

GREEN TECHNOLOGIES: CURRENT STATUS, CHALLENGES AND WAY AHEAD

- For two decades, stakeholders have deliberated on UN's sustainable goals, aiming to tackle greenhouse gases, resource depletion, and global warming with clean and green technologies.
- Green technology protects the environment by minimizing human impact through products, systems, and processes that emit minimal greenhouse gases, ensure safety, promote a healthy climate, and conserve resources while utilizing natural energy.
- Green technologies cover innovations for environmental improvement and resource efficiency, from renewables like solar and wind power to eco-friendly materials and waste management. They are vital in tackling climate change and resource scarcity, fostering sustainable growth and challenging traditional business models.
- Waste management tech transforms waste into resources, sustainable materials replace non-renewables in construction. These technologies show their broad impact on environmental challenges, a high-tech help for Mother Nature.

Ever wondered, how we can make our planet greener while still enjoying the benefits of modern technology. Here are the irresistible goals of Green Technologies, summarised as under: -

- ▶ Reduce the rate of increase in energy demand thus promoting economic growth.
- ▶ To promote the development of the green technology sector and its contribution to the national economy.
- ▶ To increase the potential for competition in the production of green technology and to improve the sector's performance in the field.
- ▶ To ensure long-term sustainability for posterity.
- ▶ In addition, to raise public consciousness about green technologies as well as to promote their wider use.
- ▶ While discussing the current promotion and coverage of green technologies, we find their footprints in various sectors such as

Energy Sector: Green Technology in electricity generation and energy resource management, including cogeneration in the manufacturing and commercial sectors.

Building Sector: Green technology is being used in the design, administration, repair, and demolition of houses.

Water and Waste Management Sector: Green technology usage in water supply control and usage, wastewater disposal, and solid waste landfills.

Transport Sector: Green technology integration into transportation infrastructure and automobiles, including bio-fuels and public transportation.

- Green technologies offer vast opportunities. Economically, they create jobs and open new markets, fostering business innovation. Environmentally, they reduce emissions, combating climate change. Socially, they improve life quality with cleaner air and water, contributing to global sustainability.
- Green technology simultaneously tackles environmental issues and supports economic growth, aligning with global priorities like climate action. It enhances living standards by fostering a sustainable climate, offering employment opportunities through green industries.
- Green technology is evolving with innovative strides, particularly in solar energy, making it more accessible and affordable. Electric vehicles are gaining ground due to improved batteries and charging. Waste management innovations aim for sustainable resource use, reducing landfill waste and emissions. Green architecture promotes energy efficiency and urban sustainability.
- Sustainable farming technologies like precision farming with AI and IoT are revolutionizing agriculture, making it eco-friendlier and more efficient, crucial for addressing global environmental challenges.
- Manufacturing consumes 40% of national energy and emits substantial greenhouse gases. Transitioning to renewables like biomass, green coal, and solar power can cut emissions and improve sustainability in production.

The initiative taken by Government of India under Production Linked Incentive scheme is presented in pictorial form:

- Another initiative is National Green Hydrogen Mission, which will lead to significant decarbonisation of the economy, reduced dependence on fossil fuel imports, and enable India to assume technology and market leadership in Green Hydrogen. Initially, two distinct financial incentive mechanisms proposed with an outlay of 17,490 crore up to 2029-30, are:

- ▶ Incentive for manufacturing of electrolyzers
- ▶ Incentive for production of green hydrogen

- It will support the development of supply chains that can efficiently transport and distribute hydrogen. This includes the use of pipelines, tankers, intermediate storage facilities, and last-leg distribution networks for export as well as domestic consumption. Here are the Mission outcomes presented in pictorial form: -
- Green technologies face challenges like high initial costs, funding barriers, integration issues, regulatory hurdles, and the need for public awareness and behaviour change to reduce energy consumption and waste.
- Designing products for longevity and recyclability is key. In agriculture, balancing productivity and eco-friendly practices is complex. Green tech aims to reduce water consumption, combat air pollution in cities, and lower carbon footprints through renewable energy and sustainable lifestyles.
- Vertical and no-till farming, along with dietary changes and innovative foods, can reduce carbon footprints in food production. Challenges like solar supply chain dependence on imports can be addressed by developing a domestic solar value chain to boost renewable energy use and job creation in manufacturing.
- Bioenergy can significantly reduce carbon emissions, especially in challenging sectors. It involves renewable energy from organic matter like agricultural waste or energy crops. However, its adoption in manufacturing faces obstacles due to biomass resource misalignment.
- Solutions like efficient supply chains and supportive policies are needed for widespread adoption and sustainability
- Electric and hybrid vehicles in logistics can cut emissions significantly. Companies like 'Exponent Energy' with fast-charging infrastructure for commercial EVs and 'Log9 Materials' with commercial vehicle batteries are leading this emission-reducing shift.

Way Forward

India's evolving policies promote a shift to sustainable living, facilitating global investment in green tech. Initiatives like the 'Aspirational District Programme' engage local communities for unified development. The 'Aspirational District Programme' aims to make India a global leader in green energy by 2030, serving as a model for worldwide replication.

UNDERSTANDING GREEN TECHNOLOGIES FOR FUTURE

Green Technology encompasses innovative approaches that promote environmental well-being, including resource efficiency, renewable energy use, and waste minimization. Recognizing its evolution is vital for advancing a sustainable future and ensuring a healthier planet for generations to come.

Environmental Benefits of Green Technology

Green technology mitigates climate change, reduces emissions, promotes renewables, curbs pollution, conserves resources, and preserves biodiversity for a healthier, sustainable planet for current and future generations.

