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iCED

GREEN FILES VOLUME 56

Sustainable Extraction: Ensuring Sustainability, Governance and Public Accountability

International Centre for Environment Audit and Sustainable Development (iCED)

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Acknowledgement

We thank all the contributors for their immensely valuable contributions and for making this endeavour a success.

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Foreword

Dr. Abhishek Gupta

The extractive industries occupy a central position in the global and national economy, serving as a backbone for infrastructure development, energy security, and industrial growth. At the same time, these sectors present complex challenges relating to environmental sustainability, governance, and equitable resource utilisation. Balancing economic imperatives with ecological stewardship and social responsibility is therefore critical.

As a Global Training Facility of INTOSAI Working Groups on Environmental Auditing and Audit of Extractive Industries, iCED continues to play a pivotal role in strengthening the capacities of Supreme Audit Institutions in addressing these emerging challenges. Through training, research, and knowledge-sharing initiatives, iCED contributes to enhancing audit methodologies that support sustainable and accountable resource management.

It is in this context that *Green Files Volume 56* focuses on the theme *"Sustainable Extraction: Ensuring Sustainability, Governance and Public Accountability."* The articles featured in this volume collectively examine the evolving landscape of extractive industries through multiple dimensions including sustainable mining practices, circular economy approaches, ESG integration, critical mineral security, environmental governance, technological innovation, and audit perspectives.

The contributions also highlight how public audit can assess policy effectiveness, ensure transparency in revenue management, evaluate environmental impacts, and strengthen governance frameworks in the field of extractive industries. By integrating audit perspectives with sustainability concerns, this volume underscores the importance of evidence-based decision-making in the extractive sector.

A notable feature of this edition is the inclusion of sections The contributions from experts and professionals associated with the European Court of Auditors, SAI Indonesia, and other institutions provide valuable international perspectives on sustainable energy transition, environmental governance, and public accountability.

I sincerely appreciate all contributors, faculty members, and colleagues from partner Supreme Audit Institutions whose valuable insights and experiences have enriched this volume and strengthened the spirit of international knowledge sharing and cooperation.

I am confident that *Green Files Volume 56* will serve as a valuable resource for auditors, policymakers, researchers, and practitioners engaged in environmental governance and extractive industry oversight.

We look forward to your suggestions to make Green Files as informative and user friendly as possible. Your contributions within the broad scope of this quarterly journal will be highly appreciated, including any feedback you may like to share on the featured articles.

(Dr. Abhishek Gupta)
Additional Dy. Comptroller and Auditor General
and Director General,
iCED, Jaipur

Editorial

It gives me great pleasure to present Green Files Volume 56, the quarterly journal of iCED for the period October to December 2025, centred on the theme 'Sustainable Extraction: Ensuring Sustainability, Governance and Public Accountability', while also featuring national and international environmental developments and experiences from Supreme Audit Institutions and international experts."

iCED, Jaipur, continued its efforts to strengthen audit competencies and promote sustainability through a wide range of national and international training programmes, workshops, and webinars during late 2025. These initiatives covered key areas such as extractive industries, natural resource accounting, ESG, environmental accounting, and emerging technologies like AI in audit. The programmes involved experts from leading institutions and saw participation from IA&AD officers as well as multiple Supreme Audit Institutions worldwide. Through these activities, iCED enhanced knowledge sharing, capacity building, and adoption of best practices in environmental and sustainability auditing.

This edition of *Green Files* brings together a diverse set of articles examining the extractive industries through the lens of sustainability, governance, and audit. The volume covers critical themes such as sustainable coal mining, circular economy approaches in mining, ESG integration, critical mineral security, and audit frameworks for financial and regulatory oversight.

The articles collectively explore how audits can assess policy implementation, institutional coordination, utilisation of resources, and achievement of intended outcomes in the extractive sector. They also highlight the increasing role of technology—including GIS, remote sensing, and data analytics—in strengthening audit effectiveness and evidence-based assessments.

The volume also provides perspectives on global developments, national policies, and innovative practices that can support sustainable resource management. The insights offered in these articles reinforce the importance of transparency, accountability, and informed governance in managing natural resources.

The volume includes perspectives from senior professionals in the European energy and environmental sectors on themes such as net-zero electricity infrastructure and Auditors from SAI Indonesia on auditing renewable energy, enriching the journal with broader insights on sustainable energy transition, circular economy practices, and climate resilience.

