

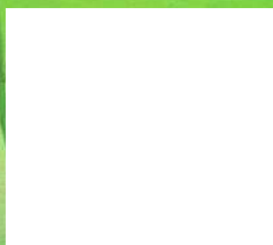
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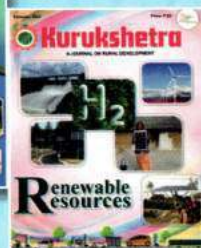
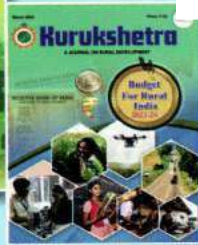
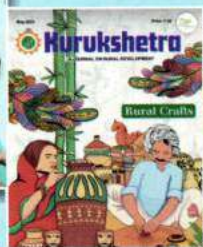
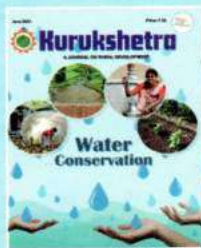
Towards Embracing Green Technologies





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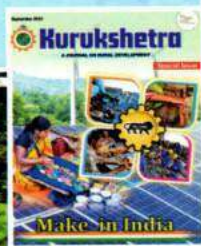
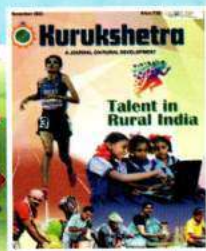
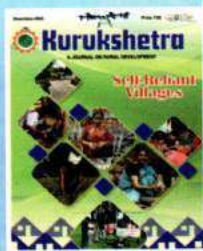
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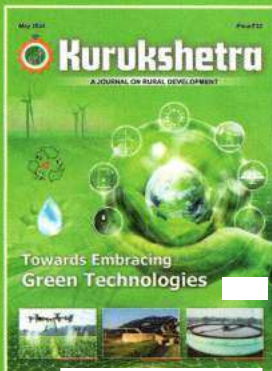
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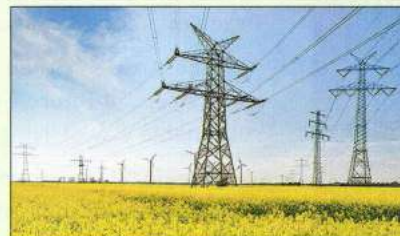
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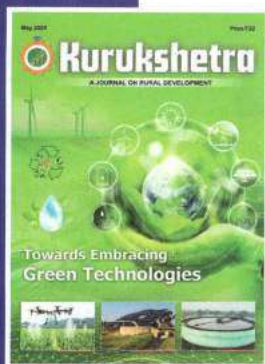


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Editorial

The term “Green technology” describes about the use of technology and science to reduce human impacts on the natural environment. Green technology encompasses a wide area of scientific research, including energy, atmospheric science, agriculture, material science, and hydrology. Green technology offers numerous environmental, economic and social advantages. Sustainable green technologies add much to a sustainable society while promoting environmental protection and economic development. The future of green technology holds immense potential for innovation and sustainability.

The Article **“Green Technologies: Current Status, Challenges and Way Ahead”** indicates that how the concept of future Green Technologies is changing from the mere new gadgets and solutions to more sustainable way of living.

Article **“Understanding Green Technologies for Future”** emphasizes that embracing Green Technologies is not an option but an imperative for protecting the well-being of present and future generations. It elaborately discusses about the environmental, economic, social, agricultural and global aspects of adopting these technologies.

The dependence on fossil fuels for energy production exacerbating climate change, making it imperative to shift to the maximum use of renewable and clean energy sources. The Article **“Green technologies for Clean and Renewable energy”** discusses about all the available renewable and clean energy sources and technologies.

The Article **“Empowering Rural Communities: Embracing Green Waste Tech In India”** underlines the need for adoption and scaling up green waste technologies for paving the way to a greener and more inclusive future for rural India. It explores the potential of embracing green waste technologies to empower rural communities and mitigate environmental impacts.

The Article **“Biodiversity Conservation using Remote Sensing and GIS Tools”** focuses on the potential and utilization of geospatial tools in terms of forest cover maps, land use, land cover maps, vegetation maps to check the Biodiversity Conservation problems of habitat loss, over-exploitation, pollution, invasive species, and global warming, especially in places of inaccessible, rugged terrain.

Water being a scarce resource, the sustainable water management is the utmost necessity in rural as well as in urban areas. The article **“Usage of Green Technologies in Sustainable Water Management”** throws light on how the drinking water, wastewater, rainwater, stormwater and drainage water in a collective form can be managed together truly in efficient and sustainable manner with the use of modern green technologies.

The use of green technologies in enhancing the agriculture production sustainably while making ecological balance is very important. Article **“Green Technologies for Sustainable Agriculture”** discusses about the future agricultural technologies which must prioritise both profitability and environmental impact while acknowledging the importance of natural resources and ecosystem services.

By embracing Green technology, information, and transparency, we can effectively address long-standing challenges, formalize the rural sector, and unlock the immense potential of rural communities. Through collaborative efforts among stakeholders, the technology can act as a powerful catalyst accelerating sustainable rural development. Let us harness the full potential of Green Technology and create sustainable and inclusive growth. □

Green Technologies

Current Status, Challenges and Way Ahead



The future of green technology is not just about new gadgets and solutions; it is more about a shift in mindset towards a more sustainable way of living. India's continually evolving policies and reforms focused on attaining nationally determined contributions are clearing a path for faster adoption of green technologies and for facilitating investors across the globe. Economically, Green technologies open new markets and create jobs. These technologies also foster business innovation, enabling companies to develop new products and services that meet growing consumer demand for sustainability. Environmentally, green technologies significantly reduce carbon emissions contributing to the fight against climate change and environmental degradation. Socially, they improve the quality of life by providing access to cleaner air and water. And they also offer a path to achieving global sustainability at the national level.

* **Manjula Wadhwa**

In view of the huge impact of greenhouse gas emissions, depletion of natural resources, continuously increasing global warming, various stakeholders, for the past two decades have been pondering over United Nation's sustainable development goals (SDGs) and their implementation using clean and green technologies. Clean technology refers to the use of conventional energy resources to address the energy demands, without causing environmental damage and green technology refers to the use of

environmentally friendly renewable energy sources.

Let us understand the concept of green technology. It is the creation and application of products, systems, and frameworks that aim to protect the natural environment and its properties by mitigating and reducing the negative consequences of human activities. To simplify, the term "green technology" refers to devices, services, or processes that follow certain criteria, i.e., it emits no or very few greenhouse gases (GHGs), is safe to use, and encourage a healthy and better climate for all forms of life. It reduces electricity and natural

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resource consumption and also encourages the use of natural energy. Green technologies broadly encompass innovations focused on environmental enhancement and resource efficiency. They range from renewable energy solutions like solar and wind power to advanced waste management solutions and eco-friendly materials. These technologies are crucial in addressing global environmental challenges such as climate change and resource scarcity, marking a significant shift from traditional practices to sustainable alternatives. They offer new opportunities for growth and development, challenging conventional business models and promoting sustainable business operations. This shift is evident in the rise of green startups and investments in sustainable innovations. Renewable energy technologies for energy production, such as solar and wind power, are at the forefront, offering alternatives to fossil fuels. Energy efficiency technologies, focusing on reducing energy consumption in buildings and industries, are also critical. Green transportation technologies, including electric vehicles and sustainable public transit systems, are gaining momentum. Furthermore, waste management technologies are revolutionising the way we handle waste, turning it into sustainable resources or energy. Lastly, sustainable materials are replacing traditional, non-renewable materials in the construction industry. These varied types of technologies underscore the comprehensive scope they can have in addressing environmental

challenges. Thus, it is like giving Mother Nature a high-tech helping hand.

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.

Now that we have dipped our toes into the world of green technology, let us dive deeper into the heart of the matter. The opportunities presented by green technologies are vast. Economically, they open new markets and create jobs. These technologies also foster business innovation, enabling companies to develop new products and services that meet growing consumer demand for sustainability. Environmentally, green technologies significantly reduce carbon emissions contributing to the fight against climate





change and environmental degradation. Socially, they improve the quality of life by providing access to cleaner air and water. Additionally, they offer a path to achieving global sustainability at the national level. These opportunities can augment the pace of economic growth and serve as a step towards a more sustainable and equitable world.

It is the best way to address environmental issues while still promoting economic development. It also aligns with the global agenda of governments currently prioritising environmental betterment, including the phenomena of climate change. The greatest advantage of using green technologies is that it improves people's quality of living by making the climate more sustainable. If air, water, and noise pollution continues, it would have a very bad effect on the quality of life. The negative effect on the climate is minimised as we use green technologies. Green technology has a lot of promise for propelling the nation forward. Industries that use or produce goods based on green technologies may help the local population find work.

In the coming days, the green technology landscape will be marked by several adventurous innovations. One important development is in the realm of solar energy, where advances have led to more efficient and affordable solar panels, making renewable energy from solar energy accessible

to a broader audience. Another area of notable progress is being witnessed in the electric vehicle technology. EVs are becoming popular day by day, thanks to improvements in battery life and charging infrastructure. Waste management technologies are also undergoing transformation. Innovations in recycling and waste-to-energy processes are enabling more sustainable management of resources. These technologies have the potential to reduce landfill waste and greenhouse gas emissions. Moreover, green architecture is gaining momentum, with sustainable buildings designed for energy efficiency and minimal environmental impact. These structures utilise sustainable materials and incorporate features like green roofs and energy-efficient lighting, contributing considerably to urban sustainability and lowering temperatures in adjacent areas.

While looking at the Agricultural sector, we find sustainable farming technologies are evolving. Techniques like precision farming, which uses Artificial Intelligence and the Internet of Things (IoT) for efficient resource usage, are revolutionising food production, making it more sustainable and less harmful to the environment. These illustrations clearly signify the dynamic and impactful nature of green technologies. They are not just transforming industries but are also paving the way for a more sustainable and eco-friendly future. The continued evolution and adoption

of these technologies will, undoubtedly, be crucial in addressing the global environmental challenges of our time.

Currently, the manufacturing sector contributes to nearly 40% of the country's total energy consumption and is one of the major sources of greenhouse gas emissions. As manufacturing sector continues to witness growth, its rapid consumption of coal, oil, and natural gas has become a concern due to their significant contribution to pollution. The adoption of renewable energy sources offers opportunities for companies to reduce their carbon footprint. Renewable energy such as biomass, green coal, and solar power can provide reliable energy for manufacturing processes. The initiative taken by Government Of India under Production Linked Incentive schemes, presented in pictorial form:

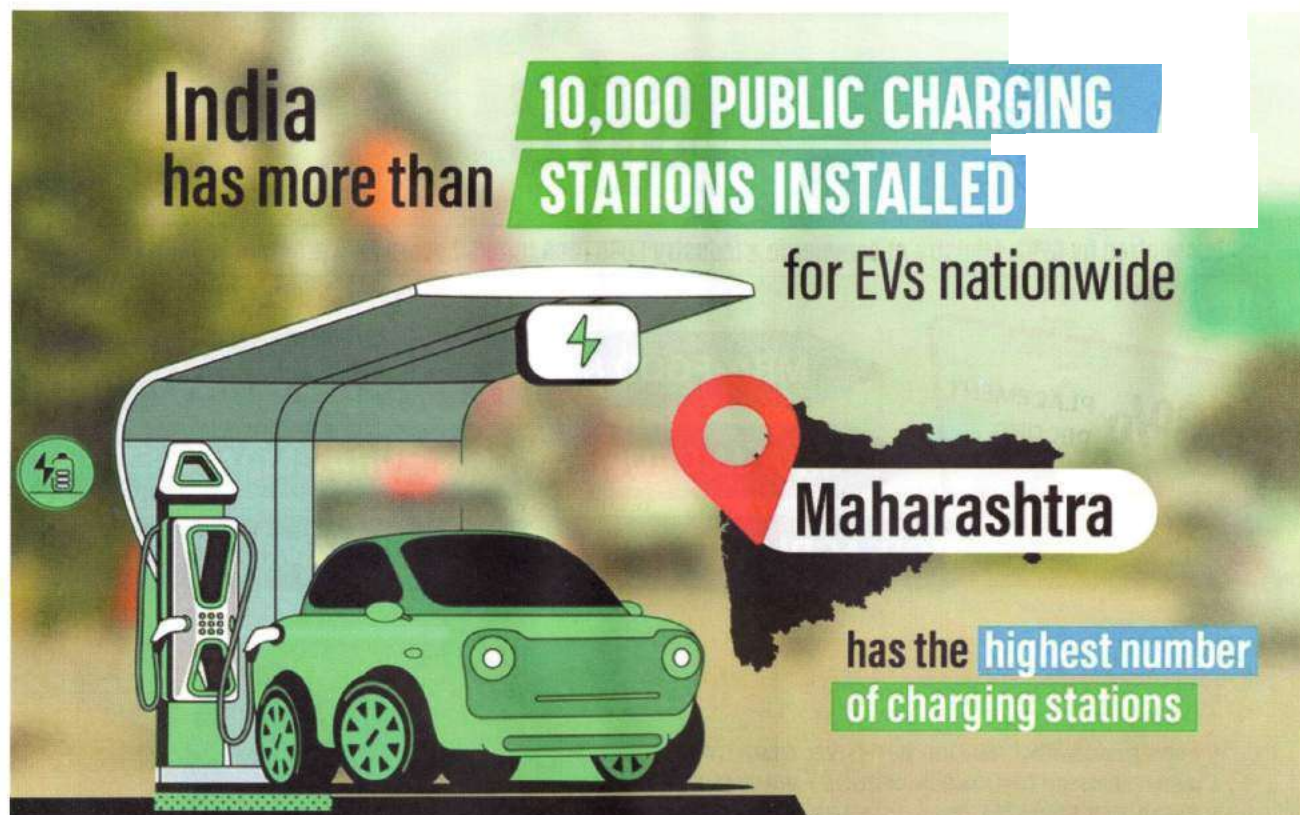
Another initiative is National Green Hydrogen Mission, which will lead to significant decarbonisation of the economy, reduced dependence on fossil fuel imports, and enable India to assume technology and market leadership in Green Hydrogen. Initially, two distinct financial incentive mechanisms proposed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