Here are some environmental benefits associated with green technology:

- **Reduced Carbon Emissions:** Green tech prioritizes renewables like solar, wind, and hydro power, emitting fewer greenhouse gases than fossil fuels. Transitioning to these sources can curb climate change by cutting CO2 emissions.
- **Energy Efficiency:** Green tech enhances energy efficiency in buildings, transport, and industry, cutting energy use and lessening environmental harm from production, including pollution.
- **Resource Conservation:** Green tech optimizes resource use like water, land, and materials. Innovations like water-saving agri-tech and waste recycling reduce waste and conserve resources.
- **Biodiversity Preservation:** Green technologies in agriculture and land management preserve biodiversity by safeguarding habitats, minimizing chemical use, and reducing habitat destruction, fostering healthier ecosystems and wildlife conservation.
- **Improved Air and Water Quality:** Green tech reduces air pollution by shifting from fossil fuels to cleaner energy sources, curbing emissions of pollutants like sulphur dioxide, nitrogen oxides, and particulates. Wastewater treatment and pollution control technologies enhance water quality and protect aquatic ecosystems.
- **Climate Resilience:** Green tech aids in climate resilience against extreme weather, sea-level rise, and drought. Sustainable land practices combat erosion and floods, while decentralized renewable energy lessens vulnerability to disruptions.
- **Mitigation of Environmental Degradation:** Green tech combats environmental degradation like deforestation and habitat loss. Using tools like remote sensing and GIS, reforestation can restore landscapes and sequester carbon.

Economic Implications of Green Technology

Green tech spurs economic growth, fuels innovation, green job creation, energy security, and resource efficiency, bolstering sustainable development and resilience.

Here are some of the key economic benefits associated with green technology:

- **Job Creation:** Green tech transition opens diverse job sectors like renewable energy, efficiency, waste management, and sustainable transport, needing skilled workers for various roles.
- **Innovation and Competitiveness:** Green tech investment spurs innovation, leading to new products/services. Leading in green tech innovation offers a competitive edge, attracting investment and driving growth.
- **Cost Savings:** Green tech's initial costs may exceed traditional ones, but long-term benefits include lower operational expenses. Efficiency and sustainability yield substantial savings in utilities, fuel, and maintenance.
- **Energy Independence and Security:** Green tech like solar, wind, and bio-energy boosts energy independence by reducing fossil fuel reliance, diversifying sources, and mitigating economic risks from oil prices and geopolitics.
- **Market Opportunities:** Businesses focusing on green tech capitalize on the rising demand for eco-friendly products/services. Energy-efficient appliances, eco-packaging, sustainable agriculture, and clean transport cater to environmentally conscious consumers and new markets.
- **Resilience to Climate Change:** Adaptation measures, such as sustainable infrastructure development and climate-resilient agriculture, can reduce the economic losses caused by climate-related disasters and protect livelihoods.
- **Policy Support and Investment:** Government policies incentivize green tech adoption via financial perks, tax breaks, subsidies, and supportive regulations, encouraging sustainable investments. Combined public and private investments drive economic growth and tech innovation.

Social Impacts and Equity Considerations

The adoption and implementation of green technology have significant social impacts and equity considerations that need to be addressed to ensure a fair and inclusive transition to a sustainable future.

Here are some key points to consider:

- **Health Benefits:** Green tech improves public health by cutting pollution from fossil fuels and industries. Cleaner energy and sustainable practices reduce health disparities and advance environmental justice.
- **Access to Clean Energy and Services:** Equal access to clean energy and sustainable services is vital to combat energy poverty and promote social fairness. Policies prioritizing resource distribution and community initiatives can bridge these gaps.
- **Job Creation and Training Opportunities:** Green tech drives job growth and skills training, especially in renewables, efficiency, and sustainable farming. Inclusive workforce programs are vital, benefiting women, minorities, and marginalized groups.
- **Community Empowerment and Participation:** Involving communities and empowering locals in green tech projects fosters social unity and sparks grassroots innovation.
- **Affordability and Cost Burdens:** Green tech benefits are clear but initial costs may challenge low-income households and businesses. Policies like subsidies, incentives, and financing can make it accessible to everyone.
- **Resilience to Climate Change:** Climate change hits vulnerable communities hardest, from coastal to arid regions, facing sea-level rise, extreme weather, and food insecurity. Green tech aids resilience through sustainable disaster prep, water management, and agri adaptation.
- **Environmental Justice:** Environmental justice promotes fair inclusion in decision-making for all, irrespective of race, income, or location. Green tech must prioritize marginalized communities, distributing benefits and burdens equitably.

Key Areas of Green Technology Adoption

Green technology adoption spans various sectors and encompasses a wide range of innovations aimed at promoting sustainability and reducing environmental impact. Here are some key areas where green technology adoption is particularly significant:

- **Renewable Energy:** Switching to renewables like solar, wind, hydro, and geothermal power is vital in green tech. These offer clean, sustainable alternatives, cutting emissions and resource dependence.
- **Energy Efficiency:** Green tech also focuses on energy efficiency in buildings, transport, and industry. Efficient appliances, lighting, HVAC systems, and smart energy management cut costs and emissions effectively.
- **Sustainable Transportation:** Green tech in transportation spans electric vehicles, hybrids, fuel-efficient engines, public transit, biofuels, and hydrogen. Sustainable options cut pollution, congestion, fuel dependence, enhancing mobility and accessibility.
- **Waste Management and Recycling:** Green tech in waste management focuses on reducing waste, recovering resources, and curbing pollution. Advanced recycling, composting, and waste-to-energy tech promote a circular economy.
- **Water Management:** Sustainable water management tech optimizes usage, conserves, and prevents pollution in agriculture, industry, and cities. Innovations like drip irrigation, rainwater harvesting, and efficient appliances protect freshwater ecosystems.
- **Green Building Design and Construction:** Green buildings combine energy-efficient design, sustainable materials, and renewables for minimal impact and better occupant well-being. Features like passive solar design, green roofs, and efficient systems improve sustainability.
- **Agricultural Sustainability:** Green tech in agriculture encourages sustainable practices, preserving soil, water, and biodiversity while reducing chemicals. Precision ag, agroforestry, organics, and soil conservation enhance yields, soil health, and climate resilience.
- **Smart Grid and Energy Storage:** Smart grid technologies enable more efficient and reliable electricity distribution by integrating renewable energy sources, energy storage systems, and demand-side management strategies.

Climate Adaptation and Resilience

Green tech adoption tackles climate impacts like sea-level rise and extreme weather, focusing on resilience. Resilient infrastructure, ecosystem restoration, and disaster prep foster sustainability and collaboration for a

better future. Green tech adoption covers renewables, efficiency, transport, waste, buildings, and agriculture. Innovation is vital for a low-carbon, resource-efficient economy, reducing environmental impacts broadly.

