Promoting green technology, raising awareness, adherence to e-waste management and environmental policies.	Food, paper, and e-waste sent to energy facilities as MSW.
Automobile	Ashok Leyland, Maruti Suzuki, Tata Motors, Mahindra & Mahindra adopting wind, solar, and bio-diesel technologies.	LEED buildings, HVAC maintenance, brushless DC motors, LEDs, waste heat recovery, electric traction.	Green belts, water reservoirs, carbon-neutral activities, and awareness initiatives.	Waste heat recovery, water recycling, oil circulation, air preheating.
Cement	ACC, Lafarge, RAMCO Cement using wind, biomass energy; ACC	Energy-saving techniques: closed-circuit cement mills, coal mill optimization, fuel	Promoting green initiatives, water management, strengthening infrastructure:	Air preheaters, waste heat recovery devices, water recycling.

Sector	Renewable Energy	Energy Efficiency	Adaptation	Resource Conservation
	targeting 9% renewable capacity.	mix optimization, waste heat recovery from pre-heaters, clinker cooler, kiln, motor efficiency.	vertical mills, grinding units, CPP.	
Pharmaceuticals	Dr. Reddy's Lab rooftop solar promotes green energy.	Water/energy audits, green buildings, HVAC, solvent recovery, green chemistry.	Properly storing raw materials, water, and chemicals supports manufacturing and supply.	Reducing toxicity, water recycling, catalyst usage.
Chemicals	Tata Chemicals, Aditya Birla Carbon investing in wind and solar plants.	Better catalyst consumption, VFDs in blowers and fans, and spray technologies reduce energy.	Increasing rainwater collection, tree planting, chemical storage, and toxin reduction.	Reusing chemicals where possible, water filtration with high precaution.
Hospitality	ITC using wind energy, Taj Hotels using renewable sources for 6.91% of their energy.	Expanding rainwater collecting, tree planting, chemical storage, and toxicity reduction.	Earthquake resilience, water storage, green building qualifications.	Waste-to-energy plants gather food, clothes, and rubbish.
Heavy Engineering	Bharat Forge, BHEL, Thermax, Punj Lloyd investing in biofuels, solar, biomass, and waste-to-energy projects.	Energy-saving techniques: energy-efficient pumps, advanced cooling towers, VFDs, waste heat recovery, welding inverters.	Strengthening infrastructure: boilers, furnaces, manufacturing units, cables, towers, water reservoirs, promoting carbon-neutral events.	Waste heat recovery, scrap material reuse.
Financial	YES Bank, ICICI, HSBC investing in clean energy projects, supporting CDM projects.	Lighting energy savings, HVAC monitoring, cooling tower inspection, DG set inspection.	Encourage water saving, construction certifications, environmental awareness, and high-rise seismic resilience.	Paper waste reuse for various purposes.

Sector	Renewable Energy	Energy Efficiency	Adaptation	Resource Conservation
Construction	House of Hiranandani using hybrid wind-solar systems, DLF India sourcing wind energy.	Energy efficiency: Hollow block insulation against high temperatures, automated light switching, DG set & transformer operation, enough cabling, line loss monitoring.	Earthquake resistance, underground cable installation, building floor care, water saving, green belt.	Raw, scrap, and unwanted material reuse.
Coal Mining	Coal India, Neyvelli Lignite investing in solar and wind energy projects.	LV distribution lines, engine overhauls, filter and hose checks, DG set audits save energy.	Raising awareness of green belt and water harvesting programs.	Methane reuse from coal beds for industrial applications.
Aluminum	BALCO (Vedanta), NALCO using wind and solar energy, NALCO with 98 MW capacity.	Dry scrubbing in fume treatment plants, point feeder prebaked technology, and cooling tower fan VFDs save energy.	Promote green belt, water harvesting, environmental projects.	Public awareness campaigns, use of aluminum industry waste by other industries.
Railways	Indian Railways implementing solar and wind projects, researching biodiesel.	Regenerative braking, 3-phase propulsion, static converters, power factor correction, and energy-efficient rolling stock save energy.	Rainwater harvesting, strengthening of bridges, overhead lines, stations, workshops, and car sheds.	Water recycling, bio-toilets, food waste, and waste-to-energy plants

The survey found that India's power, iron and steel, oil and gas, IT, autos, cement, and other industries are using renewable energy and energy efficiency. Solar, wind, biomass, energy-saving technology, green buildings, and waste heat recovery improve sustainability and reduce environmental impact.

DISCUSSION

An informative synopsis of India's initiatives to increase energy efficiency in several industries and include renewable energy sources is given in the report. It emphasises the substantial contributions of sustainability-focused government policies and private sector actions in cutting down on fossil fuel use. Solar, wind, and biomass power have all seen significant growth thanks to government initiatives spearheaded by organisations like the Ministry of New and Renewable Energy and the Bureau of Energy Efficiency. The country's growing capacity for renewable energy sources is a reflection of this trend. Wind power ranks first with 23,444 MW, followed by small hydro and biomass, while solar power is gaining significant traction. To diversify India's energy mix, further investment and innovation are needed, as the report highlights the unrealised potential of small hydro sources and alternative fuels. Equally important have been industry-wide initiatives, with cement, power, oil and gas, information technology, vehicle, and electricity

companies among the most vocal adopters of renewable energy and energy-saving technology. Significant decreases in energy consumption and carbon emissions have been achieved via the implementation of energy-efficient technology such as regenerative burners, waste heat recovery, and variable frequency drives (VFDs). Environmental and economic pressures are pushing several sectors, including the cement and power generating industries, to switch to renewable energy sources in an effort to save costs and improve sustainability. In addition, India's sustainable development goals are bolstered by resource conservation methods such as collecting rainfall, treating wastewater, and recycling industrial by-products. Despite the fact that renewable energy is becoming more popular, the report notes that underutilised industries such as biomass, biogas, and biofuels have a lot of untapped potential. Meeting India's energy demands responsibly requires the combination of renewable energy and energy efficiency technology, together with government incentives and corporate accountability. Overall, renewable energy and energy-saving technology are becoming more popular in India. However, to achieve sustainability in the long run and reduce carbon emissions in accordance with global climate goals, a more targeted and diverse strategy across all sectors, particularly through biomass, biofuels, and small hydro, is required.

CONCLUSION

Renewable energy, energy efficiency, and resource conservation are highlighted in the report as India makes progress towards sustainability across sectors. Power, iron and steel, oil and gas, information technology, and autos have invested heavily in solar, wind, biomass, and waste-to-energy technologies, as well as waste heat recovery, efficient HVAC systems, and VFDs. To reinforce infrastructure and assure sustainability, companies are using green construction certifications, water conservation, and adaption methods. Policy-driven initiatives and industry activities show the government's commitment to lowering non-renewable energy use and tackling climate change through various, creative techniques. India needs this thorough shift to improve energy security, reduce carbon emissions, and boost economic growth.

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