The journey of green technologies is of course, quite optimistic but not without challenges. Economically, the high initial investment costs for green tech is a big barrier. Businesses may face challenges in securing the necessary funding for implementing green technologies. There are also challenges in achieving widespread adoption and integration into existing systems and infrastructures. Regulatory hurdles can impede the development and implementation of these technologies. Furthermore, public acceptance and awareness remain crucial for widespread adoption. One of the key challenges in adopting green technology is the need for reduced energy

consumption, which requires us to change our habits and lifestyles. Reducing Waste is yet another challenge. Green technology promotes a circular economy where waste is minimised and resources are reused or recycled. However, to achieve it, we not only need to recycle more, rather design products and systems that generate lesser waste. Products need to be designed not just for functionality and efficiency but also for longevity and end-of-life recyclability. In Agriculture, the shift towards more eco-friendly practices may pose a challenge. It is a complex issue that requires a balance between maintaining productivity and protecting the environment. Green technology also aims to reduce water consumption. Realising this objective, particularly in the industries where water use is high, requires an out of the box approach and a staunch commitment to conservation. Another challenge is reducing Air pollution, particularly in big cities where pollution levels are very high. Effectuating it requires cleaner energy sources, improved industrial processes and stricter regulations. Reducing Carbon footprints, though a global challenge, is the one that green technology is uniquely equipped to tackle. Not only renewable energy sources and energy efficient technologies are required but also a societal shift towards sustainable lifestyles. Addressing these challenges is essential for the successful integration and maximisation of green technologies' potential. The Vertical Farming, No-till Farming, changing dietary habits, and embracing innovative foods like plant-based meat substitutes and Precision Fermentation can help us to create foods which can reduce our carbon footprints and contribute to more sustainable food systems. In the manufacturing sector, the challenges hinder the widespread adoption of renewable sources. For instance, India heavily relies on imported materials for the solar supply chain, leading to foreign exchange pressure. Based on conservative estimates, more than 50% of the project costs for each megawatt of solar PV power plant installation in India lead to the outflow of foreign exchange. To overcome this, developing a domestic solar value chain could help stimulate the usage of renewable energy in manufacturing sector as well as lead to the creation of jobs. Bioenergy offers promising solutions to mitigate carbon emissions, especially in sectors that are challenging to transition



to sustainable and clean practices. Bioenergy involves deriving renewable energy from organic matter, such as agricultural waste or energy crops. However, the adoption of bioenergy in manufacturing faces obstacles, particularly in regions where consumer and producer markets for manufacturing products are not abundant in biomass resources. This misalignment creates logistical barriers to integrating and utilising biomass. To enable widespread adoption, solutions such as developing efficient supply chains, establishing biomass collection and processing infrastructure, and implementing supportive policies and incentives are needed. Overcoming these challenges would allow the manufacturing sector to tap into the potential of bioenergy, reducing greenhouse gas emissions and promoting sustainability. The adoption of electric vehicles (EVs) and hybrid vehicles for logistics and transportation can significantly reduce emissions. Certain companies like 'Exponent Energy' have developed a charging infrastructure and battery pack that enables rapid 15-minute charging for commercial electric vehicles, which have different requirements than passenger vehicles. 'Log9 Materials' is also developing batteries specifically designed for commercial vehicles. This shift toward electric mobility

can play a crucial role in bringing down emissions throughout the manufacturing supply chain.

Way Forward

Looking ahead, we visualise the future of green technology is not just about new gadgets and solutions; it is more about a shift in mindset towards a more sustainable way of living. India's continually evolving policies and reforms focused on ease of doing business and attaining nationally determined contributions are clearing a path for faster adoption of green technologies and for facilitating investors across the globe. India's 'Aspirational District Programme' is the best initiative to channel such a transformation by leveraging local communities, as it removes heterogeneities in regional variations in development. The programme, with its increased scope in energy transitions, will power India's ambitions as a world leader in green energy and achieve Agenda 2030. It serves as a lighthouse not just for our green energy revolution but also provides a model that is replicable across the world. To conclude, we must remember the words of Bob Brown, the Senator of Australian Greens:

"The future will either be green or not at all" □

Understanding Green Technologies For Future

As humanity stands at a critical juncture in history, the transition to green technology offers a pathway towards a sustainable and resilient future. By harnessing the transformative power of innovation, collaboration, and collective action, we can overcome the challenges of environmental degradation and build a world where prosperity is harmonised with planetary health. Embracing green technology is not merely an option but an imperative for safeguarding the well-being of current and future generations.



* Subhash Chand

** Sheikh Amjid

Understanding Green Technology means understanding new ways to help the environment. It is defined by principles such as resource efficiency, renewable energy adoption, and waste reduction. Knowing how these ideas have changed over time is important for realising how they can help make the world a better place. By learning about Green Technology, we can all work together to

create projects that are good for the planet, making it healthier and safer for everyone, now and in the future. Understanding its evolution and development is crucial for navigating towards a greener future and achieving environmental sustainability.

Environmental Benefits of Green Technology

Green technology offers numerous environmental advantages, including mitigating climate change by reducing greenhouse gas emissions and promoting

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Hydrogen, the Fuel of the Future, Powering Tomorrow's World

renewable energy sources. It also plays a pivotal role in curbing pollution and emissions, conserving natural resources and preserving biodiversity, ensuring a healthier and more sustainable planet for current and future generations. Here are some environmental benefits associated with green technology:

Reduced Carbon Emissions: Green technologies often focus on renewable energy sources such as solar, wind, and hydroelectric power, which produce significantly fewer greenhouse gas emissions as compared to fossil fuels like coal and oil. By transitioning to renewable energy sources, we can mitigate climate change by reducing carbon dioxide and other greenhouse gas emissions.

Energy Efficiency: Many green technologies are designed to improve energy efficiency in buildings, transportation, and industrial processes. By using energy more efficiently, we can reduce overall energy consumption and decrease the environmental impact associated with energy production, including air and water pollution.

Resource Conservation: Green technologies promote the efficient use of resources such as water, land, and raw materials. For example, innovations in water-saving technologies for agriculture and urban infrastructure can help conserve water resources, while recycling and waste-to-energy technologies can reduce the amount of waste sent to landfills.

Biodiversity Preservation: Sustainable agricultural practices and land management techniques supported by green technologies can help preserve biodiversity by protecting natural habitats, reducing habitat destruction, and minimising the use of harmful chemicals that can degrade ecosystems and harm wildlife.

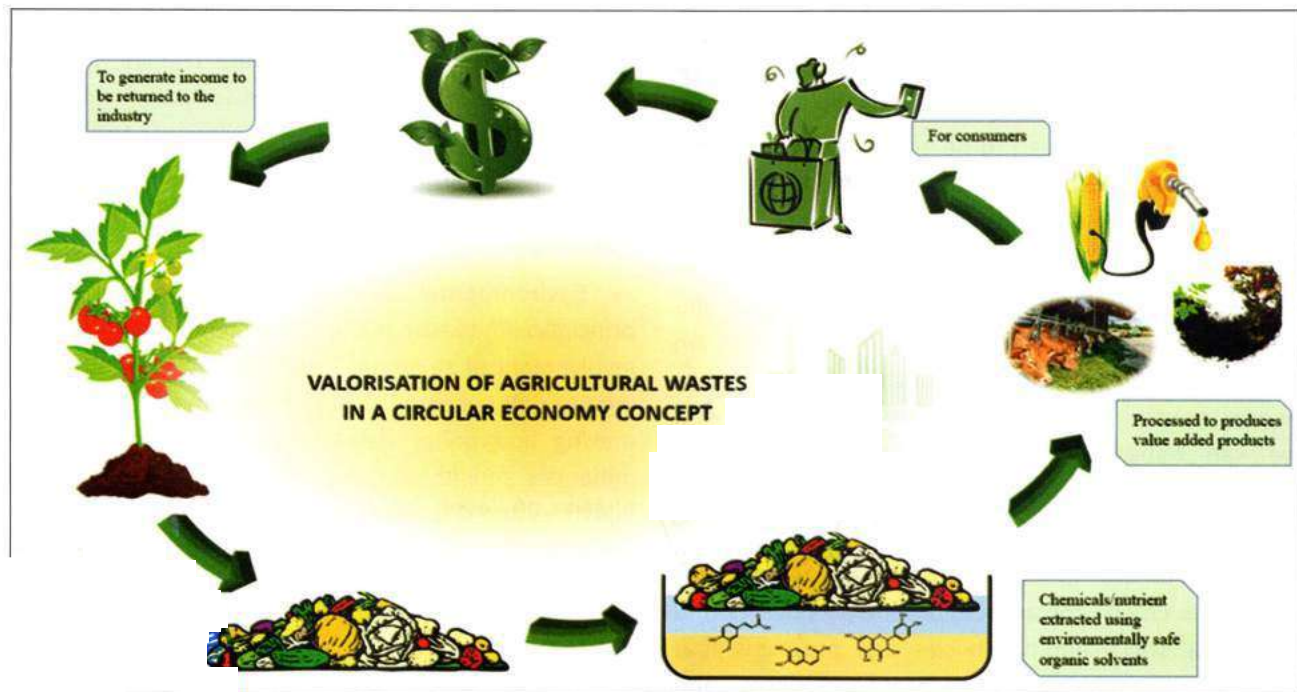
Improved Air and Water Quality: By reducing reliance on fossil fuels and adopting cleaner energy sources, green technologies can help improve air quality by reducing emissions of pollutants such as sulphur dioxide, nitrogen oxides, and particulate matter. Additionally, technologies for wastewater treatment and pollution control can help improve water quality and protect aquatic ecosystems.

Climate Resilience: Green technologies can also contribute to building resilience to climate change impacts such as extreme weather events, sea-level rise, and drought. For example, sustainable land management practices can help mitigate soil erosion and flooding, while renewable energy systems can provide decentralised power sources that are less vulnerable to disruptions.

Mitigation of Environmental Degradation: Green technologies offer solutions to address various forms of environmental degradation, including deforestation, desertification, and habitat destruction. For instance, reforestation efforts supported by technology tools such as remote sensing and geographic information systems (GIS) can help restore degraded landscapes and sequester carbon.

Economic Implications of Green Technology

The adoption of green technology drives economic growth by stimulating innovation and entrepreneurship in sustainable industries. It creates new opportunities for green jobs and industries, enhances energy security by reducing reliance on fossil fuels, and fosters economic resilience by promoting resource efficiency and mitigating environmental risks, thereby contributing to long-term sustainable development. Here are some of the key economic benefits associated with green technology:



Application of green principle in agricultural waste valorisation in a circular economy concept

Job Creation: The transition to green technology creates new job opportunities across multiple sectors, including renewable energy, energy efficiency, waste management, and sustainable transportation. These industries require skilled workers for manufacturing, installation, maintenance, and research and development of new technologies.

Innovation and Competitiveness: Investment in green technology fosters innovation and drives technological advancements, leading to the development of new products, processes, and services. Countries and companies that lead in green technology innovation can gain a competitive edge in the global market, attracting investment and stimulating economic growth.

Cost Savings: While the initial investment in green technology infrastructure and equipment may be higher than traditional counterparts, the long-term operational costs are often lower. Energy-efficient buildings, renewable energy systems, and sustainable transportation options can lead to reduced utility bills, lower fuel costs, and decreased maintenance expenses, resulting in significant cost savings over time.

Energy Independence and Security: Green technologies such as solar, wind, and bio-energy reduce reliance on imported fossil fuels, thereby enhancing energy independence and security. By diversifying

energy sources and promoting domestic production of renewable energy, countries can mitigate the economic risks associated with volatile oil prices and geopolitical tensions.

Market Opportunities: The growing demand for environmentally friendly products and services presents market opportunities for businesses that specialise in green technology. Companies that offer energy-efficient appliances, eco-friendly packaging, sustainable agriculture solutions, and clean transportation options can capitalise on consumer preferences for environmentally responsible products and tap into emerging 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 and incentives play a crucial role in driving the adoption of green technology by providing financial incentives, tax credits, subsidies, and regulatory frameworks that encourage investment in sustainable practices and technologies. Public and private investment in green technology research, development, and deployment can stimulate economic growth and spur technological 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 technology can lead to improved public health outcomes by reducing air and water pollution associated with fossil fuel combustion and industrial processes. By transitioning to cleaner energy sources and adopting sustainable practices, we can mitigate health disparities and promote environmental justice.

Access to Clean Energy and Services: Ensuring equitable access to clean energy and sustainable services is crucial for addressing energy poverty and promoting social equity. Policies and programs that prioritise equitable distribution of resources and support community-led initiatives can help address these disparities.

Job Creation and Training Opportunities: Green technology offers opportunities for job creation and skills development, particularly in sectors such as renewable energy, energy efficiency, and sustainable agriculture. However, it is essential to ensure that workforce development programs and training initiatives are inclusive and accessible to people from diverse backgrounds, including women, minorities, and disadvantaged communities.

Community Empowerment and Participation: Engaging communities in the decision-making process and empowering local stakeholders to participate in the development and implementation of green technology projects can enhance social cohesion and promote grassroots innovation.

Affordability and Cost Burdens: While green technology solutions offer long-term cost savings and environmental benefits, the upfront costs of implementation may pose challenges for some households and businesses, particularly those with limited financial resources. Policies such as subsidies, incentives, and financing mechanisms can help make green technology more affordable and accessible to low-income individuals and communities.

Resilience to Climate Change: Vulnerable communities, including those living in coastal areas, arid

regions, and low-lying islands, are disproportionately affected by the impacts of climate change, such as sea-level rise, extreme weather events, and food insecurity. Green technology can contribute to building resilience by providing sustainable solutions for disaster preparedness, water management, and agricultural adaptation.

Environmental Justice: Environmental justice principles emphasise the fair treatment and meaningful involvement of all people, regardless of race, ethnicity, income, or geography, in environmental decision-making and policy development. Green technology initiatives should prioritise addressing environmental injustices and disparities by considering the needs and perspectives of marginalised communities and ensuring equitable distribution of environmental benefits and burdens.

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: Transitioning to renewable energy sources such as solar, wind, hydroelectric, and geothermal power is one of the most critical aspects of green technology adoption. Renewable energy technologies offer clean, sustainable alternatives to fossil fuels and can help reduce greenhouse gas emissions and dependence on finite resources.

Energy Efficiency: Improving energy efficiency in buildings, transportation, and industrial processes is another key area of green technology adoption. Energy-efficient appliances, lighting systems, heating, ventilation, and air conditioning (HVAC) systems, as well as smart energy management systems, can significantly reduce energy consumption and operating costs while lowering carbon emissions.

Sustainable Transportation: Green technology solutions in transportation include electric vehicles (EVs), hybrid vehicles, fuel-efficient engines, public transit systems, and alternative fuels such as bio-fuels and hydrogen. By promoting sustainable transportation options, we can reduce air pollution, congestion, and reliance on fossil fuels while improving mobility and accessibility.

Waste Management and Recycling: Green technology innovations in waste management and recycling aim to minimise waste generation, maximise resource recovery, and reduce environmental pollution. Advanced recycling technologies, composting systems, and waste-to-energy facilities help divert waste from landfills and promote a circular economy where materials are reused, recycled, or repurposed.

Water Management: Sustainable water management technologies focus on efficient water use, conservation, and pollution prevention in agriculture, industry, and urban areas. Innovations such as drip irrigation systems, rainwater harvesting, wastewater treatment plants, and water-efficient appliances help optimise water resources and protect freshwater ecosystems.