The contributions from experts, faculty members, and professionals from partner Supreme Audit Institutions have added significant value to the journal by bringing diverse perspectives and international experiences. I extend my sincere gratitude to all contributors whose support and expertise have helped make this edition a richer platform for learning, collaboration, and knowledge sharing.

I hope this edition will serve as a useful reference for auditors and stakeholders, encourage meaningful discourse, and contribute to strengthening audit practices in the extractive industries.

(Meena Bisht)
Director (Training & Research)
iCED, Jaipur

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Strategic Engagements and outreach by iCED

Institutional Highlights

The International Centre for Environment Audit and Sustainable Development (iCED), Jaipur, sustained its efforts to enhance audit competencies and foster sustainability-oriented knowledge exchange through a diverse range of training programmes and workshops during the fourth quarter of 2025. These initiatives were designed for officers of the Indian Audit and Accounts Department (IA&AD), officials from other government organisations underscoring iCED's expanding international engagement and its commitment to high standards of professional capacity building.

Trainings at iCED

1. **National Training Programme on "Audit of Extractive Industries" from 07th to 10th October 2025.**

Figure 1: NTP on "Audit of Extractive Industries"

During this four-day training programme, experts from IA&AD and other reputed organizations such as Indian Bureau of Mines (IBM), CSIR, IIT Kharagpur etc. delivered the sessions on various aspects of extractive industries ranging from role of IBM, environmental impacts and sustainable development framework for mining, use of emerging technologies and newer areas as critical minerals etc. Further, state specific audit reports were also discussed to highlight risk areas, auditing challenges, audit findings and use of technologies in audit.

2. **National Training Programme on "Natural Resource Accounting" from 07th to 10th October 2025.**

Figure 2: NTP on "Natural Resource Accounting"

During this four-day training programme, experts from IA&AD and other reputed organizations such as Ministry of Statistics & Programme Implementation (MoSPI), New Delhi; Indian Bureau of Mines (IBM), Nagpur; National Water Academy (NWA), Pune and Indian Institute of Technology (IIT), Bombay delivered the sessions on accounting frameworks for different natural resources. Further, state specific case studies were also presented during the training to highlight challenges and best practices in respective states.

3. **International Webinar on "Environmental Impacts of Extraction in Extractive Industries" on 8 October 2025**

iCED in its capacity as Global Training Facility (GTF) of INTOSAI Working Group on Audit of Extractive Industries (WGEI) organized an International Webinar on "Environmental Impacts of Extraction in Extractive Industries" on 08th October 2025 through virtual mode in passociation with INTOSAI (WGEI).

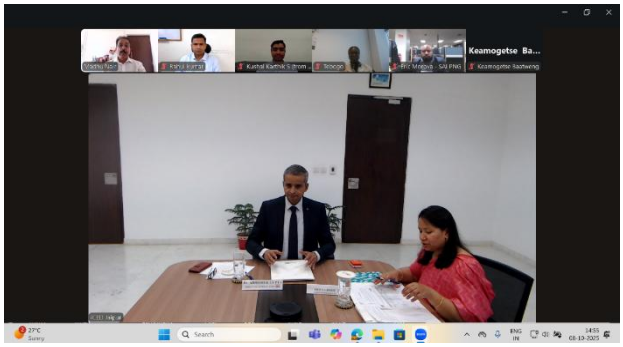

Figure 3: International Webinar on "Environmental Impacts of Extraction in Extractive Industries"

A total of 43 participants from 19 SAIs across the globe participated in this webinar. The webinar included a keynote technical session on "Environmental Impacts of Extraction in Extractive Industries", delivered by Shri Madhusoodanan Nair. The session focused on the environmental and social risks associated with extractive industries and highlighted the role of Supreme Audit Institutions in promoting transparency, accountability and sustainable resource management. The presentation was highly appreciated by the participants

