Emerging Environmental Technologies in India

For Prelims: National Solar Mission, Extended Producer Responsibility (EPR) Policies, National Action Plan for Chemical and Waste Management, Carbon Capture and Storage (CCS) Technologies, National Green Hydrogen Mission, Paris Agreement, Loss and Damage Fund (LDF), Green Climate Fund (GCF)

For Mains: Role of Government Policies in Sustainable Development and Challenges and opportunities in Scaling up Emerging environmental Technologies

Context

India faces significant environmental challenges, including severe **air and water pollution** (**World Air Quality Report 2024** ranks India as the **5th most polluted country**), adverse impacts of climate change, and the pressing challenge of transitioning towards **sustainable development**.

What are the Key Environmental Emerging Technologies in India?

Renewable Energy Technologies

- **Solar Energy:** India has set an ambitious **renewable energy** target, aiming for 500 GW of renewable energy capacity **by 2030** (as per **India's COP26 pledge**), with a major emphasis on **solar energy**.
    - As India aims to reduce the cost of solar power and enhance efficiency, initiatives like the **National Solar Mission,** technologies like **Solar Photovoltaic cells**, and **various state-level incentives have played a crucial role** in promoting the adoption of solar technologies.
- **Wind Energy:** Wind energy is rapidly expanding in India, with both onshore and offshore wind power. As of 2023, **India was ranked fourth in wind power capacity globally, with states like Tamil Nadu, Gujarat, and Maharashtra** leading the way.
    - New technological advancements in **high-efficiency wind turbines**, **grid integration systems**, and **energy storage** solutions are helping address intermittency issues and improve grid stability.
- **Hydropower & Bioenergy:** Hydropower continues to play a vital role in **India's clean energy transition**, particularly small-scale hydroelectric plants. They provide reliable, renewable power to rural areas.
    - **Bioenergy** from agricultural residues, waste, and organic matter is another important area, with **biofuels**, **biogas**, and **biomass-based energy** contributing significantly to rural energy needs.

Waste Management and Recycling

- **Waste-to-Energy (WtE) Technologies:** **WtE technologies** include:

    - Biomethanation **utilizes organic waste to produce biogas**, which can be used to generate power. **Gasification** converts waste into **synthesis gas (syngas)**, which can be used to generate electricity.
- **Plastic Waste Management:** With increasing plastic waste in urban areas, India is focused on **plastic recycling innovations** and **biodegradable plastics**. Efforts to reduce plastic pollution include the use of **Extended Producer Responsibility (EPR) policies** that require producers to take responsibility for the lifecycle of their products, including post-consumer waste.
- **E-Waste Management:** **E-waste management** is a growing concern in India, with the country being one of the largest producers of electronic waste globally. As a major producer of e-waste, India is focusing on safe recycling technologies, such as reverse logistics, **under the E-Waste (Management) Rules, 2022**.
    - Reverse logistics involves the **collection, disassembly, remanufacturing, recycling, and responsible disposal of end-of-life (EOL)** electrical and electronic products to minimize environmental harm.

Innovation in Water Purification and Wastewater Treatment

- **Desalination Technologies:** With **water scarcity** in coastal areas, **solar desalination technologies** are gaining importance. These systems use solar energy to desalinate seawater, providing an eco-friendly and cost-effective way to produce fresh water. Large-scale **reverse osmosis (RO) systems** are also being installed in coastal regions to meet urban and industrial water needs.
- **Rainwater Harvesting and Reuse Technologies:** Rainwater harvesting is a key component of sustainable water management, particularly in **drought-prone regions.** For example- The Kundi (also known as kund) is a **traditional rainwater harvesting system used in Rajasthan**.
    - **IoT-based smart water management systems** use sensors and data analytics to optimize water usage, detect leaks, and ensure efficient conservation.
    - India's water conservation policies promote rainwater harvesting (**National Water Policy & Urban guidelines**) at the household and community levels.