Green Building Design and Construction: Green building practices integrate energy-efficient design, sustainable materials, and renewable energy systems to minimise environmental impact and enhance occupant's comfort and health. Green building technologies include passive solar design, green roofs, high-performance insulation, and energy-efficient lighting and HVAC systems.

Agricultural Sustainability: Green technology adoption in agriculture promotes sustainable farming practices that conserve soil, water, and biodiversity while minimising the use of synthetic fertilisers and pesticides. Techniques such as precision agriculture, agro-forestry, organic farming, and soil conservation practices help improve crop yields, soil health, and resilience to climate change.

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 technology adoption also includes measures to adapt to and mitigate the impacts of climate change, such as sea-level rise, extreme weather events, and ecosystem degradation. Climate-resilient infrastructure, ecosystem restoration projects, and disaster preparedness strategies help communities to build resilience and adapt to changing environmental conditions. These key areas of green technology adoption represent opportunities for innovation, investment, and collaboration to address pressing environmental challenges and create a more



sustainable and resilient future. Green technology adoption spans various sectors, including renewable energy, energy efficiency, sustainable transportation, waste management, green building, and agriculture. Embracing innovation in these areas is critical for transitioning towards a low-carbon, resource-efficient economy and mitigating environmental impacts across diverse sectors of society.

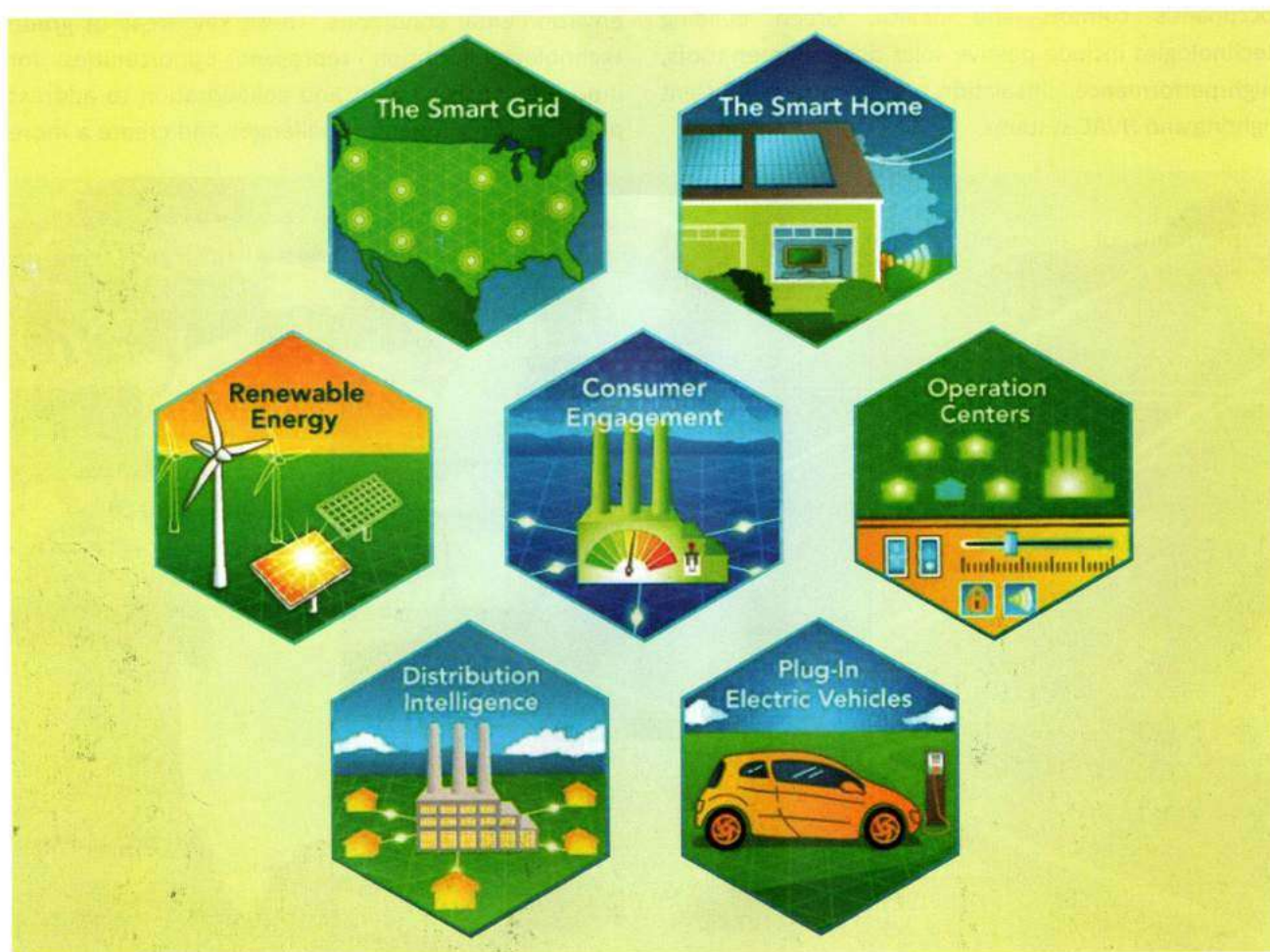
Challenges and Barriers to Adoption

Despite the benefits, green technology adoption faces obstacles such as technological limitations, high costs, regulatory hurdles, and resistance to change. Overcoming these challenges requires concerted efforts to address infrastructural constraints, provide financial incentives, enact supportive policies, and foster societal shifts towards sustainable practices. While green technology offers promising solutions for addressing environmental challenges and promoting sustainability, its widespread adoption faces several challenges and barriers. Here are some of the key obstacles:

Costs and Investment: One of the primary barriers to green technology adoption is the upfront costs associated with implementing new technologies or upgrading existing infrastructure. Despite the long-term cost savings and environmental benefits, the initial investment required for renewable energy systems, energy-efficient equipment, and sustainable practices can be prohibitive for businesses, governments, and individuals.

Lack of Financial Incentives: The absence of financial incentives, subsidies, and supportive policies can hinder the adoption of green technology. Without adequate incentives such as tax credits, rebates, feed-in tariffs, or low-interest loans, businesses and consumers may be less motivated to invest in renewable energy, energy efficiency upgrades, or sustainable practices.

Technological Challenges: Some green technologies face technical limitations, performance issues, or scalability constraints that impede their widespread adoption. For example, renewable energy sources such



Case Studies of Successful Green Technology Initiatives

Examining successful green technology initiatives worldwide provides valuable insights into effective strategies for sustainable development.

Case Study	Location	Initiative
Renewable Energy Transition in Germany	Germany	Transition to Renewable Energy Sources
Sustainable Transportation in Curitiba, Brazil	Curitiba, Brazil	Integrated Bus Rapid Transit System
Waste Management Innovations in Sweden	Sweden	Waste-to-Energy Plants and Recycling
Green Building Initiatives in Singapore	Singapore	Sustainable Building Design and Practices
Agro-ecological Farming Practices in Costa Rica	Costa Rica	Organic Farming and Biodiversity Conservation

Case studies from Germany's renewable energy transition to Costa Rica's agro-ecological farming practices showcase the transformative potential of green technologies in achieving environmental, social, and economic objectives on both local and global scales. These case studies highlight successful green technology initiatives implemented in various regions across the globe, showcasing the effectiveness of innovative solutions in addressing environmental challenges and promoting sustainable development.

as solar and wind power are intermittent and require energy storage solutions to ensure reliability and grid stability. Similarly, advanced recycling and waste-to-energy technologies may require further development to become economically viable at scale.

Infrastructure Constraints: The transition to green technology often requires significant upgrades to infrastructure, such as electricity grids, transportation networks, and water supply systems. Inadequate infrastructure or regulatory barriers can hinder the deployment of renewable energy projects, electric vehicle charging stations, and smart grid technologies, limiting their effectiveness and accessibility.

Market Barriers and Competition: Established industries and vested interests in fossil fuels may resist the adoption of green technology, leading to market barriers and competition. Subsidies and regulatory frameworks that favour fossil fuel extraction and consumption can distort market incentives and disadvantage clean energy alternatives. Additionally, monopolies or oligopolies in energy markets may limit competition and innovation in renewable energy and energy efficiency sectors.

Policy and Regulatory Challenges: Inconsistent or unclear policies, regulations, and permitting processes can create uncertainty and deter investment in green technology. Lack of political will, lobbying pressure from industry stakeholders, and regulatory barriers can delay or undermine efforts to implement renewable

energy mandates, carbon pricing mechanisms, or environmental standards.

Public Awareness and Perception: Limited public awareness, misconceptions, and scepticism about green technology can impede its adoption. Education, outreach, and communication efforts are needed to raise awareness about the benefits of renewable energy, energy efficiency, and sustainable practices and dispel myths or misinformation that may deter adoption.

Social and Equity Considerations: The distribution of costs and benefits associated with green technology adoption may not always be equitable, leading to concerns about social justice and fairness. Low-income communities, marginalised groups, and developing countries may face barriers to accessing clean energy, sustainable transportation, and other green technology solutions, exacerbating existing disparities and inequalities. Addressing these challenges and barriers to green technology adoption requires coordinated action and collaboration among governments, businesses, civil society organisations, and communities.

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: Setting renewable energy targets and mandates establishes clear goals for transitioning to clean energy sources such as solar, wind, hydroelectric, and geothermal power. Governments can mandate renewable energy standards, renewable portfolio standards (RPS), or feed-in tariffs to incentivise the deployment of renewable energy projects and stimulate investment in clean energy infrastructure.

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: Implementing carbon pricing mechanisms such as carbon taxes or cap-and-trade systems internalises the cost of carbon emissions and creates economic incentives for reducing greenhouse gas emissions. Pricing carbon encourages businesses to invest in cleaner technologies, improve energy efficiency, and transition to low-carbon alternatives.

Regulatory Standards and Codes: Establishing regulatory standards, building codes, and environmental regulations that mandate energy efficiency, emissions reductions, and sustainable practices can drive market transformation and ensure compliance with sustainability objectives. Energy performance standards for buildings, vehicle fuel efficiency standards, and emissions limits for industrial facilities help raise the bar for environmental performance.

Research and Development Funding: Investing in research, development, and demonstration (RD&D) of green technologies stimulates innovation and advances technological solutions for sustainability challenges. Government funding for research institutions, universities, and private-sector collaborations supports the development of breakthrough technologies, materials, and processes that enhance environmental performance and competitiveness.

Public Procurement Policies: Leveraging public procurement policies to prioritise green technology solutions and environmentally friendly products and services can create market demand and drive economies of scale. Governments can adopt green procurement policies that require agencies to purchase energy-efficient appliances, renewable energy systems, low-emission vehicles, and sustainable goods and services.

Education and Outreach Programs: Educating the public, businesses, and policymakers about the benefits of green technology and sustainable practices is essential for building awareness, fostering behavioural change, and mobilising support for policy action. Education campaigns, training programs, and outreach initiatives raise awareness about energy conservation, waste reduction, and climate change mitigation and adaptation strategies.

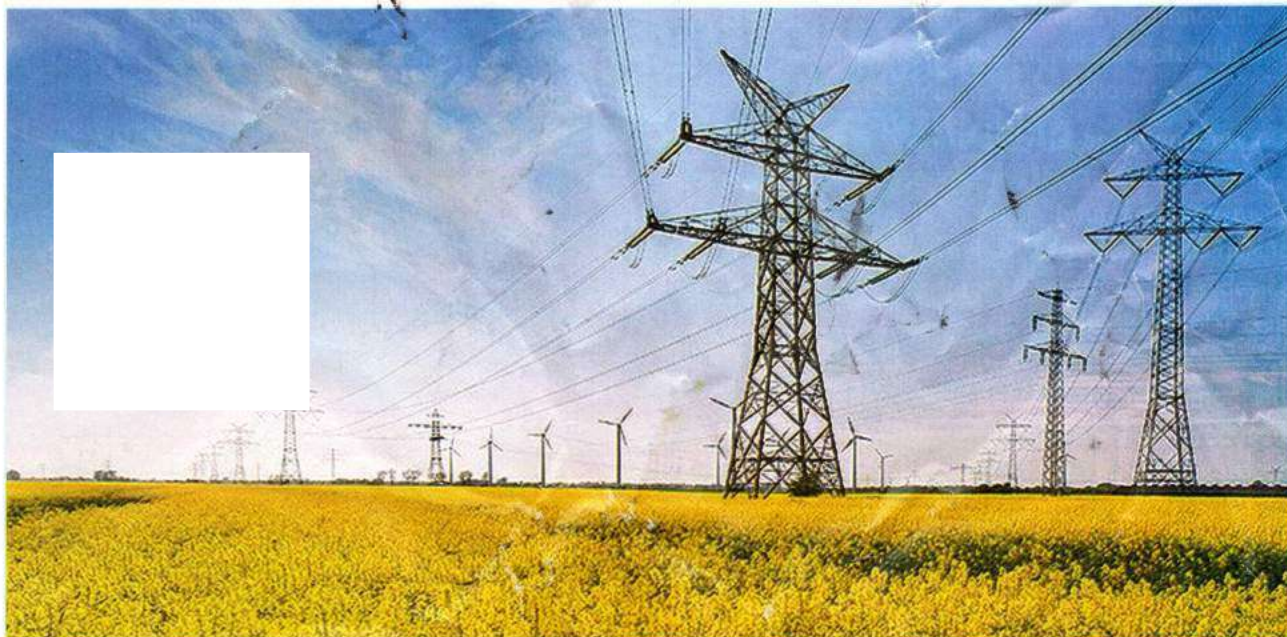
The Role of International Collaboration and Cooperation

International collaboration is essential for addressing global environmental challenges. Through agreements, knowledge sharing, and technology transfer, nations can enhance their capacity to adopt green technologies. Climate finance and green investment further support sustainable development efforts, facilitating the transition to a low-carbon economy and promoting resilience to climate change impacts on a global scale. International collaboration and cooperation play a crucial role in addressing global environmental challenges, promoting sustainable development, and advancing the adoption of green technology. Here are several ways in which international collaboration contributes to these objectives:

Knowledge Sharing and Technology Transfer: International collaboration facilitates the exchange of knowledge, expertise, and best practices in green technology development, deployment, and policy implementation. By sharing lessons learned and successful strategies, countries can accelerate technological innovation, improve capacity-building efforts, and overcome barriers to adoption.

Joint Research and Development: Collaborative research and development (R&D) initiatives bring together scientists, engineers, and innovators from different countries to work on shared environmental and technological challenges. By pooling resources, expertise, and infrastructure, international R&D collaborations can drive innovation, accelerate technology development, and address complex sustainability issues more effectively.

Capacity Building and Training: International collaboration supports capacity-building efforts in developing countries by providing technical assistance, training programs, and knowledge-sharing platforms. Capacity-building initiatives enhance local expertise, promote technology transfer, and empower



communities to adopt green technology solutions that address their specific needs and priorities.