4. International Webinar on "Green Fiscal Policy Tools" on 15th October 2025

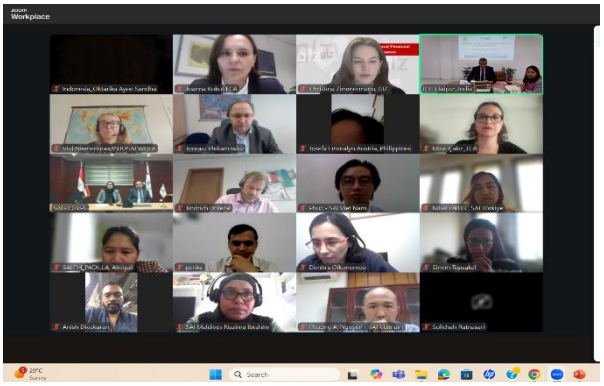

Figure 4: International Webinar on "Green Fiscal Policy Tools"

iCED in its capacity as Global Training Facility (GTF) of INTOSAI Working Group on Environmental Auditing (WGEA), organized a webinar on "Green Fiscal Policy Tools", in virtual mode in association with INTOSAI(WGEA). A total of 172 participants from 29 SAIs across the globe participated in this webinar.

The virtual sessions by experts from international organizations, including the European Court of Auditors, UN Environment Programme, German Corporation for International Cooperation, and the INTOSAI WGEA Secretariat focused on green fiscal policy tools, the Green Fiscal Policy Network, revenue from non-recycled plastic packaging waste, and audits of green bonds.

During webinar, virtual breakout rooms were created, where participants engaged in discussions with the resource persons on topics as environmentally harmful subsidies, environmental taxation and audit of these green fiscal policy tools. Resource persons shared their insights on these discussions followed by a wrap up and key message by experts from ECA and Dr. Vivi, Secretary General, INTOSAI WGEA.

5. International Webinar on "Sustainability Reporting" on 29th October 2025

Figure 5: International Webinar on "Sustainability Reporting"

The International Webinar on "Sustainability Reporting" was organized on 29th October 2025 through virtual mode in association with INTOSAI(WGEA). A total of 136 participants from 31 SAIs across the globe participated in this webinar.

During the webinar, a series of virtual sessions featured presentations and case studies on sustainability reporting and auditing standards. Experts from Supreme Audit Institutions such as SAI Thailand, SAI Indonesia, and SAI Maldives, shared project experiences and country-specific case studies. A technical presentation on sustainability reporting under the International Public Sector Accounting Standards Board was also delivered, along with an overview of ISSA 5000 by a representative of the International Auditing and Assurance Standards Board. The programme concluded with an interactive discussion and Q&A session involving all participants.

6. National Workshop on "ESG Reporting – Strengthening Public Assurance" on 29th October 2025

Figure 6: National Workshop on "ESG Reporting – Strengthening Public Assurance"

This one-day workshop was designed to provide participants with comprehensive exposure to the evolution of ESG concepts, their alignment with the Sustainable Development Goals (SDGs) and the BRSR framework introduced by SEBI.

The workshop commenced with a keynote address by Shri Anand Mohan Bajaj, Deputy Comptroller and Auditor General (Commercial & Report Central), who traced the global evolution of ESG reporting—from frameworks such as Global Reporting Initiative, Sustainability Accounting Standards Board, and Task Force on Climate-related Financial Disclosures to its adoption in India through SEBI's Business Responsibility and Sustainability Reporting (BRSR) framework

Shri Sunil S. Dadhe (DAI, Retd.), Shri Ajay Phatak, Trustee, Ecological Society, and Shri Amit Goswami, Director (ESG & Impact Investments), delivered expert inputs on ESG concepts, their linkage with SDGs and the BRSR framework, climate risks, ESG measurement tools, and the role of the Comptroller and Auditor General of India in ESG reporting and strengthening public assurance.

7. International Webinar on "Environmental Accounting" on 05th November 2025

Figure 7: International Webinar on "Environmental Accounting"

The International Webinar on "Environmental Accounting" hosted 110 participants from 30 SAIs across the globe.

During the webinar, experts from Supreme Audit Institutions and reputed organizations delivered sessions on environmental accounting initiatives, including an overview of the INTOSAI Working Group on Environmental Auditing Environmental Accounting Project (2023–25), the United

Kingdom's approach to natural capital and environmental accounts, and SAI India's initiatives on natural resource accounting. The webinar also featured breakout discussions on environmental accounting frameworks across countries and their relevance for SAIs, followed by feedback from participants and a concluding wrap-up session by Dr. Vivi, Secretary General, INTOSAI WGEA.