Climate Change Mitigation and Adaptation Technologies

- **Carbon Capture and Storage (CCS):** In line with India's updated **Nationally Determined Contributions (NDCs)**, which aim for a **45% reduction in emissions by 2030**, the country is placing increasing emphasis on transitioning to clean energy. In this context, **CCS technologies** have **emerged as a vital solution** for reducing industrial emissions and meeting global climate commitments. The CCS approaches include:
    - **Point-source CCS**, which involves capturing CO2 directly at the site of its production, such as industrial smokestacks.
    - **Direct air capture (DAC)**, focuses on removing CO2 that has already been emitted into the atmosphere.
- **Green Hydrogen:** **Green hydrogen** is being explored for its potential use in **heavy industries**, **transportation**, and **power generation**. It is considered a viable solution for decarbonizing sectors that are difficult to electrify, such as steel manufacturing and long-haul transport.
    - The **National Green Hydrogen Mission** **(NGHM)** (launched in 2023) aims to produce 5 Million Metric Tonnes (MMT) of green hydrogen **annually by 2030**, contributing significantly to the nation's **clean energy transition**.

Use of Drones and GIS in Environmental Monitoring

- **Drones (Unmanned Aerial Vehicles - UAVs) and Geographic Information Systems (GIS):** **Drones** capture high-resolution imagery using sensors like **LiDAR (Light Detection and Ranging)** to monitor vegetation, water quality, and land-use changes.
    - They help track **land degradation**, **deforestation**, and assess habitat changes, with **GIS** aiding in data analysis for conservation.
    - Drones also **monitor climate change impacts**, such as **glaciers**, **coastal erosion**, and **wildfires**, while GIS supports long-term climate modeling.

- For instance, **ISRO** uses satellite-based drones to track **glacier melting and coastal erosion in the Himalayas**. Additionally, India is **deploying drones for border surveillance**, which also assist in monitoring environmental changes in sensitive areas.

Geoengineering for Climate Change Intervention

- Geoengineering technologies **can be broadly classified into two main categories**:
  - **Solar radiation management (SRM):** SRM involves deploying materials in space to reflect **solar rays** away from the Earth. This method, while still conceptual, draws inspiration from natural phenomena such as volcanic eruptions.
    - For example, **Mount Pinatubo's 1991 eruption** in the Philippines reportedly reduced Earth's temperature by 0.5°C that year.
  - **Carbon Dioxide Removal (CDR):** Techniques include CCS, Direct Air Capture (DAC), and **Carbon Capture, Utilisation and Storage (CCUS)**, with the focus on long-term reduction of atmospheric **CO2 levels**.
    - **DAC:** It involves extracting CO_2 directly from ambient air using large devices (**often called "artificial trees"**) for storage or use.
      - DAC has greater potential benefits as it can address historical CO_2 emissions, though it also faces more significant challenges.
    - **CCUS:** Some captured CO_2 is repurposed in industrial processes, while the **remainder is stored**.

What are the Global Initiatives for Environmental Sustainability?

- **Paris Agreement**
- **United Nations Sustainable Development Goals (SDGs)**
- **The Global Environment Facility (GEF)**
- **Loss and Damage Fund (LDF)**

- **Green Climate Fund (GCF)**

What are the Challenges Related to Emerging Environmental Technologies in India?