Policy Harmonisation and Coordination:

International cooperation helps harmonise policies, regulations, and standards related to environmental protection, energy efficiency, and sustainable development. By aligning policy frameworks and coordinating efforts, countries can create a more conducive environment for green technology adoption, investment, and trade while minimising regulatory barriers and trade conflicts.

Financing and Investment:

International collaboration mobilises financial resources and investment capital for green technology projects through multilateral development banks, international funds, and public-private partnerships. By leveraging public and private sector financing, countries can scale up investments in renewable energy, energy efficiency, sustainable infrastructure, and climate resilience projects, particularly in developing countries.

Global Environmental Governance: International collaboration strengthens global environmental governance frameworks and institutions responsible for coordinating international efforts to address environmental challenges such as climate change, biodiversity loss, and pollution. Treaties, agreements, and multilateral forums provide platforms for dialogue, negotiation, and collective action on shared environmental priorities.

Technology Diplomacy and Innovation Networks:

International collaboration fosters technology diplomacy and innovation networks that promote cross-border cooperation, trust-building, and mutual benefits. Diplomatic initiatives, joint research partnerships, and innovation clusters facilitate collaboration between governments, businesses, academia, and civil society organisations, driving progress towards common sustainability goals.

Climate Diplomacy and Negotiation: International collaboration is essential for advancing global climate diplomacy and negotiating international agreements such as the Paris Agreement. Through diplomatic negotiations, countries commit to collective action, emission reduction targets, and climate finance commitments, demonstrating a shared commitment to addressing climate change and promoting low-carbon development pathways.

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

Current reliance on fossil fuels for energy production is exacerbating climate change, making it imperative to make a rapid transition to renewable and clean energy sources. Renewables, including solar, wind, hydroelectric, nuclear, and emerging technologies like green hydrogen, offer sustainable alternatives. Green technology advances in solar power, wind energy, hydroelectricity, nuclear power, energy storage, bioenergy, geothermal heat, and smart grids are reshaping the energy landscape, making clean energy more efficient, cost-effective, and scalable. Clean energy investment increased nearly 50% between 2019-2023, reaching USD 1.8 trillion in 2023. The transition to renewable energy is projected to boost global GDP and employment. India has a target to achieve 50 percent cumulative electric power installed by 2030 from renewables and achieve net-zero carbon emissions by 2070. Clean energy will be key to limiting global warming to 1.5 degrees Celsius or as close to that as possible compared with the preindustrial era.



*** Dr. Harender Raj Gautam**

Energy is vital for development and according to 'Electricity, 2024 Report' from the International Energy Agency (IEA), electricity demand worldwide is expected to accelerate during the next three years. The report found that the global growth of demand for electricity is expected to speed up to a 3.4% average from this year through 2026 and approximately 85% of the global increase in demand for electricity is predicted to come from India, China and South-East

Asian countries. Renewable and clean energy sources with low-emissions made up only 40% of the planet's electricity generation in 2023. Thus, energy is at the heart of the climate challenge because a large chunk of the greenhouse gases is generated through the process of energy production by burning fossil fuels to generate electricity and heat. Energy is the dominant contributor to climate change, accounting for around 60 percent of total global greenhouse gas emissions. Thus, to avoid the worst impacts of climate change, emissions need to

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be reduced by almost half by 2030 and reach net-zero by 2050. To achieve this, we need to end our reliance on fossil fuels and invest in green technologies to develop alternative sources of energy that are clean, accessible, affordable, sustainable, and reliable.

Present Renewable Energy Scenario

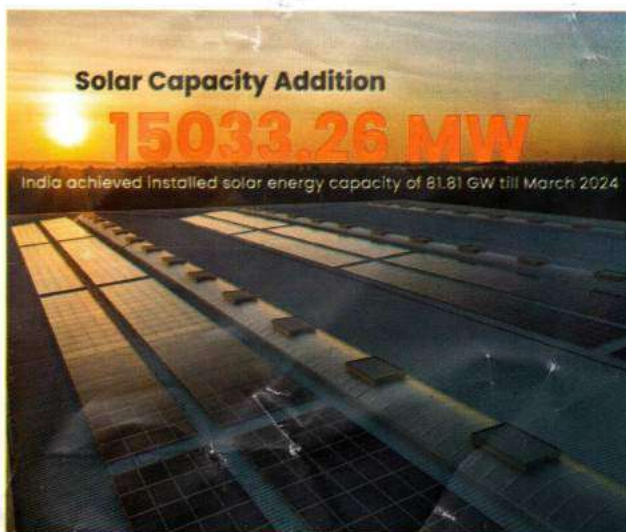
We need to rely on renewable energy sources which are available in abundance all around us provided by the sun, wind, water, waste, and heat from the Earth. Cleaner sources of energy are gaining ground and about 29 percent of electricity currently comes from renewable sources. As per the statistics released by the International Renewable Energy Agency (IRENA), at the end of 2023, global renewable power capacity amounted to 3,870 GW. Solar accounted for the largest share of the global total, with a capacity of 1,419 GW. The deployment of solar PV, wind power, nuclear power, electric cars, and heat pumps from 2019 to 2023 avoids around 2.2 billion tonnes (Gt) of emissions annually. Without them, the increase in CO₂ emissions globally over the same period would have been more than three times larger. Renewable hydropower and wind energy accounted with total capacities of 1,268 GW and 1,017 GW, respectively. Other renewable capacities included 150 GW of bioenergy and 15 GW of geothermal, plus 0.5 GW of marine energy. In India, renewable energy sources, including large hydropower, have a combined installed capacity of 183.49 GW, and about 13.5 GW of renewable energy capacity was added during 2023. While solar energy maintained its dominance, contributing 75.57 GW, wind energy contributed 44.15 GW. India aims for 500 GW of renewable energy installed capacity and five million tonnes of green hydrogen by 2030. India has set a target to reduce the carbon intensity of the nation's economy by less than 45% by the end of the decade, achieve 50 percent cumulative electric power installed by 2030 from renewables, and achieve net-zero carbon emissions by 2070. India aims to produce five million tonnes of green hydrogen by 2030.

Green Technologies for Clean Energy

Emerging green technologies for clean energy are playing a crucial role in shaping the future of renewable energy projects, making them more efficient, cost-effective, and scalable. According to the IEA, from 2019 to 2023, clean energy investment increased nearly 50%, reaching USD 1.8 trillion in 2023 and growing at around

10% per year across this period. Important innovations of green technologies with commercial potential and different stages of scalability are as follows:

Solar Power: Solar energy is an abundant and renewable energy resource and the amount of sunlight that hits the earth in a single hour contains more energy than the world needs in a year. Sunlight can be converted directly into electricity with a device called a photovoltaic (PV) cell. Photovoltaic solar cells have been the backbone of solar power generation. However, emerging technologies are revolutionising PV technology by enhancing efficiency and reducing costs. Innovations such as multi-junction cells, tandem cells, and perovskite-silicon hybrid cells are enabling higher energy conversion efficiency and making solar power more affordable. Concentrated Solar Power (CSP) systems utilise mirrors or lenses to focus sunlight onto a receiver, generating heat that drives a turbine for electricity production. Emerging technologies in CSP, such as molten salt storage and advanced heat transfer fluids, improve the efficiency and storage capabilities of these systems, enabling continuous power generation even when the sun is not shining. Tandem solar cell technology is more efficient in converting sunlight into electricity and achieving power-conversion efficiencies of over 30%. Here, an ultrathin perovskite solar cell is stacked on top of a standard silicon solar cell. Silicon-based photovoltaics which are presently in use convert only a small range of longer wavelengths of sunlight into electricity. However, when combined, an ultrathin layer of perovskite on top of a silicon solar cell can convert more sunlight into usable electric energy than either cell alone.

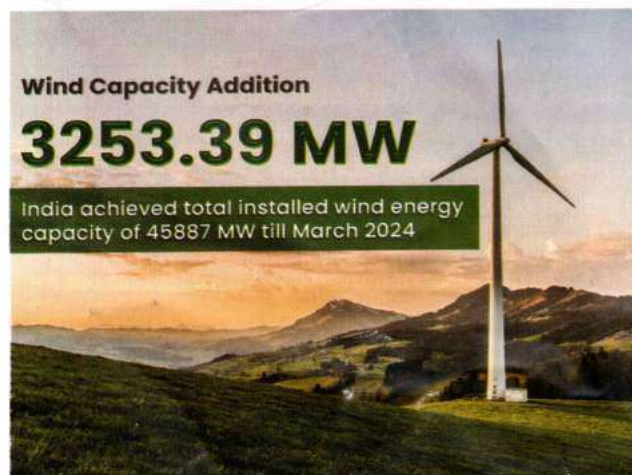


At the heart of recent solar innovations is 'Passivated Emitter and Rear Contact' (PERC) solar cells technology where PERC solar cells are modified conventional cells that enable the cells to produce 6 to 12 percent more energy than conventional solar panels. PERC solar cells have an extra layer within the back side of the cell. Adding to the array of solar innovations is Heterojunction (HJT) technology and it combines amorphous and crystalline silicon layers, resulting in panels with higher efficiency and superior temperature performance. Vehicle-integrated photovoltaics is also an emerging technology which refers to the integration of solar panels into various parts of a vehicle to generate electricity from sunlight, reducing reliance of vehicles on fossil fuels and lowering greenhouse gas emissions. Solar panels on a vehicle could charge the on-board battery, increasing the electric range of electric and hybrid vehicles and reducing fuel consumption. To widen the applicability of solar power, offshore solar power by installing solar panels on bodies of water (oceans, lakes, reservoirs) allows to convert solar energy into electricity. This approach conserves land resources in densely populated areas, efficiently uses water bodies, and benefits from the cooling effect of water, enhancing solar panel efficiency.

Wind Power: The wind power grew at an increased rate of 13% in 2023 and total wind capacity reached 1,017 GW. The generation capacity has increased both in on-shore and off-shore wind power installation capacity. The wind power industry is witnessing a rapid influx of cost-effective and reliable innovations, including rooftop bladeless wind turbines, vertical-axis turbines, floating multi-turbine technology platforms, and more. According to IEA, technology advancements could unlock 80% more wind energy potential during

this decade. Continued turbine scaling, emphasising low material use and more efficient manufacturing processes, remains a key option, with cost reductions estimated at 11-20% by 2030. The development of taller wind turbines with longer blades has dramatically increased their capacity to capture energy, even in areas with less wind. Another area of progress is in bladeless wind energy generation, where structures use the oscillation of wind to generate power without the traditional turbine structure, reducing maintenance and potentially mitigating the impact on wildlife. Offshore wind is poised for significant growth, with floating turbine technology. These innovations not only allow for tapping into stronger wind currents but also open up new areas for development, promising higher energy outputs than ever before. WindFloat is another top wind energy trend and unlike traditional offshore wind turbines, WindFloat uses a drag-embedment anchor that supports the turbine without any construction on the seafloor. Vertical axis wind turbines (VAWTs) offer a compelling alternative to traditional horizontal axis wind turbines. VAWTs are designed to capture wind from any direction, making them suitable for urban environments and areas with complex wind patterns. Kite wind energy systems utilise large kites tethered to the ground to capture high-altitude winds. The kites generate significant amounts of clean energy while requiring fewer resources compared to conventional wind turbines. Enabling technologies include innovative power electronics, use of permanent magnet generators, and super conductor technology. Digitalisation, through advanced sensing and controls, enables predictive maintenance and is already reducing operation and maintenance costs. Artificial Intelligence (AI)-Enhanced Turbines, with the use of artificial intelligence, is revolutionising how wind turbines operate. By analysing data in real-time, AI enables turbines to adjust to wind conditions dynamically, improving efficiency and reducing wear and tear. This leap in technology means wind farms can expect lower maintenance costs and higher energy production.

Hydroelectric Energy: Hydropower 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.





Kameng Dam and Hydro Power Station, Arunachal Pradesh

Hydroelectricity generation increased by almost 70 TWh (up close to 2%) in 2022, reaching 4,308 TWh. Hydroelectric power is experiencing a renaissance with advanced turbine designs that are fish-friendly and capable of operating efficiently at low water velocities. This greatly reduces environmental impact and extends hydroelectricity's viability to previously unsuitable locations. Additionally, kinetic hydro turbines, which harvest energy from flowing water without the need for large dams or reservoirs, are showing promise for small-scale power generation in rivers and streams. Tidal power generation harnesses the predictable and constant movement of ocean tides to generate electricity. Innovations in tidal power systems include underwater turbines and barrages, which efficiently convert tidal energy into electrical power. Run-of-river hydroelectric systems utilise the natural flow of rivers to generate electricity without the need for large-scale dams. These systems have lower environmental impacts and allow for more flexible installation and operation. Underwater turbines harness the kinetic energy of ocean currents to generate renewable electricity. These innovative turbines

can be installed in various locations, including coastal areas and ocean currents, providing a consistent and reliable source of clean power.