Challenges and Barriers to Adoption

Green tech faces barriers like tech limits, costs, regulations, and resistance to change. Overcoming needs infrastructure, incentives, policies, and societal shifts for sustainability.

Here are some of the key obstacles:

- **Costs and Investment:** High initial costs hinder green tech adoption, despite long-term benefits. Upgrades to renewables, energy efficiency, and sustainability can be expensive for businesses, governments, and individuals.
- **Lack of Financial Incentives:** Lack of financial incentives and supportive policies can deter green tech adoption. Incentives like tax credits, rebates, or low-interest loans encourage investment in renewables and energy efficiency.
- **Technological Challenges:** Technical limitations and scalability hinder green tech adoption. Renewables like solar and wind need storage for reliability and grid stability. Recycling and waste-to-energy may require more development for scale viability.
- **Infrastructure Constraints:** Green tech transition needs infrastructure upgrades like grids, transport, and water systems. Poor infrastructure or regulations can hinder renewables, EV chargers, and smart grids, limiting their reach.
- **Market Barriers and Competition:** Fossil fuel industries resist green tech, creating market barriers. Favourable subsidies and regulations for fossil fuels harm clean energy. Energy market monopolies stifle renewables and efficiency.
- **Policy and Regulatory Challenges:** Unclear policies deter green tech investment. Political hesitation, industry lobbying, and regulatory complexity delay renewable mandates, carbon pricing, and environmental standards.
- **Public Awareness and Perception:** Public awareness gaps and misconceptions hinder green tech uptake. Education and outreach are vital to showcase renewable energy, efficiency benefits, and dispel myths deterring adoption.
- **Social and Equity Considerations:** Green tech's costs and benefits may not always be fair, raising social justice concerns. Marginalized communities and developing nations face barriers to access, deepening inequalities. Coordinated efforts are needed for equitable adoption.

Policy Frameworks and Strategies for Promoting Green Technology

Promoting green technology requires comprehensive policy frameworks and strategies that incentivise investment, drive innovation, and facilitate the adoption of sustainable practices across various sectors. Here are some key policy approaches and strategies for promoting green technology:

- **Renewable Energy Targets and Mandates:** Mandating renewable energy targets like solar, wind, hydro, and geothermal power promotes clean energy transition. Governments can use RPS, feed-in tariffs to incentivize investments.
- **Financial Incentives and Subsidies:** Providing financial incentives, subsidies, and tax credits for renewable energy deployment, energy efficiency upgrades, and sustainable practices can help offset the upfront costs and accelerate adoption.
- **Carbon Pricing Mechanisms:** Carbon pricing through taxes or cap-and-trade systems internalizes emissions' cost, spurring investments in cleaner tech and low-carbon options while reducing greenhouse gases.
- **Regulatory Standards and Codes:** Regulatory standards and codes for energy efficiency, emissions, and sustainability drive market change. Standards for buildings, vehicle efficiency, and industrial emissions raise environmental performance.

- **Research and Development Funding:** RD&D investment in green tech fosters innovation, addressing sustainability challenges. Government funding for research, universities, and collaborations promotes breakthroughs, improving environmental performance and competitiveness.
- **Public Procurement Policies:** Green procurement policies drive market demand and economies of scale. Governments can require agencies to buy energy-efficient appliances, renewables, low-emission vehicles, and sustainable goods.
- **Education and Outreach Programs:** Education about green tech benefits and sustainability drives awareness and policy support. Campaigns, training, and outreach programs promote energy conservation, waste reduction, and climate action strategies.

The Role of International Collaboration and Cooperation

International collaboration is crucial for tackling global environmental challenges. Agreements, tech transfer, and finance bolster green tech adoption, supporting sustainable development and resilience to climate change worldwide.

Here are several ways in which international collaboration contributes to these objectives:

- **Knowledge Sharing and Technology Transfer:** International collaboration accelerates green tech innovation, sharing knowledge and best practices in development, deployment, and policy. Lessons learned improve capacity-building and overcome adoption barriers.
- **Joint Research and Development:** International R&D collaborations unite experts globally to tackle shared environmental challenges. Pooling resources and expertise fosters innovation, accelerates technology development, and addresses sustainability complexities effectively.
- **Capacity Building and Training:** International collaboration aids capacity-building in developing nations with technical assistance, training, and knowledge sharing. Empowering local expertise and tech transfer are pivotal in green tech adoption.
- **Policy Harmonisation and Coordination:** Global collaboration harmonizes environmental policies, energy efficiency, and sustainability standards. Aligning policies fosters a conducive environment for green tech, investment, and trade, reducing barriers and conflicts.
- **Financing collaboration and Investment:** International cooperation mobilizes funds for green tech via development banks, funds, and partnerships. By leveraging public-private financing, countries boost investments in renewables, efficiency, infrastructure, and climate resilience, especially in developing nations.
- **Global Environmental Governance:** Global collaboration fortifies environmental governance, coordinating efforts on climate, biodiversity, and pollution. Treaties, agreements, and forums foster dialogue and collective action on shared environmental goals.
- **Technology Diplomacy and Innovation Networks:** International collaboration fuels technology diplomacy, trust-building, and mutual gains. Diplomatic initiatives, research partnerships, and innovation hubs unite governments, businesses, academia, and civil society toward shared sustainability goals.
- **Climate Diplomacy and Negotiation:** Global collaboration is vital for climate diplomacy, negotiating agreements like the Paris Agreement. Countries commit to action, emission targets, and finance, showing dedication to climate action and low-carbon growth.

Future Directions and Opportunities

The future of green technology holds immense potential for innovation and sustainability. Advancements in technology, including artificial intelligence and digitalisation offer new opportunities for enhancing resource efficiency and environmental protection. Embracing circular economy principles and decentralised energy systems can further promote sustainability, fostering a transition towards a more resilient and regenerative economy that meets the needs of both present and future generations.

GREEN TECHNOLOGIES FOR CLEAN AND RENEWABLE ENERGY

Global electricity demand, as per the IEA's 'Electricity, 2024 Report,' is set to rise by 3.4% annually till 2026. India, China, and South-East Asia are expected to drive 85% of this growth.