8. International Webinar on "Environmental, Social, and Governance (ESG) Considerations in Extractive Industries" on 07th November 2025

Figure 8: International Webinar on "Environmental, Social, and Governance (ESG) Considerations in Extractive Industries"

The International Webinar on "Environmental, Social, and Governance (ESG) Considerations in Extractive Industries" on 07th November 2025, in association with INTOSAI (WGEI) Hosted 107 participants from 26 SAIs across the globe.

The session on "Environmental, Social, and Governance (ESG) Considerations in Extractive Industries" was delivered by Pierre Petit-De Pasquale, Standards Director at the Initiative for Responsible Mining Assurance. His comprehensive and insightful presentation was well received and highly appreciated by the participants.

9. 13th ITP on "Evolving Landscape of Environment Audit and Sustainability Issues-Challenges and Role of SAIs" from 10th to 18th November 2025

Figure 9: International Training Programme on "Evolving Landscape of Environment Audit and Sustainability Issues-Challenges and Role of SAIs"

iCED as GTF of INTOSAI (WGEA) organised the 13th ITP from 10th to 18th November 2025. A total of 10 participants from 06 SAIs participated in the training programme.

During the training programme, experts from INTOSAI WGEA, SAI Thailand, SAI India and other renowned Institutions shared their perspectives with relevant case studies to elaborate the various aspects of Environmental Auditing.

Figure 10: Dr. Abhishek Gupta, DG, iCED with participants during official dinner

Apart from the academic sessions, participants attended a cultural visit and dinner at Chokhi Dhani, along with local study tours to Amber Fort, Hawa Mahal, and Jantar Mantar. A field visit to the Dravyavati River Project was also organised to provide practical insights into urban river rejuvenation efforts.

In addition, an official dinner was hosted at iCED for ITP participants and officers from C&AG field offices in Jaipur to facilitate interaction and enhance understanding of the diverse functions of C&AG offices

10. In-Service Training (IST) Programme on "Blue Economy: A Multi-Dimensional Overview with Special Focus on Marine and Coastal Ecosystem Conservation Measures" from 24th to 28th November 2025.

Figure 11: In-Service Training (IST) Programme on "Blue Economy: A Multi-Dimensional Overview with Special Focus on Marine and Coastal Ecosystem Conservation Measures"

During this five-day in-Service training programme, insightful sessions were delivered by experts from IA&AD Ministry of Earth Sciences, New Delhi; DES Pune University, Pune; Tamil Nadu Green Climate Company (TNGCC), Chennai; National Institute of Ocean Technology, (NIOT), Chennai; National Centre for Coastal Research (NCCR), Chennai; The ICAR-Central Marine Fisheries Research Institute (CMFRI), Kochi; Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and Ministry of New and Renewable Energy (MNRE), New Delhi. The sessions covered India's Blue Economy policy, SDG 14, marine biodiversity, pollution, and CRZ governance, enriched with audit case study experiences.

Figure 12: Field visit Jaipur's iconic historical sites

An excursion trip to Jaipur's iconic historical sites viz. Amber Fort and Hawa Mahal was organized on 26.11.2025. The visit offered participants an opportunity to explore the city's rich architectural heritage and cultural legacy, providing a refreshing and enriching experience alongside the training programme.

11. Training Programme on "Use of Artificial Intelligence and Machine Learning in Environment Audit and ESG in collaboration with IIT-Madras" From 24th to 28th November 2025

Figure 13: Training Programme on "Use of Artificial Intelligence and Machine Learning in Environment Audit and ESG in collaboration with IIT-Madras"

This training programme was conducted as part of a collaboration between the Indian Institute of Technology Madras and the International Centre for Environment Audit and Sustainable Development, for which a Memorandum of Understanding (MoU) signed on 24 February 2025 in New Delhi to promote capacity building and research in environmental auditing and ESG issues.

The first batch under this collaboration was held at iCED from 21 to 25 April 2025, and this programme constituted the second batch, marking another significant step in advancing digital transformation within the Indian Audit and Accounts Department.

During the five-day programme, participants attended lectures and hands-on sessions conducted by faculty from IIT Madras, using tools such as RapidMiner and Anaconda. The training also explored real-world applications through case studies on natural language processing for sustainability audits, probabilistic auditing, and policy analysis.