Nuclear Power: Nuclear power 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

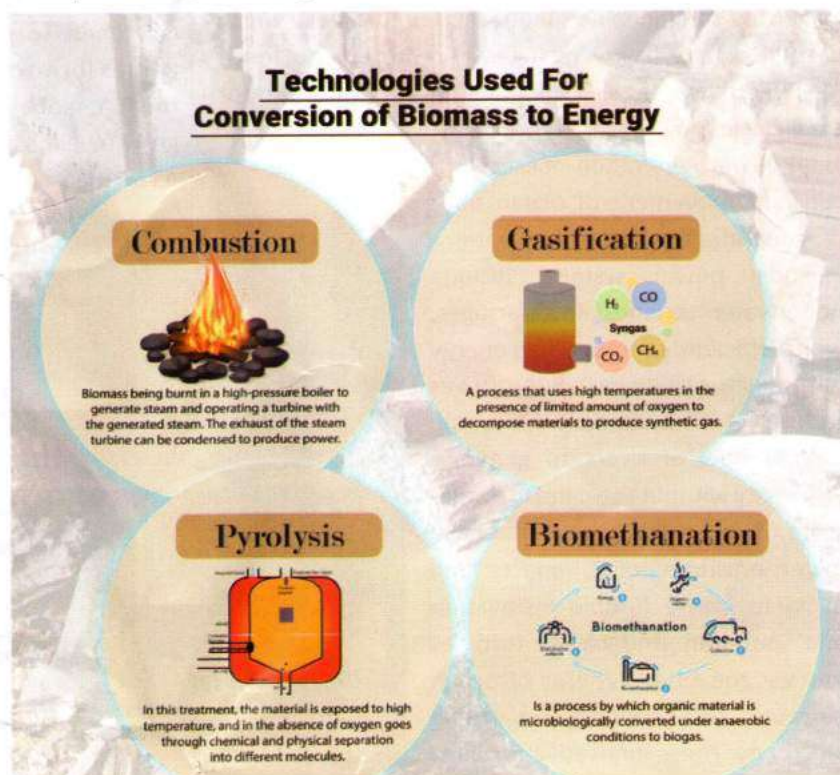


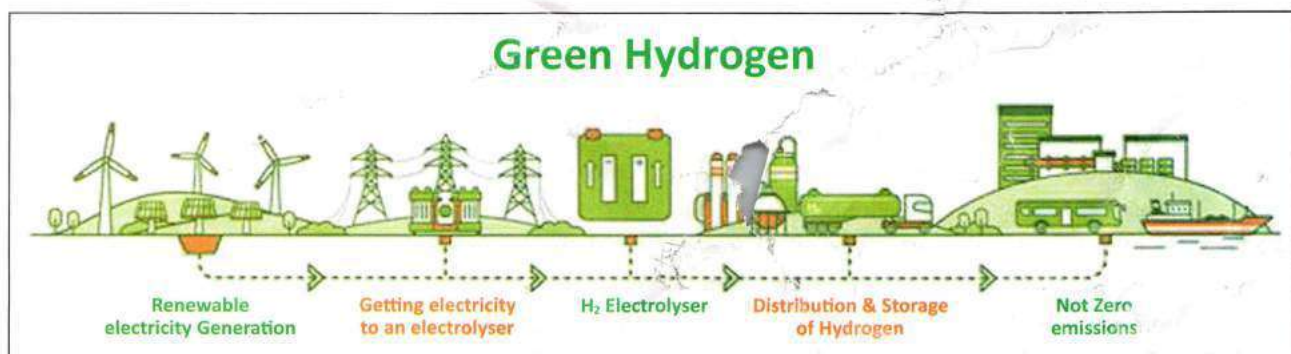
Rajasthan Atomic Power Station

in operation totalling more than 3,68,000 MW(e) in installed capacity in 31 countries. Small modular reactors (SMRs) are advanced nuclear reactors that typically generate up to 300 MW(e). SMRs technology is set to broaden global access to nuclear energy because they are more suitable for small electricity grids and more easily integrated with renewable energy sources. There are more than 80 SMR designs in various stages of development in 18 countries, with SMR units already deployed in China and the Russian Federation and one design under construction in Argentina. While traditional reactors and some advanced technology use water as a heat transfer medium, some new technologies are using other substances like molten salt or liquid metals. This allows reactors to run safely at high temperatures and lower pressures while providing lower construction and design costs because the materials do not require components that can withstand extremely high pressure like water reactors. Micro-reactors are named because of their size. They are one percent or less of the size of traditional reactors operating today. Micro-reactors produce approximately 1 to 10 megawatts and are mobile, which means they can be moved from location to location depending on where they are needed. This technology will be crucial in remote areas that currently rely on fossil fuels, for example. Micro-reactors are the answer to providing these areas with clean, carbon-free energy as they can easily be transported to where they need to be, operated for weeks or months, then moved to their next location.

Energy Storage-Advanced Technologies in Batteries: Batteries are an effective energy storage technology, particularly for the incorporation of renewable resources, due to their compact size and wide availability. However, present battery technologies have a long way to go before meeting the cost criteria for stability, extraordinary power operation, high energy efficiency, and large-scale energy storage. The stationary electric energy storage market has recently seen the introduction of Lithium Ion Batteries (LIBs) for use in mobile devices and electronic vehicles. The current annual

demand for lithium-ion batteries (LIB) is around 1 TWh. Sodium-ion batteries (SIBs) are currently evolving as a viable substitute for lithium-ion batteries (LIBs) because of the abundant availability and reasonable cost of sodium. Furthermore, sodium-ion batteries can use aluminum for the anode current collector instead of copper, which is used in lithium-ion cells. Furthermore, they can be safer than lithium-ion batteries as they can be stored at zero volts in comparison to around 30% state of charge in LIBs, causing less risk during transportation. Conversely, Na-ion batteries do not have the same energy density as their Li-ion counterpart (respectively 75 to 160 Wh/kg compared to 120 to 260 Wh/kg). Aqueous zinc ion batteries have also emerged as promising alternatives to lithium-ion battery technology for energy storage systems due to their inherent safety, environmental friendliness, and cost-effectiveness. These use a water-based electrolyte and offer several advantages that make them attractive for various applications. They are safer compared to other chemistries and are cost-effective because zinc is abundant and relatively low-cost. Potassium-ion batteries use potassium as the anode material and are interesting for energy storage applications due to potential for high energy density, abundant and comparatively low-cost of potassium, high charge and discharge rates for rapid energy transfer and high-power





performance, low self-discharge rate, and increased safety compared to other types of batteries. Another alternative, solid-state batteries use a solid electrolyte instead of the liquid electrolyte in traditional Li-ion batteries. This makes them safer, as they are less prone to overheating or catching fire. Solid-state batteries can also offer higher energy density and faster charging rates. Unlike conventional electrochemical batteries where energy is stored in electrodes, in redox flow batteries (RFBs) energy is stored in the electrolytes. In the RFBs, the charge/discharge processes are based on reversible electrochemical reactions of two redox couples that are dissolved in electrolytes.

Bio-Energy: Bioenergy 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. MFCs are bio-electrochemical devices that can directly convert chemical energy in biodegradable organic matter to electrical energy by exo-electrogenic bacteria as catalyst. *Geobacter* and *Shewanella* species have predominantly been utilised in MFC technology. Another related and refined process is Plant-Microbial Fuel Cells (PMFC) technology which is more holistic in using bio-resources. PMFC technologies are based on the principle of rhizodeposition, which is the excretion of organic compounds from the roots that is the source of electrons and electricity generation by electrochemically active bacteria in a microbial fuel cell.

Geothermal heat: Geothermal energy 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. Typically, these fluids occur in reservoirs at depths of up to 3,000 metres and can be recovered by drilling wells. Surface facilities convert geothermal heat into useful form of energy like electricity. The heat inside the Earth's core is continually generated by the decay of the long-lived radioactive isotopes of uranium, thorium, and potassium, which are present in the Earth. Added to this heat, there are other potential sources of heat such as the primordial energy of planetary accretion. About 14,000 megawatts (MW) of geothermal electricity are produced around the world till 2023. Conventional geothermal power plants are typically located near geysers and steam vents, which indicate the presence of hydrothermal resources belowground. Next-generation technology in geothermal heat includes 'superhot rock energy', where deep drilling reaches temperatures 400°C or hotter, is thought to be abundant enough to theoretically fulfill the world's power requirements. In fact, just 1% of the world's superhot rock potential could provide 63 terawatts of clean firm power, which would meet global electricity demand nearly eight times over. Medium/low-temperature hydrothermal resources refers to geothermal energy resources at moderate depths, typically reservoirs at 1,500 to 3,000 metres below surface, and characterised by moderate to high temperatures (150°C to 300°C). Energy is harnessed through drilling of deep wells and injection of fluids to capture heat.

Green Hydrogen: Green hydrogen is produced by splitting water into hydrogen and oxygen using electrolysis. The electricity used to power the electrolysis process comes from renewable energy sources, which makes green hydrogen a clean and sustainable fuel. Green hydrogen can be used to power fuel cells, which are devices that convert the chemical energy of

hydrogen into electricity. Adoption of green hydrogen as an alternative source of energy can enable India to abate 3.6 gigatonnes of CO₂ emissions cumulatively till 2050 and reduce industrial coal imports by 95 per cent. Approval of the National Green Hydrogen Mission is a step ahead to make India a global hub for the production, utilisation, and export of Green Hydrogen and its derivatives. Hydrogen storage technologies, such as hydrogen fuel cells and hydrogen electrolysis, are emerging as promising solutions for long-duration energy storage and transportation. These technologies enable the conversion of excess renewable energy into hydrogen, which can be stored and used to generate electricity or power fuel cell vehicles. Ongoing research aims to enhance the efficiency and cost-effectiveness of hydrogen storage systems.

Other Promising Options of Renewable Energy Sources: Triboelectric nanogenerator in ocean energy devices is one such option which convert mechanical energy into electrical energy through the triboelectric effect. In the context of ocean energy, they are used to harness the mechanical energy generated by ocean waves, currents, and motion for various applications. Low-temperature direct ammonia fuel cells is also a promising technology that efficiently converts ammonia into electricity at low temperatures (below 100°C). It offers advantages such as high energy density, clean and carbon-free energy production, reduced heat management complexity. Ammonia is an abundant fuel source and a clean-burning fuel that does not produce carbon dioxide during combustion. Direct seawater electrolysis is also a promising process that uses electricity to split seawater into hydrogen and oxygen. It has recently gained interest as a method for producing H₂, and it offers several advantages: abundant raw material, lower environmental impact by using renewable energy, high purity of the H₂ produced, simultaneous production of O₂, solution for storage of energy, integration with renewable energy sources and grid systems, applications in marine environments, and potential for carbon capture.

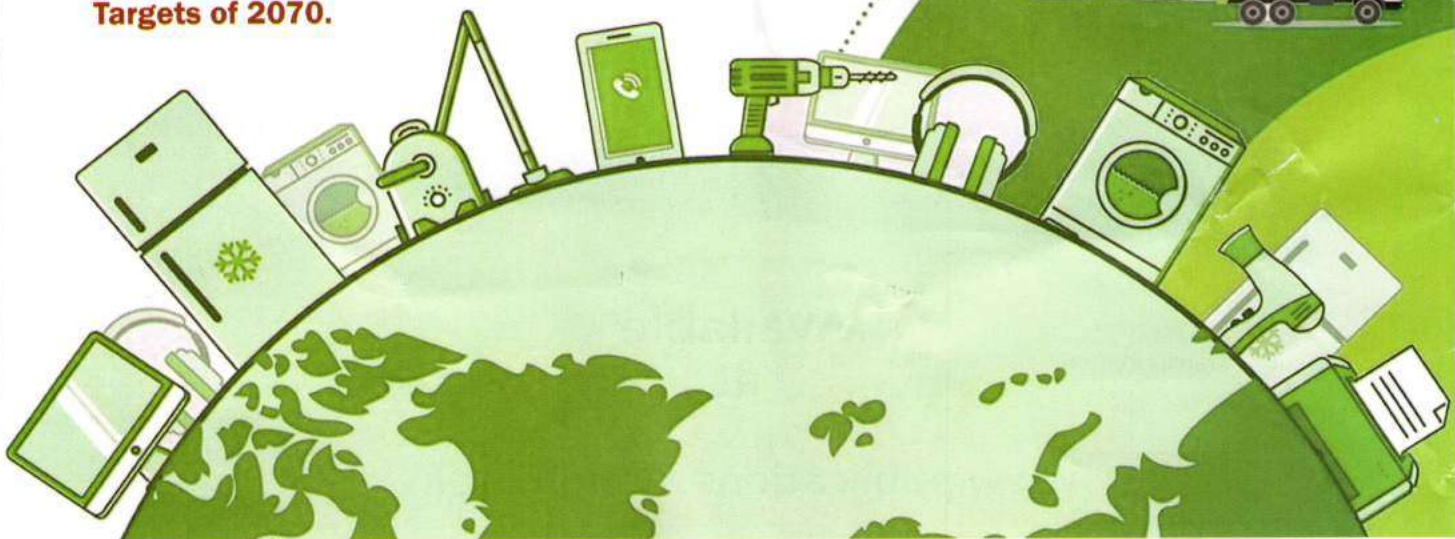
Smart Grids: A smart grid is an electricity network that co-ordinate the needs and capabilities of all generators, grid operators, end users, and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience, flexibility, and stability. The

transition to green energy requires an intelligent grid system capable of managing the complexities associated with renewables. Advanced technologies have also been developed for managing renewable energy. Integration of renewable energy into the grid is being streamlined by the Internet of Things (IoT) and smart grid technologies. These systems utilise sensors and analytics to predict energy supply and demand, balance loads, and even automatically adjust to optimise energy flow and storage. Sophisticated AI-infused analytic software can help grid operators turn information into actionable intelligence too. At the same time, machine learning could help in managing asset maintenance programmes, upkeep of records, forecasts, and weather tracking. A smart grid can leverage the benefits of digital twin technology, one of the most promising applications of the early industrial metaverse that creates virtual replicas of physical objects. Currently, grids in distant locations use fiber-supporting Supervisory Control and Data Acquisitions (SCADA) connectivity for remote monitoring and control. Digital twins will allow operators to clone the entire environment of a power grid, gain valuable operational insights in real-time and not just experience the physical world in a virtual space, but to control it. The shift to renewables is triggering a new trend, the proliferation of microgrids in the energy sector. Microgrids operate independently from the traditional grid. They offer immense efficiency and flexibility, especially when it comes to distributed energy resources like solar. Since microgrids can operate during outages, it reinforces grid resilience and help mitigate disturbances.

The IEA's Electricity 2024 report forecasts that renewable energy is set to overtake the world's use of coal by early 2025 and will account for more than one-third of the world's total electricity generation. Renewables and nuclear energy, which in 2023 accounted for 40 percent of the world's power generation, but the said report projects that renewable energy sources will account for almost half of the world's power generation by 2026. The energy transformation would also boost gross domestic product (GDP) by 2.5% and total employment by 0.2% globally in 2050. IRENA is monitoring the progress towards the 11 terawatts (TW) of power required by the year 2030. The outlook is key because the United Nations has said a move to clean energy will be key to limiting global warming to 1.5 degrees Celsius or as close to that as possible compared with the preindustrial era. □

Empowering Rural Communities Embracing Green Waste Tech In India

Rural India faces significant challenges in waste management, leading to environmental degradation and socio-economic disparities. This article explores the potential of embracing green waste technologies to empower rural communities and mitigate environmental impacts. It evaluates the current state of waste management, analyses the impact of green waste technologies, identifies barriers to adoption, and proposes potential solutions and innovations. Bridging urban-rural socio-economic gaps and ensuring equitable resource distribution are imperative for a circular economy transition and achieving Net Zero Targets of 2070.



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Current State of Waste Management in Rural Regions

Overview of Green Waste Development in Rural India: Waste management in rural regions globally, especially in India, remains undeveloped, leading to detrimental environmental impacts as the waste management practices are not upto mark in comparison to the rate

at which the waste is generated. With a large portion of the population residing in rural areas, it becomes imperative to empower these communities while addressing environmental concerns for sustainable development. 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

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waste management systems, particularly in Rural India. Also, rural landscapes are increasingly threatened by urbanisation and agribusiness sectors, impacting organic farming, natural habitats, and biodiversity. Rural communities further face climate-induced hazards (floods, drought, erosion, etc.) and socio-economic challenges (migration, poverty, poor infrastructure, etc.). However, the current state of waste management in rural areas presents both challenges and opportunities.

Rural/ Smart village waste, includes Solid wastes (organic material like Agricultural Residues, Wet waste, Plastic waste, Biomedical waste, E-waste, Plastic waste and C & D waste. With the right approach and technology, it can become a valuable resource for rural communities. Implementation of green waste practices, such as energy recovery from waste and recycling, can not only mitigate environmental impact but can also generate economic value for rural communities. A study by Shadbahr et al. (2022) highlights the potential of waste-to-energy pathways in rural regions, indicating a possible 36% cost saving but with higher greenhouse gas emissions compared to fossil-based heating, underscoring the need for technological advancements.