In 2023, 40% of electricity was from renewable sources. Energy production, primarily fossil fuels, is the major source of greenhouse gases. To combat climate change, emissions must halve by 2030 and hit net-zero by 2050 through transitioning to sustainable energy.

Present Renewable Energy Scenario

- Renewable energy sources like solar, wind, water, waste, and geothermal are abundant and cleaner. Currently, 29% of electricity is from renewables, with solar leading at 1,419 GW capacity. They have helped avoid 2.2 Gt of emissions yearly.
- India's renewable energy capacities include 1,268 GW of hydropower, 1,017 GW of wind, 150 GW of bioenergy, 15 GW of geothermal, and 0.5 GW of marine energy. In 2023, India added 13.5 GW of renewable capacity, with solar leading at 75.57 GW. India targets 500 GW of renewables by 2030 and net-zero emissions by 2070.

Green Technologies for Clean Energy

Green technologies are enhancing renewable energy projects, increasing efficiency and scalability. IEA reports a 50% rise in clean energy investments, reaching USD 1.8 trillion in 2023, growing 10% annually. Important innovations of green technologies with commercial potential and different stages of scalability are as follows:

Solar Power: Solar energy, abundant and renewable, offers more energy in an hour than the world needs in a year. Photovoltaic cells convert sunlight directly to electricity, with innovations like multi-junction and perovskite-silicon cells boosting efficiency and affordability.

Concentrated Solar Power (CSP) uses mirrors or lenses to focus sunlight on a receiver, creating heat for turbines. Advancements like molten salt storage improve CSP efficiency and allow continuous power generation. Tandem solar cells combine perovskite and silicon for higher energy conversion, harnessing a wider range of sunlight. Recent solar innovations include PERC solar cells, boosting energy production by 6-12%. HJT technology combines silicon layers for higher efficiency. Vehicle-integrated photovoltaics reduce fossil fuel reliance by generating electricity from sunlight on vehicles. Vehicle-integrated solar panels can extend electric vehicle range and cut fuel use. Offshore solar farms on water bodies optimize land use, benefit from water's cooling effect, and boost solar panel efficiency.

Wind Power: Wind power surged by 13% in 2023, hitting 1,017 GW capacity. Onshore and offshore installations both expanded. Innovations like rooftop bladeless turbines and vertical-axis turbines are boosting wind energy's potential.

Turbine scaling focuses on low material use and efficient manufacturing, with cost reductions of 11-20% by 2030. Taller turbines with longer blades capture more energy, including in low-wind areas. Bladeless wind energy reduces maintenance and wildlife impact. Offshore wind grows with floating turbines. These wind innovations tap stronger currents, expand development, and promise higher energy outputs. Wind Float's drag-embedment anchor differs from traditional turbines, while VAWTs and kite systems offer versatile solutions for diverse environments. Kite systems generate clean energy efficiently, using fewer resources. Technologies like innovative power electronics, permanent magnet generators, and AI enhance turbines, enabling predictive maintenance and improving efficiency for lower costs and higher production.

Hydroelectric Energy: It remains the largest renewable source of electricity, generating more than all other renewable technologies combined. In the Net Zero Emissions by 2050 Scenario, hydropower maintains an average annual generation growth rate of close to 4% in 2023-2030 to provide approximately 5,500 Terawatt hours (TWh) of electricity per year.

Hydroelectricity surged by nearly 70 TWh in 2022, totaling 4,300 TWh. Innovative fish-friendly turbines operate efficiently in low water, reducing environmental impact and expanding hydro's reach. Kinetic hydro turbines offer small-scale river energy without big infrastructure.

Tidal power taps ocean tides for electricity using underwater turbines and barrages. Run-of-river hydroelectric systems generate power from river flows without large dams, offering flexible, low-impact installations. Underwater turbines harness ocean currents for consistent, clean energy.

Nuclear Power: It is the second-largest source of low-carbon electricity today. Nuclear energy, with around 413 gigawatts (GW) of capacity operating in 32 countries, contributes to both goals by avoiding 1.5 gigatonnes (Gt) of global emissions and 180 billion cubic metres (bcm) of global gas demand a year. According to the IEA, global nuclear power generation is forecast to grow by almost 3% annually on average through 2026. As of August 2023, there are 410 nuclear power reactors in operation totalling more than 3,68,000 MW(e) in installed capacity in 31 countries.

Small modular reactors (SMRs) offer up to 300 MW(e) and are poised to expand nuclear energy access globally. They suit small grids and integrate well with renewables. Over 80 designs are progressing worldwide. Micro-reactors operate at higher temperatures and lower pressures, reducing costs. They are about 1% the size of traditional reactors, producing 1-10 MW and are mobile, offering clean energy solutions in remote areas.

Energy Storage-Advanced Technologies in Batteries: Batteries are vital for storing energy from renewables, but current tech must improve in cost, stability, power, efficiency, and scalability. Lithium-ion batteries are emerging in stationary energy storage for mobile devices and EVs.

Lithium-ion batteries (LIBs) are in high demand at 1 TWh annually. Sodium-ion batteries (SIBs) are becoming popular due to cheaper sodium and safer transportation, though they have lower energy density. Aqueous zinc ion batteries are safe, eco-friendly, and cost-effective alternatives to lithium-ion tech, using water-based electrolytes. They are safer, cheaper due to zinc, while potassium-ion batteries offer high energy density, rapid charging, and safety benefits. Solid-state batteries replace liquid electrolytes with a solid one, reducing fire risks. They boast higher energy density and faster charging. Redox flow batteries store energy in electrolytes rather than electrodes, using reversible electrochemical reactions for charge/discharge.

Bio-Energy: It is a source of energy from the organic material that makes up plants, known as biomass. Biomass contains carbon absorbed by plants through photosynthesis. When this biomass is used to produce energy, the carbon is released during combustion and simply returns to the atmosphere, making modern bioenergy which is a promising near zero-emission fuel. Modern bioenergy is the largest source of renewable energy globally today, accounting for 55% of renewable energy and over 6% of global energy supply. Microbial fuel cells (MFCs) is another promising source which is gaining ground. Microbial Fuel Cells (MFCs) convert organic matter to electricity using bacteria like *Geobacter* and *Shewanella*. Plant-Microbial Fuel Cells (PMFCs) expand this concept, leveraging root excretions for electron and electricity generation by bacteria.