- **High Initial Costs:** Many environmentally sustainable technologies, such as carbon CCS and solar power installations, involve **significant upfront investments**.
    - For instance, the cost of setting up CCS in industries like steel and cement is still high, and **many businesses may be reluctant to invest without guaranteed returns** or **government subsidies**.
    - Schemes like the **Production-Linked Incentive (PLI)** in certain sectors have been slow to take off, **highlighting the challenges in incentivizing private sector participation** without clear financial benefits or policy support.
- **Technical and Operational Complexity:** Emerging technologies often require specialized knowledge and expertise for implementation.
    - Emerging technologies like **AI-driven** climate modeling require specialized expertise, but **India lags in developing localised AI systems (e.g., China's DeepSeek, US 's OpenAI)**. Scarce R&D investment, skill gaps in AI/ML, and poor integration of global systems with local infrastructure **(e.g., delayed smart city waste management)** hinder progress, raising costs and delaying sustainability goals compared to global competitors.
- **Regulatory and Policy Barriers:** The **rollout of electric vehicle (EV)** charging infrastructure in India, despite government initiatives like **Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME) Scheme Phase-II is hindered by ambiguous regulations**, unclear incentives for private investment, and long delays in obtaining regulatory clearances.
    - The ongoing debate over whether **EV charging should be classified as a service or a sale further complicates the issue**, making it difficult for businesses to establish charging stations and discouraging private sector participation.
- **Public Acceptance and Environmental Impact**:
    - Emerging technologies often face challenges related to public awareness, acceptance, and their potential environmental or social impacts. For example, **genetically modified crops** like drought-resistant varieties **may encounter public opposition** despite their potential to address **food security** and environmental sustainability.
    - Similarly, the p**roduction of biofuels from food crops such as corn can create a conflict between food security and energy production**, raising concerns about their broader environmental and social consequences.

Way Forward

- **Increased Focus on Green Tech Investments:** Accelerating investments in clean technologies, such as renewable energy and energy-efficient solutions, is key for sustainable growth.
    - Initiatives like the **NGHM can drive innovation and scale**, supported by **green bonds** and **carbon credits** to finance eco-friendly projects.
- **Circular Economy Transition:** India must adopt **circular economy models**, focusing on eco-design, resource efficiency, and waste minimization.
    - A significant step in this direction was the **12th Regional 3R and Circular Economy Forum**, held in March 2025. The forum centered on **"Realizing Circular Societies Towards Achieving SDGs and Carbon Neutrality in Asia-Pacific,"** emphasizing sustainable practices and cross-sector collaboration.
- **Strengthen Policy Frameworks for Sustainability:** The government can create a national sustainability roadmap, aligning policies across sectors to ensure long-term consistency in promoting green technologies and encouraging corporate accountability.
    - For instance, **Tesla decided to invest in India after PM Modi's visit to the US**, signaling how government engagement can attract big investments.
- **Encourage Collaboration Between Public and Private Sectors:** Foster partnerships between the government, private sector, and research institutions to co-develop and deploy sustainable

technologies.
    - An example of **such a partnership is the private arm of ISRO, Antrix Corporation**, which works with private companies to launch satellite launches and technology transfers to private players.
    - **Public-private partnerships (PPPs)** can be created to share the financial and technical risks associated with large-scale green projects, such as **smart grid systems** or WtE plants.
- **Focus on Sustainable Agriculture and Food Systems:** Promote sustainable farming practices, including precision agriculture, which reduces water, fertilizer, and pesticide use while increasing crop yield.
    - **Sikkim, India's first fully organic state, demonstrates how government subsidies and policy support** can drive significant change.
    - By partnering with **agri-tech startups and incentivizing organic farming**, the government can scale these practices nationwide.

Conclusion

The adoption of cutting-edge environmental technologies can not only address pollution and resource depletion but also fuel innovation and economic growth. By embracing these advancements, India has the potential to shift from reactive measures to proactive solutions, fostering a more sustainable and resilient economy.

UPSC Civil Services Examination Previous Year Questions (PYQs)

Prelims

Q. With reference to 'Water Credit', consider the following statements: (2021)

1. It puts microfinance tools to work in the water and sanitation sector.
2. It is a global initiative launched under the aegis of the World Health Organization and the World Bank.
3. It aims to enable the poor people to meet their water needs without depending on subsidies.

Which of the statements given above are correct?

(a) 1 and 2 only

(b) 2 and 3 only

(c) 1 and 3 only

(d) 1, 2 and 3

Ans: C

Mains

Q. Suggest measures to improve water storage and irrigation system to make its judicious use under the depleting scenario. **(2020)**

Q. Access to affordable, reliable, sustainable and modern energy is the sine qua non to achieve Sustainable Development Goals (SDGs)".Comment on the progress made in India in this regard. **(2018)**