Bridging urban-rural socio-economic gaps and ensuring equitable resource distribution are imperative for a circular economy transition and achieving Net Zero Targets of 2070. To address these challenges, localised waste management plans are essential, detailing collection, transportation, and treatment strategies. This underscores the urgent need to enhance waste management services for rural communities globally.



Analysis of the Impact of Green Waste Technologies on Rural Communities: India's rural areas are at the forefront of environmental challenges, grappling with both the consequences of fossil fuel use and inadequate waste management systems. Despite the abundance of organic waste in livestock-rich villages, the potential of technologies to convert this waste into renewable energy and fertilisers remains largely untapped.

Utilising such technologies not only addresses resource depletion but also offers economically viable and eco-friendly energy solutions. For instance, renewable energy technologies like Micro-Hydro Power (MHP) have shown promise in driving rural development and poverty alleviation efforts. According to research conducted by Kalyani & Pandey (2014), the choice of waste conversion processes depends on several factors including the type, quantity, and properties of the feedstock, energy requirements, economic considerations, environmental standards, and project-specific factors. Common conversion processes include thermal conversions (such as incineration, pyrolysis, gasification, and refuse-derived fuel), bio-chemical conversions (like composting, vermicomposting, and anaerobic digestion), and chemical conversions (such as trans-esterification for converting plant and vegetable oils into biodiesel). Each process offers distinct advantages based on the characteristics of the waste and the desired outcomes. Gasification stands out as a widely used method for converting coal and biomass into energy, with successful implementations observed in countries such as Japan, the USA, and various European nations. Notably, gasification produces less waste and fewer greenhouse gas emissions compared to traditional methods.

Waste-to-Energy solutions hold immense potential in sustainable waste management practices while simultaneously reducing reliance on fossil fuels, as highlighted by Shadbahr et al. (2022). Moreover, Kannangara et al. (2018) have developed a machine learning tool capable of predicting the composition and volume of different Municipal Solid Waste (MSW) streams based on population centres. In conclusion, the adoption of green waste technologies holds immense promise for sustainable rural development. By harnessing these technologies effectively, rural communities can pave the way towards a greener, more prosperous future.

Benefits of Implementing Green Waste Technologies

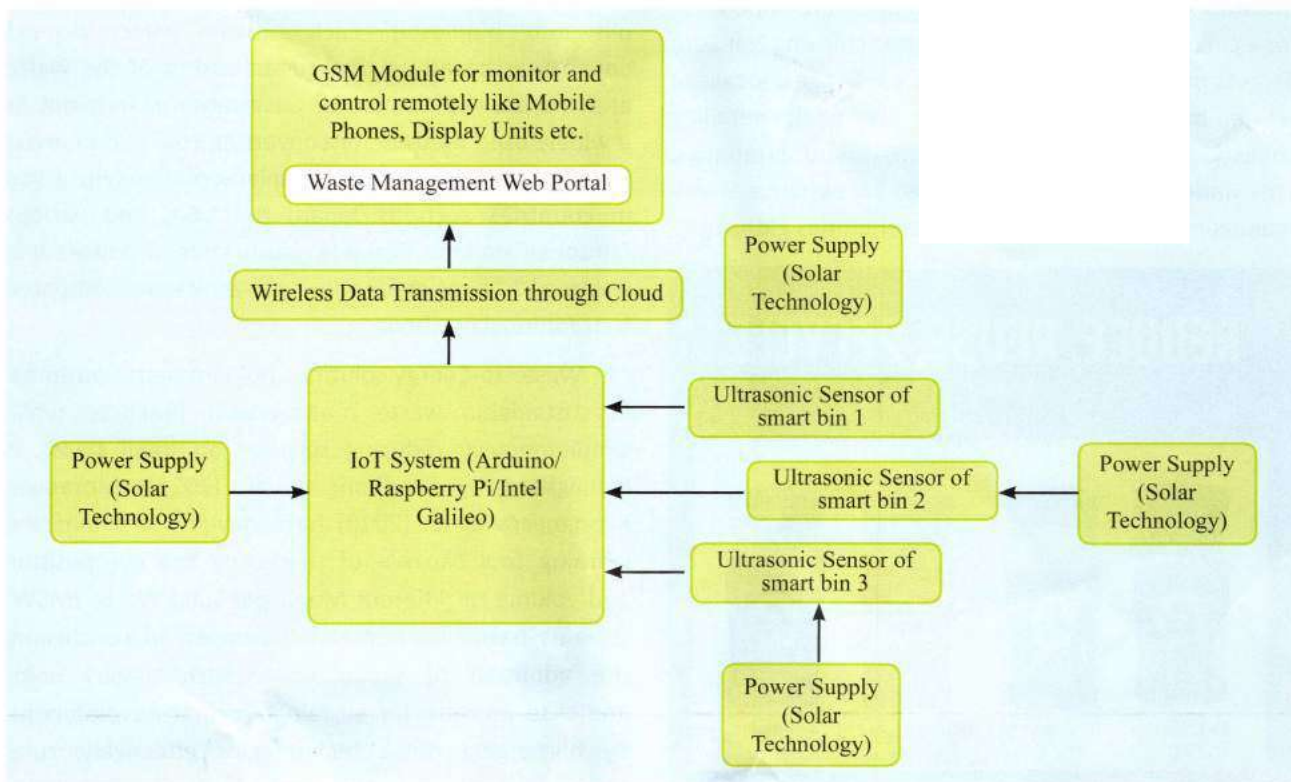
- Empowering Rural Communities:** Green waste technologies offer multifaceted benefits, including environmental conservation and socio-economic development.
- Environmental Sustainability:** Composting and biogas generation help manage organic waste sustainably while enhancing soil fertility and reducing greenhouse gas emissions.
- Economic Opportunities:** Green waste technologies create income streams through the sale of compost and biogas, fostering rural entrepreneurship.
- Climate Resilience:** Proper waste management reduces greenhouse gas emissions, mitigating climate change impacts.
- 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 areas, open burning of agricultural residues, e-waste, and plastics release harmful pollutants, exacerbating air pollution

and climate change. Inefficient waste management systems also deprive rural populations of potential resources and economic opportunities. Further, rural villages face unique challenges due to limited infrastructure, resources, and awareness about proper disposal practices. In many rural communities, it is often burned or disposed of in landfills, leading to harmful consequences for both the environment and public health.

Potential Solutions and Innovations

Smart Waste Management System (SWM) : SWM Systems employing IoT, are revolutionising waste processing, enhancing efficiency, and promoting sustainability. With ultrasonic sensor-equipped smart bins scattered across rural localities, these systems collect real-time data, communicated to a central control centre via cloud platforms. Solar-powered sensors ensure continuous operation, while optimised route scheduling minimises fuel costs. When waste levels exceed 80%, GPS-guided trucks efficiently collect waste, saving time and resources. This integration empowers rural India with greener, smarter waste management solutions. Figure 1 is a basic block diagram of an IoT-based Smart waste management system.



Source: (Patnaik et al., 2020)

Block diagram of IoT-based smart waste management system

Best Practices for Successful Implementation of Green Technologies in Rural Regions : Successful implementation of green waste technologies in rural regions requires the adoption of best practices and community-driven initiatives. Projects like the National Biogas and Manure Management Program (NBMMP) and the Swachh Bharat Mission have facilitated the establishment of biogas plants and decentralised waste management systems, yielding positive socio-economic and environmental outcomes. Community-driven initiatives, such as self-help groups promoting composting and organic farming, demonstrate the transformative potential of empowering rural communities through green waste technology.

Case Studies

- 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.
- In Gujarat**, Punsari village exemplifies sustainable development by generating electricity from village waste, showcasing the potential of waste-to-energy initiatives.
- 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 : In rural India, where formal waste management systems often fall short, waste pickers emerge as unsung heroes, diverting recyclable materials from landfills and

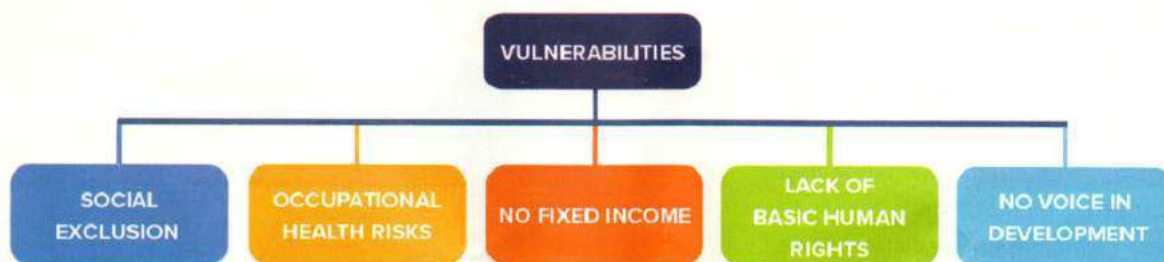
contributing to environmental conservation. Estimates suggest approximately 4 million waste pickers in India earn their livelihoods from waste management (NITI Aayog, 2021). Waste pickers, who play a crucial role in recycling and waste management, often encounter humiliation, discrimination, and socio-economic marginalisation. Despite their valuable contributions, they operate in hazardous conditions, facing various health risks. By recognising their contributions and integrating them into local economies and communities, rural villages can not only address waste management issues but also promote social equity and environmental sustainability. Figure 2 below details the vulnerabilities faced by waste pickers.

To address these challenges, a comprehensive framework for the social protection of waste pickers is imperative (Figure 3). This framework should encompass recognising their contributions, granting access to basic services, ensuring occupational health and safety, stabilising incomes, promoting social inclusion and empowerment, and fostering collaboration. It is imperative that policymakers, practitioners, and advocates work together to implement and uphold this framework, transforming the lives of waste pickers and advancing the goals of sustainable development.

Benefits of Including Social Protection for Rural Waste Pickers-

- Resilience to future risk
- Better mitigation capacities for vulnerabilities
- Promotion of Circular economy
- Legitimacy and recognition
- Encouragement for entrepreneurship

Digital Monitoring of Waste Management : Digital monitoring of waste management is transforming rural Indian villages. Traditional methods struggle to



Source: (NITI Aayog, 2021)

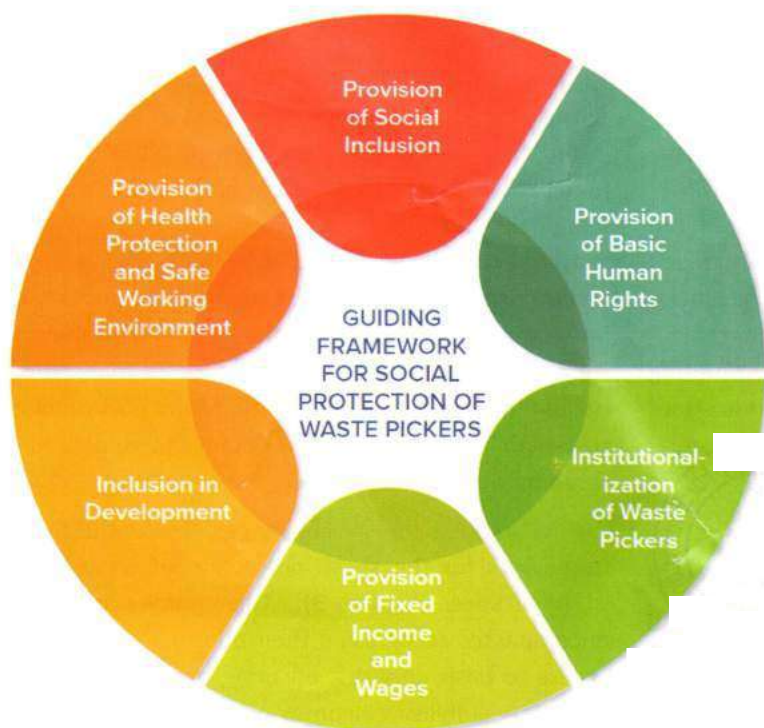
Vulnerabilities of Waste Pickers in Rural India

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 community composting initiatives using smart composting systems. These systems utilise sensors to monitor temperature, moisture levels, and aeration, optimising the composting process and producing high-quality compost for use in agriculture or landscaping.

b. Smart Waste Modelling: Use data analytics platforms to 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 and improve recycling rates.



Source: (NITI Aayog, 2021)

Framework for Social Protection of Waste Pickers in Rural India

meet growing waste disposal needs, but technology offers innovative solutions. Digital monitoring systems (Figure 4), utilising IoT, mobile apps, and data analytics, streamline waste collection and disposal. These systems integrate stakeholders—waste pickers, recyclers, ULBs, and citizens—via mobile apps, creating a digital cloud. Real-time data tracks the waste supply chain from collection to recycling. Real-time data from the field can be integrated into a centralised cloud platform, facilitating seamless tracking of the waste supply chain from collection points to recyclers. Embracing such digital solutions promises to enhance efficiency, transparency, and sustainability in rural waste management. *The Eco Green Village Mobile Application for Waste Management*, pioneered in Indonesia, targets rural areas to improve cleanliness, predict climate impacts, and advance Smart Kampung initiatives through technology (Utama & Pratama, 2021).



Source: (NITI Aayog, 2021)

Digital monitoring of Waste Management in Rural Village in India

- 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:** Introducing AI robotics into recycling centres enhances waste sorting efficiency, diverting recyclable materials from landfills. With AI robots capable of accurately differentiating between materials, recycling centres can operate longer hours, processing larger volumes of waste. Studies show that incorporating robotics in recycling processes can increase recycling rates by up to 50%.
- e. **Pneumatic Waste Pipes:** Installing pneumatic waste pipes below public containers streamlines waste transportation to processing centres, reducing the need for traditional trash pickups. This innovative system minimises vehicle emissions and prevents container overflow, contributing to cleaner and more efficient waste management practices.
- f. **Solar-Powered Trash Compactors:** Solar-powered compactors increase trash bin capacity by up to five times, reducing the frequency of pickups and optimising waste collection processes. Equipped with waste level sensors, these smart containers enable efficient scheduling of pickups, further 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.
- d. Promote Cohesion policies between Urban and Peri-Urban areas.
- e. Concept of Sustainable 'Green' Rural Municipalities should be promoted.

Conclusion

Supportive policy frameworks are essential, incentivising green waste technology adoption and creating a conducive environment for sustainable waste management. Financial incentives, subsidies, and technical assistance are crucial for small rural entrepreneurs and rural enterprises. Realising these benefits requires concerted efforts from policymakers, development agencies, and local stakeholders. Public-private partnerships can facilitate technology transfer, fostering innovation and entrepreneurship in rural areas. By promoting adoption and scaling up green waste technologies, India can pave the way towards a greener and more inclusive future for its rural population. □

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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.