Geothermal heat: It is literally the heat contained within the Earth. In effect, the earth serves as a boiler in which geothermal fluids can achieve the high temperatures and pressures necessary for commercial development. Geothermal fluids at up to 3,000m depth are recovered via wells. Surface facilities convert this heat into electricity. Earth's core heat, from radioactive decay and planetary accretion, powers about 14,000 MW of global geothermal electricity. Traditional geothermal plants are near geysers, tapping into hydrothermal resources. Cutting-edge 'superhot rock energy' uses deep drilling for 400°C+ heat, potentially meeting global electricity needs. Medium/low-temperature hydrothermal resources use deep wells and fluid injection for heat capture.

Green Hydrogen: Green hydrogen is created via electrolysis, using renewable electricity. It's a clean fuel, powering fuel cells to generate electricity. India's use of green hydrogen could slash CO2 emissions and coal imports significantly. India's National Green Hydrogen Mission aims to establish the country as a global hub for green hydrogen production, use, and export. Hydrogen storage technologies like fuel cells and electrolysis offer promising long-term energy storage and transportation solutions. Ongoing research focuses on improving efficiency and cost-effectiveness.

Other Promising Options of Renewable Energy Sources: Triboelectric nanogenerators in ocean energy devices harness mechanical energy from waves, currents, and motion via the triboelectric effect. Low-temperature direct ammonia fuel cells efficiently convert ammonia into electricity below 100°C. Ammonia offers high energy density, clean production, and simplified heat management. Direct seawater electrolysis splits seawater into hydrogen and oxygen, providing abundant, pure hydrogen with minimal environmental impact, storage capabilities, and integration with renewables.

Smart Grids: It is an electricity network that co-ordinate the needs and capabilities of all generators, grid operators, end users, and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience, flexibility, and stability. Green energy transitions need smart grid systems to handle renewables efficiently. IoT and smart grid tech streamline renewable integration, using sensors, analytics, and AI to predict, balance loads, optimize energy flow, and manage maintenance and forecasts. Smart grids benefit from digital twin technology, creating virtual replicas of physical objects. Remote grids use fibre-supported SCADA for monitoring. Digital twins clone power grid environments, offering real-time insights and operational control, enhancing grid resilience amid renewables' rise and fostering microgrid proliferation for energy efficiency and flexibility. The IEA's Electricity 2024 report predicts renewable energy will surpass coal globally by early 2025, constituting over a third of total electricity. By 2026, renewables may make up nearly half, alongside nuclear. This transition could boost GDP by 2.5% and employment by 0.2%. IRENA monitors progress towards 11 TW by 2030, crucial for limiting global warming.

EMPOWERING RURAL COMMUNITIES: EMBRACING GREEN WASTE TECH IN INDIA

Current State of Waste Management in Rural Regions

Overview of Green Waste Development in Rural India: Rural India faces significant challenges in green waste management, causing environmental harm due to inadequate practices. Empowering rural communities is vital for sustainable development, given the substantial population residing in these areas and their impact on the environment. Rural communities face serious waste mismanagement practices e.g., open dumping, e-waste open burning, river dumping, pollution from plastic waste, etc. due to a lack of or poor access to formal waste management systems, particularly in Rural India. Urbanization and agribusiness are endangering rural areas, affecting organic farming, habitats, and biodiversity. These regions also contend with climate-related risks and socio-economic issues, while waste management poses challenges and opportunities.

- Rural and smart village waste encompasses various categories like solid, plastic, biomedical, e-waste, and construction & demolition waste. With proper technology, this waste can be a valuable resource, aiding in energy recovery and recycling, reducing environmental impact, and creating economic value for rural areas. Shadbahr et al.'s (2022) study emphasizes the potential of waste-to-energy methods in these regions, highlighting cost savings but also noting higher greenhouse gas emissions compared to fossil-based heating, emphasizing the importance of technological progress.
- To achieve Net Zero Targets by 2070, bridging urban-rural socio-economic gaps is crucial. Localized waste management plans, focusing on collection, transportation, and treatment, are vital for rural communities globally.

Analysis of the Impact of Green Waste Technologies on Rural Communities: India's rural areas face environmental challenges due to fossil fuel use and inadequate waste management. Despite organic waste abundance in livestock-rich villages, technology's potential to convert waste into energy and fertilizers is largely untapped.

- Using such technologies tackles resource depletion and provides economically viable, eco-friendly energy solutions. Micro-Hydro Power (MHP), for instance, aids rural development and poverty alleviation, as noted by Kalyani & Pandey (2014).
- Common waste conversion processes include thermal (e.g., incineration, pyrolysis, gasification, and refuse-derived fuel), bio-chemical (e.g., composting, vermicomposting, anaerobic digestion), and chemical (e.g., trans-esterification for biodiesel). Each method offers distinct advantages based on waste characteristics and desired outcomes. Gasification, notably used in Japan, the USA, and Europe, produces less waste and fewer emissions than traditional methods.
- Waste-to-Energy solutions, highlighted by Shadbahr et al. (2022), offer sustainable waste management and reduce fossil fuel dependence. Kannangara et al. (2018) developed a tool predicting Municipal Solid Waste (MSW) based on population centers, emphasizing green waste tech's promise for rural development.

Benefits of Implementing Green Waste Technologies

a. Empowering Rural Communities: Green waste technologies offer multifaceted benefits, including environmental conservation and socio-economic development.

b. Environmental Sustainability: Composting and biogas generation help manage organic waste sustainably while enhancing soil fertility and reducing greenhouse gas emissions.

c. Economic Opportunities: Green waste technologies create income streams through the sale of compost and biogas, fostering rural entrepreneurship.

d. Climate Resilience: Proper waste management reduces greenhouse gas emissions, mitigating climate change impacts

e. Community Engagement and Awareness: Promoting green waste technologies empowers communities with knowledge and skills, fostering ownership and responsibility.

Identification of Barriers to the Adoption of Green Technologies in Rural Regions: In rural regions, burning farm residues, e-waste, and plastics worsens air quality and climate change. Poor waste management denies resources, impacting economies. Limited infrastructure hampers proper disposal, risking environmental and health harm.