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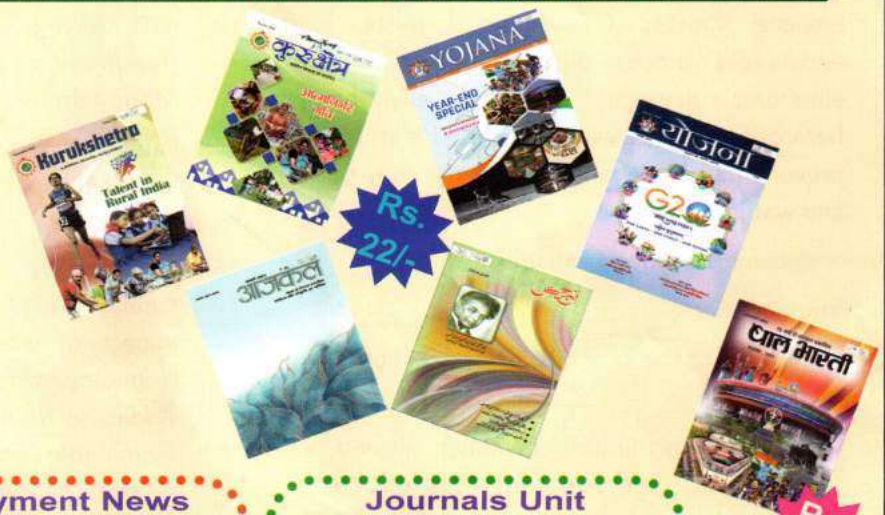
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Biodiversity Conservation using Remote Sensing and GIS Tools

Growing human-led exploitation of natural resources and climatic changes has put biodiversity of India (which is one of the twelve mega biodiverse countries in the world) under severe threat. Globally also, it comes under increasing pressure on account of factors such as habitat fragmentation/habitat loss, over-exploitation, pollution, invasive species, and global warming. In such a scenario, the potential of geospatial tools needs to be utilised in terms of forest cover maps, land use, land cover maps, and vegetation maps especially in places of inaccessible, rugged terrain for further macro and micro level planning.

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Biodiversity is variability among organisms from all sources including terrestrial, marine and other ecosystems at three levels - species, genetics, and ecosystem. It deals with the degree of nature's variety in the biosphere. Variety of ecosystems which occur in deserts, forests, wetlands, mountains, lakes, rivers, and agricultural

landscapes encompass overall biodiversity on earth. Consumptive use value of biodiversity covers the direct utilisation of timber, food, fuelwood, and fodder by local communities. Globally also, biodiversity has come under increasing pressure on account of factors such as habitat fragmentation/habitat loss, over-exploitation, pollution, invasive species, and global warming.

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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 is a legally binding instrument to address biological diversity with three objectives, viz. conservation of biodiversity, sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources. The Convention has near universal membership with 196 countries (including India) as Parties.

Talking about the information on the global extinction risk status of species, International Union for Conservation of Nature (IUCN) prepares the Red

List of Threatened Species which is a critical indicator of the health of the world's biodiversity. Species are classified into one of nine Red List Categories: Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, Data Deficient, and Not Evaluated. Vulnerable, Endangered, and Critically Endangered species are considered to be threatened with extinction. Conservation of biodiversity is crucial because it provides several goods and services





necessary for human survival. The need of hour is to use appropriate technologies to formulate effective and sustainable management of the natural resources. In this regard, remote sensing and Geographic Information System (GIS) play an important role in the field of conservation. GIS is a system that creates, manages, analyses, and maps all types of data. It connects data to a map, integrating location data with all types of descriptive information (www.esri.com). It facilitates storing, manipulating, and retrieving spatially referenced data. It is widely recognised that Remote Sensing and GIS are powerful tools in the assessment of biodiversity and conservation. Remote Sensing provides information on biodiversity at landscape, regional, continental, and global spatial levels (Nagendra, 2001). The derived information from mapping specific land-cover classes can aid both biodiversity assessment and conservation.

Nowadays, new imaging technologies are there to gather digital spatial information at very fine resolution. There will be change in dynamics of land-use/land-cover pattern which is the result of anthropogenic interaction with the natural environment. Information on the rate and kind of change in the use of land resources is essential for proper planning, management, and regularising the use of resources. Satellite data in association with GIS provides cost-effective tools for mapping and formulation of conservation and management plans. Geospatial tools have given a new dimension to the management of protected area. Effective management of protected area and conservation of biodiversity in general demands inventory, evaluation, planning, and management at scales ranging from local and regional to national, continental, and global (Nix et al., 2000). Previously, protected area managers combined

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.

(Source: Baseline Mapping for Namdapha National Park in Arunachal Pradesh, India using Geospatial Tools available at <http://www.igrsm.org/mjrgis/issues.html>).



topographical and land ownership maps with their knowledge of local climate, species distributions, topography, environment law, and land use to define management zones and strategies. Today, all this data can be analysed in digital databases to provide more efficient, accurate, and informed decision-making. Protected area mapping is an important aspect of protected area management. It serves as baseline for ecological modelling and future monitoring and assessment. These technologies provide vital geo-information support in terms of relevant, reliable, and timely information needed for conservation planning.

Land use/land cover mapping of inaccessible rugged terrain is helpful for further macro and micro-level planning. One can understand the underlying ecological dynamics impact of human pressure on changing vegetation patterns and thereby providing better land management options for maintaining its unique richness of biodiversity. These technologies can help in preparation of Habitat Suitability Map for species, for example in case of tigers, Habitat Suitability Mapping can guide the management plans for fragmented patches of critical tiger habitat. GIS is a powerful tool which not only analyses the present environmental scenario but also helps in projecting the future, in other words, one can effectively use it for past, present, and future studies on environment. The ecological aspects of most of the species have been studied in their natural ranges, but our knowledge is still lacking for new distribution ranges of the species. We have to strengthen our knowledge on climate change at local and regional level and its effect on biodiversity.

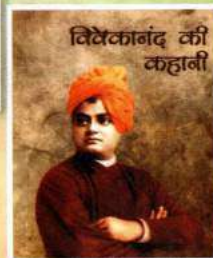
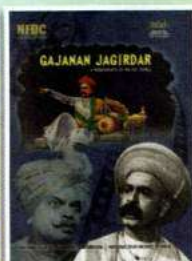
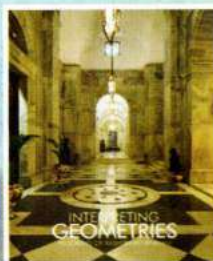
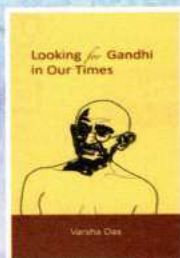
Uttarakhand Action Plan on Climate Change reveals that the abrupt changes in climatic conditions

in mountainous areas are affecting the regeneration of various plant species and there may be upward movement of the habitats of many species from their current locations. Similarly, the State of Environment Report highlights the upward shifting of tree-line and decreasing trend of the quantum of rainfall. Any minor or drastic change in the local climate of an area may affect the species' distribution and thus the structure of the entire ecosystem. Long-term studies using geospatial tools are needed to record the consequences of climate change on species and natural habitats. Unusual sighting records of various species in middle and higher Himalayas have opened the scope to revisit our existing knowledge on the distribution of species and to start working towards a landscape-level conservation model. 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. □

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Usage of Green Technologies in Sustainable Water Management

Water is an essential but scarce resource and therefore consuming and managing every drop of water is vital. Since this management involves decisions related to billions of lives and vast quantities of invigorating resources, the usage of green technology can be a correct path towards redemption. Green Technologies in the water sector can create an environment-friendly yet cost-efficient option for Indian Cities like Bengaluru which are running out of water.

*** Dr. Namrata Singh Panwar**

Sustainable water management just not a luxury but a necessity for our present and future generations. Achieving this sustainable water management requires a prolonged strategy in four main aspects which are environment, economic, social, and energy and resources. All these aspects are interdependent and should be viewed in an integrated manner. The sustainable water management approach views the whole water system as an integrated system. This whole system includes drinking water, wastewater, rainwater, and stormwater drainage in a collective form which should be managed together to be truly efficient and sustainable.

The importance of sustainable water management particularly in India arises from the fact that not enough attention is paid to the mismanagement of water resources in our daily life. A normal resident of the country is still under the impression that water is and

will always be freely available in nature and can be used without any restrictions. But the reality is far away from this impression. Due to the increasing population in the country, per capita annual availability of water which was 1816 cubic metre (cu m) in 2001, was reduced to 1544 cu m in 2011 which will reduce to 1140 cu m in the year 2050. Any situation of availability of less than 1000 cu m per capita is considered by international agencies as scarcity conditions. Besides, by 2030, the country's water demand is projected to be twice the available supply, implying severe water scarcity for hundreds of millions of people and about 6% loss in the country's GDP (NITI Aayog). This indicates that if indiscriminate exploitation and poor management continue the way it is happening, India may become one of the top 6 Water Scarce Countries very soon.

From the above facts, it can be asserted that issues like limited potential for augmenting the supply of water, falling water table, water quality, climate

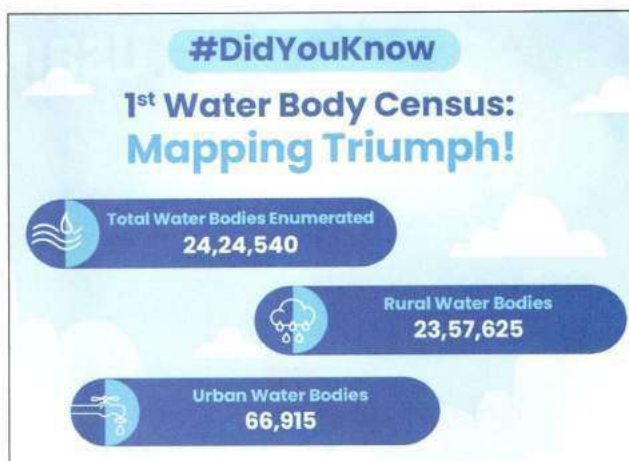
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Technology for Filtration at River Bank, Uttarakhand

change have posed new challenges and it requires innovative measures to cater to the needs of present utilisation and prospective requirements. Thus, green technology can act as the potential medicine to all our woes. Green technologies create products and facilities that are economically and environmentally efficient and limit the adverse effects of the surroundings on nature, the environment, and society. While the application of green technology could greatly harness economic opportunities by promoting productivity, prosperity, and living standards, the strategies and innovations can also balance the other environmental, social, and technical aspects, that would underpin sustainable water management into the future (ATSE 2012).

However, green technologies cannot be used indiscriminately. Every source of water has different characteristics and must undergo separate treatments and green technologies for different uses of water. For example, rainwater is much more uncontaminated than any water that has gone through human use. Thus, it is crucial to be aware of all kinds of water sources and their characteristics for fit-for-purpose treatment and applications. In the next section of the article, we will discuss the various green technologies to treat water pollution originating from various sources.



Green Technologies in Water Sector

Rainwater generally has high water quality. Although it has some particulate matter, the level of total dissolved solids (TDS) in the rainwater depends on the surface from which the rainwater is collected. According to experts, the TDS varies typically between 2 to 20 mg/litre. Stormwater mainly contains substances carried in its path of flow including dust and soil, trash, metals, oils, fertilisers, and other nutrients, chemicals and pesticides, and micro-organisms, and thus, requires diverse management. In the common course, the stormwater has to undergo three levels of treatment.

Several studies and water experts have retrofitted conventional biofilters to filter storm water by introducing a submerged (partly anoxic) zone with an embedded carbon source. With this advanced technique, denitrification and removal of copper from stormwater have improved significantly, and water quality recommended for secondary uses is achieved concerning the removal of E.Coli.

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.

S.No.	Stages	Treatment
1.	Primary Stage	Physical screening or rapid sedimentation techniques to settle down the gross pollutants and coarse sediments.
2.	Secondary Stage	Applications of finer particle sedimentation and filtration techniques to remove fine particles and attached pollutants.
3.	Tertiary Stage	This stage applies techniques to remove nutrients, heavy metal presence, pathogen removal, etc.

S.No.	Green Technology	Principles	Advantages
1.	Forward Osmosis	It uses a new eco-friendly chemical compound to draw the water molecules through a membrane leaving the salt behind. Then we separate the chemical from water through a heating process. This chemical can be reused in the process.	Use waste heat to drive separation. Low in energy use.
2.	Clathrate desalination	This technique traps water molecules in carbon dioxide and pressurises water molecules into clathrate crystals. Later, these crystals are broken down to release freshwater.	New technology has been developed which increases the size of crystals. This technique is low on energy use and can be used for any kind of water quality.
3.	Dewvapouration	This technique humidifies a stream of heated air by running a stream of saline water on a heated surface. Then collect the condensed water when the saturated air is moved along condensing heat transfer films.	Newer energy sources such as waste heat and/or solar are used in the process. The technique is highly cost-effective.
4.	Freeze Desalination	It uses the phase shift of water from liquid to solid state to remove salt from the ice crystals. These ice crystals are then melted to produce fresh water. It uses density gradients to work.	Energy and cost-effective method

The table is borrowed from the book: Green Technology for Sustainable Water Management 2016 by ASC

Bioreactors are usually equipped with separators linked to sequential tanks and a mechanical separator aimed to accelerate the split of liquid water from the biosolids. In addition, they also contain aerators for oxygen supply aimed to speed up the biochemical reactions undertaken by living microorganisms. The contact between the wastewater and bacteria/microorganisms present in the bioreactor's platform induces biochemical reactions, which in the end lead to a transformation of contaminants/pollutants to other less or non-toxic forms. In the case of metal-containing wastewater, bioreactors inoculated with sulfate-reducing bacteria produce hydrogen sulfide which precipitates the dissolved metals as insoluble metal sulfides that are recovered as valuable by-products (Barshi, 2017). These reactors are environmentally friendly and far more cost-

efficient. Some other methods to filter waste water include biofilters, bioremediation, electrowinning, etc. In the case of biofilters, microorganisms or bacteria are allowed to grow on biofilters to make a biofilm. Then wastewater is passed through biofilm which will speed up the degradation of pollutants and organic matter present in the waste water. In Bioremediation, microorganisms are applied to the wastewater sites to remove dangerous species or to convert toxins into less or non-toxic materials. This is a cost-effective method as it does not require excavation, incineration, and other cleaning strategies. Electrowinning is the process in which current is passed through wastewater with the help of electrodes. Metals are then electro-extracted from their oxidised forms to deposit on the cathode. Thus, heavy metals including copper, nickel, silver, gold,

cadmium, bismuth, cobalt, and others can be recovered from wastewater through electrowinning.

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-

The above-mentioned green technologies are evidence that environmentally friendly techniques can be cost-effective and pocket-friendly. But just knowing them is not enough. It is necessary to assess their practicability in the field. Therefore, next section of the article highlights the various success stories that have used green technology in the water sector as the base and transformed their surroundings.

Success Stories and Keys to Success

1. The Deep Tunnel Sewerage System (DTSS) is a massive underground superhighway for Singapore's used water management. It is a cost-efficient and sustainable solution designed to meet Singapore's long-term needs for used water collection, treatment, reclamation, and discharge. The DTSS comprises a 206 km-long network of deep tunnels that convey used water entirely via gravity to three centralised water reclamation plants. The treated used water is then reclaimed and further purified with excess effluent discharged to the sea in an environmentally responsible manner. The DTSS has adopted green technologies like energy-efficient pumps, advanced membrane bioreactors, and a cogeneration plant that converts biogas into electricity. This process has resulted in reduced energy consumption, lowered carbon emissions, and increased resource recovery from wastewater.
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. The Werribee Treatment Plant in Melbourne has successfully implemented green technologies to achieve sustainable management of wastewater management. The plant utilises advanced

tertiary treatment processes, such as membrane bioreactors and ultraviolet disinfection, to produce high-quality recycled water. Each year plant produces 40 billion litres of recycled water which is then used for irrigation of parks, golf courses, and agricultural lands. By implementing these technologies, the plant reduces the demand for freshwater resources and mitigates the impact on local water bodies.

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. □

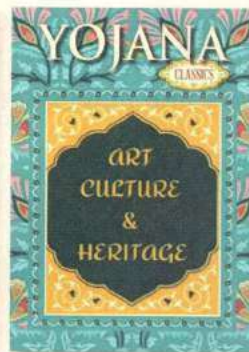
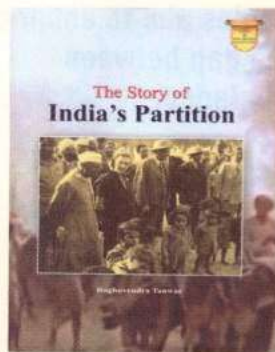
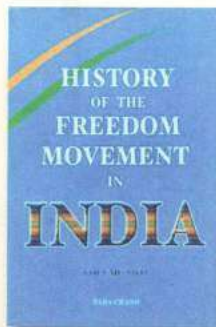
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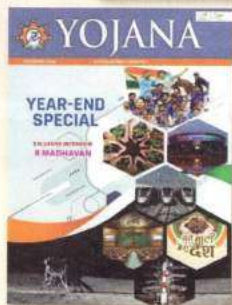


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Green Technologies for Sustainable Agriculture

Agriculture plays a vital role in providing food affordably to present and future generations. Overtime, agricultural research and development have driven the adoption of new technologies, leading to substantial increase in productivity and output. However, our current methods of measuring productivity overlook the environmental services and natural resources utilised. To ensure sustainable development, future agricultural technologies must prioritise both profitability and environmental impact, acknowledging the importance of natural resources and ecosystem services. Thus, green technologies aim to enhance production sustainably, bridging the gap between productivity and ecological balance.



* Dr. Y.S. Shivay

* Kadapa Sreenivasa Reddy

The rapid transformation of agricultural system, along with declining soil fertility and biodiversity loss, raises concerns about sustaining agricultural productivity. Agricultural development is achieved when it yields high-quality food while protecting and enhancing environmental quality. The widespread use of agrochemicals for various agricultural purposes can harm both the ecosystem and human health due to their persistent nature. To address this, we must reduce reliance on chemical-based agro-

products and seek environmental friendly alternatives. As expanding agricultural land beyond its current utilisation is constrained by the depletion of natural resources. Global urbanisation, escalating energy costs, and population growth adversely influence the environment, highlighting the urgency for technology-driven solutions to enhance energy and cost efficiency. The need is to achieve sustainable agriculture that improves yields and income without compromising environmental integrity. Sustainable agriculture is the successful management of resources to satisfy the

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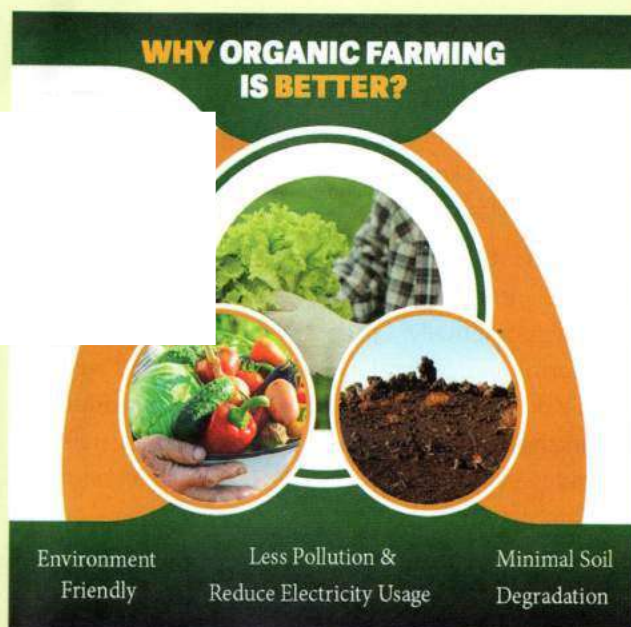
changing human needs, while maintaining or enhancing the quality of the environment, and conserving natural resources. Modern agricultural practices have taken steps towards sustainability, and integrating green technology offers a promising approach to improve agricultural methods.

Green Technology (GT) refers to environmentally beneficial technology designed to mitigate environmental damage, thereby promoting sustainable agricultural development. Green technology encompasses environmentally friendly technologies that are implemented without damaging environmental stability, also known as 'clean' technology. These technologies leverage renewable resources to minimise greenhouse gas emissions, making processes sustainable and reducing natural resource consumption (Iravani *et al.*, 2017). Green technology application in agriculture offers opportunities to increase yield, improve product quality, maintain soil fertility, and adopt to eco-friendly techniques. However, this necessitates a paradigm shift in research and policy in developing countries. Integrating research, awareness, and application of green technologies is essential to strive towards sustainable development in the agricultural sector.

Green Technologies Adopted in Agriculture

Green technologies used by farmers is not entirely new and holds the potential to increase farm yield and profits by employing environmentally sustainable, ecologically sound, and economically reliable techniques. These include organic farming, agroforestry, solar energy technology, mixed farming practices, biogas, multiple cropping, crop rotation, and integrated pest management.

Organic farming, practiced since ancient times, relies on techniques like crop rotation, green manure, compost, and biological pest control. Key features include weed management without pesticides, soil management through crop rotation, and the use of animal manure and green manure crops. Increased awareness about sustainable development has prompted farmers to manage fields more efficiently, driven by consumer demand for locally grown, organic, and sustainable products. Considered as a green technology, it relies on ecological processes to enhance soil fertility and productivity while minimising negative impacts on the environment and human health. However, further efforts are needed to advance organic farming practices.



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 is environmentally sustainable, utilising natural resources to ensure a healthy farming environment as it enhances food supply, income, and health. Practical applications include windbreak trees for protection, hedgerow barriers for erosion control and organic matter, and live fences to manage animal movement while providing fodder and nutrients.

Integrated Pest Management (IPM) offers an eco-friendly alternative to chemical pest control, sustainable method promoting the utilisation of natural pest control mechanisms to cultivate robust crops while minimising disruption to ecosystems and environmental risk. It minimises environmental risks and is applicable in both urban and rural areas. IPM involves preventive actions like growing disease-resistant crops and using deterrent strategies to discourage pests. However, implementing IPM may be challenging for farmers due to limited resources and expertise in pest management.

Solar energy, derived from the sun's radiant light and heat, can be harnessed through solar heating and photovoltaic technology. Solar photovoltaic technology converts sunlight into energy using semiconductors, applicable in agricultural production for tasks like water pumping, lighting rural houses, and pest

management. Solar water pumping offers advantages over conventional fuel methods, including no fuel costs, lower maintenance, and environmental friendliness. Benefitting from ample sunlight, solar-powered technologies like water pumping systems harness abundant solar radiation.

Biogas technology utilises agricultural waste to produce renewable energy and fertilisers, making it environmentally friendly. Anaerobic digestion transforms agricultural waste into fuel and fertiliser. The by-products are used for organic crop production, enhancing soil fertility, and serving as a sustainable alternative to inorganic fertilisers by providing nutrients and improving soil penetration capacity.



Mixed farming is a common agricultural practice, involves using crop residues to feed animals and utilising their faeces as fertiliser for growing crops, enriching the soil. This approach helps farmers to reduce the risks associated with single-crop production and is considered a leading technique for promoting eco-friendly food production.

Crop rotation offers socio-economic and environmental benefits, as it enhances profitability by introducing high-value crops and mitigates economic risks by combining crops. Diversifying rotations with pulses or vegetables boosts dietary micronutrient production to combat hidden hunger. Additionally, lowers reliance on synthetic fertilisers, reduces pollution and greenhouse gas emissions, and revives farmland biodiversity.

Agricultural biotechnology modifies organism components to enhance crop development, enabling farmers to produce abundant and cost-effective crops sustainably. Professionals engineer pest and disease-resistant plants to minimise environmental disruptions, thereby decreasing pesticide usage. Despite this, consumer resistance to genetically modified or engineered foods persists. Many consumers are unaware of the ecological benefits of biotechnology, which include advanced modification practices targeting surface-level and atmospheric pollution, facilitating phytoremediation production. These plants can remove and store pollutants from the soil, mitigating ecosystem degradation.

Drones and digital sensors as a form of green technology, support sustainable agriculture by enabling remote monitoring of crop development and gathering essential field data. They reduce transportation emissions and produce zero emissions during operation, optimising field time and minimising crop loss to increase environmental sustainability and reduce food waste. Similarly, digital sensors monitor various farming aspects, such as microclimate and soil pH, contributing to sustainability by reducing environmental impacts and health hazards. This technology empowers farmers to make informed decisions, optimise production, enhance yields, conserve resources, minimise waste, and boost productivity.

Smart irrigation systems utilise weather data and soil moisture levels to schedule irrigation, enabling them to respond to changes in plant environment



Automatic Irrigation System for Rice

and water needs. By adjusting watering based on plant requirements, these systems reduce outdoor water usage compared to traditional timers. Efficient water management is essential for sustainability, due to the finite nature of Earth's water supply. Modern technology, including wireless and remote monitoring systems, enables farmers to optimise irrigation practices, promoting smarter decision-making for sustainable agriculture.

Green nanotechnology in agriculture is an eco-friendly and cost-effective technology that enhances productivity while reducing pesticide usage. Its applications include pathogen detection, targeted delivery of nano-pesticides, and improved nutrient absorption in plants. Additionally, it conserves energy, protects soil and water resources, and addresses future agricultural challenges, particularly food security in developing countries (Igiebor *et al.*, 2023)

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

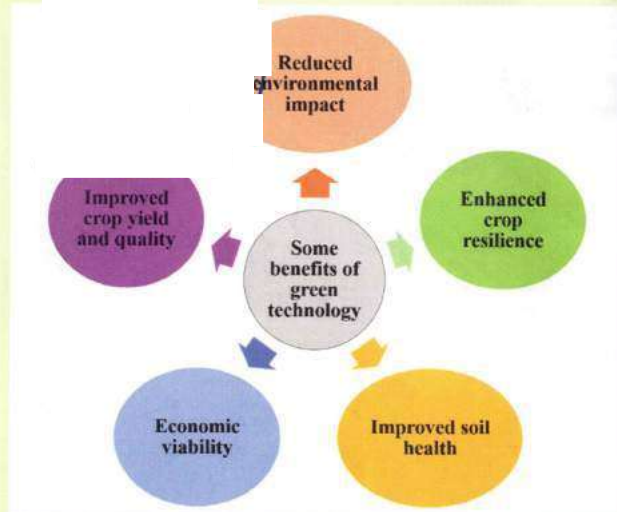
and research and development, pose challenges for adoption by small-scale farmers.

- ▶ **Limited adoption and technological dependence:** Farmers resistance to new green technologies, lack sufficient knowledge about the potentials and limitations of green technology. Often, required to understand and implement knowledge-intensive approaches like IPM and INM.
- ▶ **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 use the natural environment sustainably to enhance production, allowing farmers to promote self-reliance and environmental health. Conventional farming harms ecosystems and food security, while green technologies minimise damage and protect environment. For instance, organic farming outperforms conventional methods by prioritising its environmentally friendly practices and maximising resource efficiency.

Future of Green Technologies in Agriculture

Growing demand for quality food favours the adoption of green technology in agriculture, as it is essential for sustainable food production and environmental conservation. Recommendations include educating farmers and promoting literacy through adult education centres in rural areas. These initiatives aim to ensure sustainable farming practices and enhance farmers' profitability while safeguarding the environment and human health. Technological advancements have introduced a range of internet and GPS-based smart technologies for agriculture, leading to the rise of precision agriculture. These innovations help increase crop production and enable efficient management of fertilisers, pesticides, and irrigation. Unmanned Aerial Vehicles (UAVs) equipped



Benefits of adopting green technologies in agriculture

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,

with multiple sensors offer real-time, precise data for enhancing agricultural practices. Additionally, robotics and sensing equipment allow for monitoring vegetable growth, crop health, soil conditions, and other parameters. Advances in greenhouse technologies, including hydroponics, aeroponics, and aquaponics, offer promising prospects for vertical farming in urban areas.

Conclusion

The green technologies are revolutionising the agricultural sector, but it is important to recognise that environmental conservation requires a multifaceted approach. It won't be a single technology that can address environmental challenges, rather a combination of new green technologies, sometimes integrated with traditional methods, will be necessary. Green technology enhances resource efficiency, reduces environmental impact, and improves agricultural productivity. Moreover, there is a growing emphasis on cleaner and eco-friendly agricultural technologies for

creating a more resilient and sustainable global food chain. Collaboration between farmers and policymakers is essential to develop reliable and profitable green technologies that benefit all stakeholders while minimising environmental footprints. □

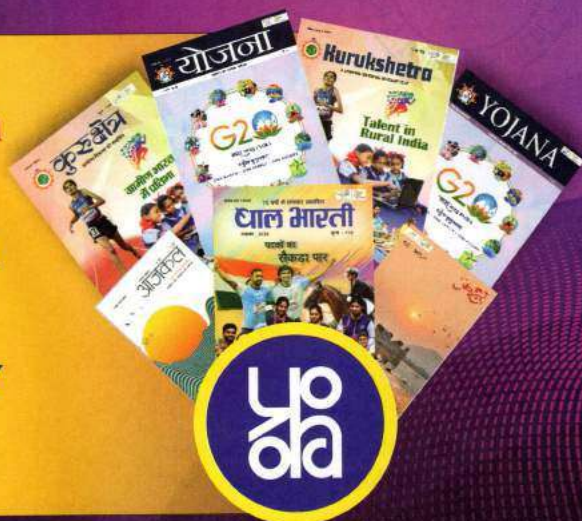
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