Potential Solutions and Innovations

- **Smart Waste Management System (SWM):** Smart Waste Management (SWM) systems are transforming waste processing, boosting efficiency, and supporting sustainability. Equipped with ultrasonic sensors, smart bins across rural areas collect real-time data sent to a central control centre via cloud platforms. Solar-powered sensors ensure uninterrupted operation, with optimized route scheduling cutting fuel expenses. Trucks guided by GPS collect waste at 80% capacity, saving time and resources. This integration empowers rural India with smarter, greener waste management solutions.
- **Best Practices for Successful Implementation of Green Technologies in Rural Regions:** Rural green waste tech success needs best practices and community initiatives. NBMMP and Swachh Bharat Mission fostered biogas and waste management, benefiting society and the environment. Community-driven efforts, like self-help groups, show the power of empowering rural areas with green tech.

Case Studies

a. In Karnataka, the "Hasiru Mane" project, pioneered by the NGO Hasiru Dala, trains women from marginalised communities to produce compost from organic waste, generating livelihoods and promoting environmental stewardship.

- b. In Gujarat, Punsari village exemplifies sustainable development by generating electricity from village waste, showcasing the potential of waste-to-energy initiatives
- c. In Punjab, the "Pind Cycle" program incentivises villagers to collect agricultural waste for biomass energy production, reducing crop burning incidents, improving air quality, and providing alternative sources of income for rural households.

Strategies for Overcoming Barriers to Adoption and Scaling up Green Technologies in Rural Regions

- **Social Inclusion of Waste Pickers in Rural Villages:** Rural India relies on waste pickers, essential for recycling and environmental balance, yet often marginalized and facing health hazards. Integrating them into local economies can enhance waste management and promote social equity and sustainability. For waste pickers, a vital framework includes recognition, access to services, safety, stable incomes, social inclusion, and collaboration. Policymakers must unite to implement this, improving waste pickers' lives and sustainable development goals.
- **Benefits of Including Social Protection for Rural Waste Pickers-**
 - a. Resilience to future risk
 - b. better mitigation capacities for vulnerabilities
 - C. Promotion of Circular economy
 - d. Legitimacy and recognition
 - e. Encouragement for entrepreneurship
- **Digital Monitoring of Waste Management:** Digital waste management is revolutionizing rural India, supplementing traditional methods. Utilizing IoT, mobile apps, and data analytics, digital monitoring systems (Figure 4) streamline waste operations. Stakeholders collaborate via mobile apps, creating a digital cloud for real-time waste tracking. Utilizing real-time data integration into a centralized cloud platform enables seamless tracking of the waste supply chain. Digital solutions like the Eco Green Village Mobile App in Indonesia promise efficiency, transparency, and sustainability in rural waste management.
- **Environmental benefits of transitioning to Green Waste Tech in Rural India:** Implementing smart waste technologies in rural villages can significantly improve waste management efficiency, reduce environmental impact, and enhance the overall quality of life for residents. Here are some smart waste technologies suitable for rural areas.
 - a. Composting Solutions:** Implement smart composting systems for community composting initiatives. These systems monitor temperature, moisture, and aeration, optimizing compost quality for agricultural or landscaping purposes.
 - b. Smart Waste Modelling:** Utilise data analytics platforms to (O21) analyse waste generation patterns, identify areas with high waste production, and optimise waste management strategies accordingly. Data-driven insights can help authorities make informed decisions to reduce waste generation improve recycling rates.
 - C. Waste-to-Energy Solutions:** Explore waste-to-energy technologies such as anaerobic digestion or biomass conversion to generate renewable energy from organic waste materials. This not only reduces landfill waste but also provides a sustainable energy source for the community.
 - d. Recycling Robots:** AI robots in recycling centers improve sorting efficiency, diverting recyclables from landfills. Their accuracy allows longer operations, processing more waste, and studies indicate up to a 50% increase in recycling rates.
 - e. Pneumatic Waste Pipes:** Implementing pneumatic waste pipes beneath public containers streamlines waste transport, minimizing traditional pickups. This innovative system reduces emissions, prevents overflow, and promotes cleaner, efficient waste management practices.

f. Solar-Powered Trash Compactors: Solar-powered compactors boost trash bin capacity, reducing pickups and optimizing waste collection. Smart sensors enable efficient scheduling, enhancing waste management efficiency.

g. E-waste Kiosks: Establishing e-waste kiosks encourages proper disposal and recycling of electronic devices, mitigating environmental hazards associated with e-waste. This will help to prevent harmful chemicals seeping into our soil and water.

Policy Recommendations and Conclusion

Recommendations

- a. Replication of the local best practices in other rural regions.
- b. Fostering Rural Entrepreneurship aligned with SDGs.
- c. Implementation of Policies to address Environmental injustice towards marginalised and remote communities.
- d. Promote Cohesion policies between Urban and Peri-Urban areas.
- e. Concept of Sustainable 'Green' Rural Municipalities should be promoted.

Conclusion

Policy support is vital for green waste tech adoption and sustainable waste management in rural areas. Incentives, subsidies, and partnerships with development agencies are crucial for entrepreneurs. Collaboration among stakeholders can drive innovation and foster a greener, more inclusive rural future in India.

BIODIVERSITY CONSERVATION USING REMOTE SENSING AND GIS TOOLS

Biodiversity encompasses organism variability across terrestrial, marine, and other ecosystems at species, genetics, and ecosystem levels, crucial for nature's diversity. It includes diverse ecosystems like deserts, forests, and wetlands, supporting consumptive use and facing global threats like habitat loss, overexploitation, pollution, invasive species, and global warming.

- India, with just 2.4% of the land area, has over 45,000 species of plants and 91,000 species of animals which have been recorded so far. Four of the 34 identified hot spots (presence of endemic species) of the world are in India: Himalaya, Indo-Burma, Western Ghats, and Sundaland.
- This Biodiversity is spread across 10 bio-geographic zones namely (1) Trans-Himalayan zone (2) Himalayan zone (3) Desert zone (4) Semiarid zone (5) Western ghat zone (6) Deccan plateau zone (7) Gangetic plain zone (8) North-east zone (9) Coastal zone (10) Islands [Rodgers and Panwar, 1988].
- The Convention on Biological Diversity aims for biodiversity conservation, sustainable use, and equitable benefit-sharing. With 196 countries, including India, it has near-universal membership.
- The IUCN's Red List categorizes species' global extinction risk, vital for biodiversity health. Conservation is key for the goods and services biodiversity offers for human survival.
- Utilizing technologies like remote sensing and GIS is crucial for effective natural resource management and conservation. GIS connects data to maps, aiding in storing, analysing, and retrieving spatial data.
- New imaging tech captures detailed spatial data, impacting land-use patterns from human-nature interaction. Understanding land-use change is vital for resource planning. Satellite data and GIS offer cost-effective tools for mapping and conservation planning.
- Protected area managers once relied on maps and knowledge for management. Digital databases now streamline data analysis for better decision-making, mapping, ecological modelling, and conservation planning with reliable geo-information.
- Mapping rugged terrain aids macro and micro-level planning. It reveals ecological dynamics and human impacts, improving land management and guiding habitat suitability mapping, crucial for species conservation like tigers.

- GIS is valuable for analysing present and future environmental conditions. It aids in studying species in their natural ranges and assessing climate change's impact on biodiversity at local and regional levels.
- The Uttarakhand Action Plan on Climate Change reports climatic changes affecting plant regeneration in mountains, possibly shifting habitats. Geospatial tools can track climate impacts on ecosystems and guide conservation efforts. Here the geospatial techniques are imperative to strengthen our conservation approaches towards mitigating the negative impact of climate change on population distribution of species in small area.

CASE STUDY

Spatial database for Namdapha National Park in Arunachal Pradesh has been created, which would be very valuable in both management and monitoring of resources and especially in regard to rugged terrain conditions coupled with inaccessibility of the park. The availability of spatial information at the Forest Range level helps in improving the efficacy of protected area management. The study intended to generate spatial database relevant to the management of the National Park, which includes maps showing classified vegetation, topography, drainage, village/town locations, water bodies and major infrastructural facilities. Secondary data for preparation of current vegetation cover/type map was obtained from various sources. Indian Remote Sensing (IRS) satellite IRS-P6, LISS-III data procured from the National Remote Sensing Centre (NRSC), Hyderabad was used. In addition, satellite data was acquired and interpreted (visually/digitally) to generate such maps. The interpretation was fully supported with adequate ground truth. Vegetation strata observed on satellite image was verified on the ground for accuracy assessment. The above information formed the basis to prepare documents for interpretation of the maps consisting of extent, status, and species composition of various vegetation types in the PA.

USAGE OF GREEN TECHNOLOGIES IN SUSTAINABLE WATER MANAGEMENT

Sustainable water management is essential for generations, requiring strategies in environment, economy, society, and energy/resources. An integrated approach considers drinking, wastewater, rainwater, and stormwater for true efficiency.

- In India, sustainable water management is critical due to widespread mismanagement and misconceptions about water availability. Population growth will further decrease water per capita by 2050.
- International agencies deem less than 1000 cu m per capita as scarcity. By 2030, India's water demand may double supply, risking severe scarcity and 6% GDP loss, potentially ranking it among top water-scarce nations.
- The challenges of limited water supply, falling quality, and climate change require innovative solutions. Green technology offers economic, environmental efficiency, promoting sustainability across various aspects for future water management.
- Green technologies must be tailored to each water source's unique characteristics. Rainwater, for instance, requires different treatment than recycled water. Understanding these distinctions is vital for effective water treatment strategies.

Green Technologies in Water Sector

- Rainwater has good quality but varies based on collection surface, with TDS typically between 2 to 20 mg/litre. Stormwater, carrying various pollutants, needs multilevel treatment for effective management.
- Studies show retrofitting biofilters with submerged zones and carbon sources improves stormwater treatment. This advanced technique enhances denitrification, copper removal, and achieves water quality suitable for secondary uses, including E. coli removal.
- In the case of wastewater treatment, bioreactors are the new buzzword. A bioreactor is a device containing bacteria and microorganisms placed on a moving bed biofilm reactor, deposited on a packed or fibrous bed, or attached to a membrane to form a biofilm.

- Bioreactors use separators and aerators to enhance microbial reactions, converting pollutants into safer forms. Sulphate-reducing bacteria in metal wastewater bioreactors create hydrogen sulphide, precipitating metals as recoverable by-products. They're eco-friendly and cost-effective.
- Other wastewater filtering methods include biofilters, bioremediation, and electrowinning. Biofilters use bacteria on biofilms to degrade pollutants. Bioremediation applies microorganisms to convert toxins. Electrowinning extracts metals like copper and gold from wastewater through electrode processes, a cost-effective alternative.
- Green technologies can also be used to harness new sources of water. For example, desalination becoming a popular option for nations like Israel which has very limited freshwater resources. The popular green innovations regarding desalination technologies to produce freshwater from seawater are stated below-
- Green technologies are proof that eco-friendly methods can be budget-friendly. However, knowing them is not sufficient; practicality in real-world scenarios is crucial. The next section shares success stories applying green tech in water sectors, transforming environments.

Success Stories and Keys to Success

1. The Deep Tunnel Sewerage System (DTSS) in Singapore is a vast underground network managing used water sustainably. It efficiently collects, treats, reclaims, and discharges water via gravity and green tech like energy-efficient pumps and biogas-powered cogeneration, reducing energy use, emissions, and enhancing resource recovery.
2. It has also been reported that the research unit of Oil India has discovered the process of reducing oil content in the water bodies near the drilling pit. They have used a Bio-remediating technique to reduce oil contamination in water bodies so that these areas can be made conducive to the growth of aquatic life.
3. Melbourne's Werribee Treatment Plant employs green tech like membrane bioreactors and UV disinfection for sustainable wastewater management. It produces 40 billion litres of recycled water yearly, reducing freshwater demand and environmental impact.

All these success stories have some elements in common which also provide a roadmap to the successful adoption of green technology in the water sector. The requisites for these successes are as follows:

1. Continuous research and development are essential for identifying and implementing green technologies that are suitable to the needs of the sector.
2. The presence of researchers, engineers, and industry professionals who are ready to innovate and collaborate is also necessary.
3. Public policy should support the adoption of green technology in the water sector. Policy frameworks can include financial incentives, tax breaks, and regulatory requirements that drive the adoption of green technologies.
4. Besides, it is crucial that the public should understand the importance of the adoption of green technology in the water sector. Massive public awareness programs along with behavioural change are the key to encourage the public and state towards the embracement of green technology.

GREEN TECHNOLOGIES FOR SUSTAINABLE AGRICULTURE

Declining soil fertility and biodiversity loss amid agricultural transformation raise concerns. Sustainable agricultural development ensures high-quality food while preserving the environment, advocating for reduced reliance on harmful agrochemicals and embracing eco-friendly alternatives.

- Expanding agricultural land is limited by resource depletion. Urbanization, energy costs, and population growth stress the environment, urging tech-driven solutions for energy and cost efficiency in sustainable agriculture.

- Green Technology (GT) mitigates environmental damage, promoting sustainable agricultural development. It includes 'clean' tech that preserves environmental stability and reduces resource consumption. GT in agriculture boosts yield, quality, and eco-friendliness but requires research, policy, and awareness integration for sustainable development.

Green Technologies Adopted in Agriculture

Farmers adopting green technologies can increase yield and profits sustainably. These include organic farming, agroforestry, solar energy, mixed farming, biogas, multiple cropping, crop rotation, and integrated pest management.

- **Organic farming**, Organic farming, ancient and eco-friendly, employs techniques like crop rotation and biological pest control. It enhances soil fertility and productivity, meeting consumer demand for sustainable products. Efforts to advance these practices are ongoing.
- **Agroforestry** integrates trees with crops or livestock on the same land, fostering ecological and economic interactions. It is a dynamic, natural resource management system that diversifies and sustains production, benefitting farmers at all levels. Agroforestry promotes environmental sustainability by enhancing food supply, income, and health. Practical applications include windbreak trees, hedgerow barriers, and live fences for erosion control, organic matter, and animal management.
- **Integrated Pest Management (IPM)** is an eco-friendly approach using natural pest control mechanisms to cultivate strong crops while minimizing environmental risks. It's applicable in urban and rural areas but may pose challenges for farmers due to resource limitations.
- **Solar energy**, from the sun's light and heat, is captured via solar heating and photovoltaic technology. Solar photovoltaic systems convert sunlight into energy, useful in agriculture for tasks like water pumping and lighting, offering cost savings, low maintenance, and environmental benefits.
- **Biogas technology** turns agricultural waste into renewable energy and fertilizers, promoting environmental friendliness. Anaerobic digestion transforms waste into fuel and fertilizer, enhancing soil fertility and serving as a sustainable alternative to inorganic fertilizers.
- **Mixed farming** uses crop residues as animal feed and their waste as crop fertilizer, enriching soil. This approach mitigates risks from single-crop production, promoting eco-friendly food production.
- **Crop rotation** brings socio-economic and environmental benefits, enhancing profitability with high-value crops and reducing economic risks. Including pulses or vegetables boosts micronutrient production, reduces reliance on synthetic fertilizers, and promotes biodiversity.
- **Agricultural biotechnology** enhances crop development sustainably by engineering pest-resistant plants, reducing pesticide use. However, consumer resistance to genetically modified foods persists despite their ecological benefits like phytoremediation, mitigating ecosystem degradation.
- **Drones and digital sensors** in green tech aid sustainable farming by remotely monitoring crops, cutting transport emissions, and minimizing waste. Sensors track microclimate and soil health, empowering informed decisions for optimized production, reduced waste, and increased productivity, enhancing environmental sustainability in agriculture.
- **Smart irrigation systems** use weather and soil data to schedule watering, responding to plant needs. By adjusting irrigation based on these factors, they reduce water usage compared to traditional methods, essential for sustainable agriculture given Earth's limited water supply.
- **Green nanotechnology** in agriculture boosts productivity, reduces pesticides, and aids pathogen detection and targeted delivery of nano-pesticides, improving nutrient absorption in plants. It conserves resources, addresses future agricultural challenges, and promotes food security.

Advantages of Green Technology in Agriculture

Green technology in agriculture provides numerous benefits, enhancing sustainability and efficiency in farming practices. By harnessing its potential, farmers can achieve a balance between productivity,

profitability, and environmental stewardship, ensuring a more sustainable and resilient food production system as depicted.

Challenges for Adoption of Green Technologies by Farmers

- **High initial costs:** Initial investments in green technologies, including equipment, infrastructure, and research and development, pose challenges for adoption by small-scale farmers.
- **Limited adoption and technological dependence:** Farmers may resist new green technologies due to insufficient knowledge about their potential and limitations. Understanding and implementing knowledge-intensive approaches like IPM and INM are often necessary.
- **Location-specific:** The environmental and natural resource impacts of technology depend on the location; technology may be profitable for one farm in a region but not for others.
- **Knowledge and training gaps:** Farmers frequently lack the necessary expertise to effectively employ green technologies, which often demand technical proficiency and the adaptation of farming practices.
- **Energy requirements:** Certain green technologies, such as precision agriculture tools and automated systems, can be energy-intensive, resulting in increased operational expenses and potential conflicts with efforts to reduce carbon footprints.

Green technology in agriculture aims to enhance production sustainably, promoting self-reliance and environmental health. It minimizes damage to ecosystems and food security, prioritizing environmentally friendly practices and resource efficiency, as seen in organic farming.

Future of Green Technologies in Agriculture

The increasing need for high-quality food drives the adoption of green technology in agriculture, crucial for sustainable food production and environmental conservation. Recommendations focus on educating farmers and promoting literacy via rural adult education centers to ensure sustainable practices, profitability, and environmental and human health protection.

Technological advancements in agriculture include internet and GPS-based smart technologies, leading to precision agriculture. UAVs with sensors provide real-time data for monitoring crop growth and soil conditions. Greenhouse technologies like hydroponics and aeroponics show promise for urban vertical farming.

Conclusion

Green technologies are transforming agriculture, yet conservation demands a multifaceted strategy. No single tech can tackle environmental challenges; a blend of new and traditional methods is crucial. These technologies boost efficiency, cut impacts, and enhance productivity, crucial for a sustainable food chain. Collaboration between farmers and policymakers is key.