12. International Webinar on "Circular Economy and Resource Efficiency in Extractive Industries" On 01st December 2025

Figure 14: International Webinar on "Circular Economy and Resource Efficiency in Extractive Industries"

This webinar was conducted by iCED in its capacity as a Global Training Facility (GTF) of the INTOSAI Working Group on Audit of Extractive Industries and was attended by 99 participants from 27 Supreme Audit Institutions (SAIs) worldwide.

A key session on Circular Economy and Resource Efficiency in Extractive Industries was delivered by Prajna Paramita Mishra, Associate Professor at the University of Hyderabad. Her comprehensive and insightful presentation was well received and highly appreciated by the participants

13. 06th International Training Programme on "Audit of Extractive Industries" in collaboration with WGEI (Part-I) from 08th to 12th December 2025

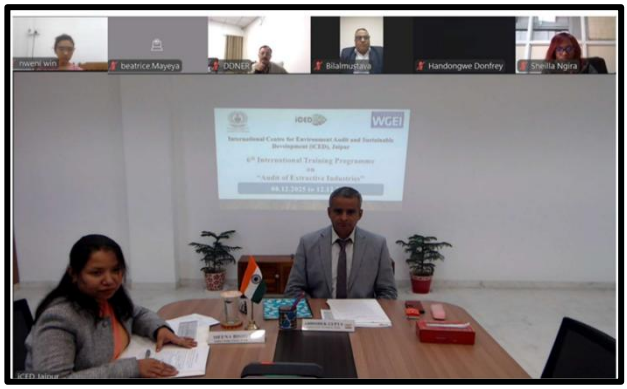

Figure 15: 06th International Training Programme on "Audit of Extractive Industries" in collaboration with WGEI (Part-I)

iCED in its capacity as a Global Training Facility (GTF) of the INTOSAI Working Group on Audit of Extractive Industries, organised Part I of the 6th International Training Programme (ITP) on "Audit of Extractive Industries" in virtual mode from 08 to 12 December 2025. The programme was attended by 57 participants from 19 Supreme Audit Institutions (SAIs) worldwide.

During the programme, experts from the Petroleum Authority of Uganda, Audit Board of the Republic of Indonesia, Office of the Auditor General Zambia, and other reputed institutions from India shared insights through presentations and case studies, covering various dimensions of monitoring and evaluation in extractive industries.

Environmental News & Global Developments

COP 30 Conference at Belém, Brazil

By: Shri Ravi Kumar Sr. Auditor &
Ms. Manju Godara, Auditor
Research Section, iCED

The COP30 was held from 10th to 21st November 2025 in Belém, Brazil, with participation from 194 countries under the framework of the United Nations Framework Convention on Climate Change (UNFCCC). The conference[1] focused on strengthening global climate action with particular emphasis on equitable adaptation, resilience building, and adaptation finance. One of the major priorities discussed was the doubling of adaptation finance by 2025 and advancing the Baku–Belém Roadmap, which aims to mobilize $1.3 trillion in climate finance by 2035.

The central focus of COP30 was moving from climate negotiations to real implementation of climate commitments and accelerating action to keep the 1.5°C global warming limit within reach.

Key thematic priorities[2] included:

- Climate adaptation and resilience
- Climate finance for developing countries
- Forest protection, especially the Amazon
- Renewable energy transition and low-carbon development
- Implementation of the Paris Agreement commitments
- Inclusion of local communities and indigenous peoples in climate action.

The Belém Gender Action Plan was adopted as one of the key outcomes of the COP30 in Belém, Brazil. The plan outlines a set of actions aimed at strengthening women's participation in climate decision-making, improving the availability of gender-related data and evidence, mobilizing financial resources, and promoting technologies that integrate gender equality into climate policies.[3]

Another key aspect of the conference was the delivery of ambitious Nationally Determined Contributions (NDCs) aligned with the 1.5°C global warming limit. During the High-Level Segment held on 17 November 2025, the Indian government emphasized that COP30 should be remembered as a "COP of Implementation" and a "COP of Delivery on Promises." India also appreciated the Government and people of Brazil for hosting the conference in the heart of the Amazon Rainforest, a region described as a living symbol of the planet's ecological wealth.

India @ COP30

The Indian government urged developed countries to demonstrate greater climate

Figure 2: Minister Bhupender Yadav with India delegates at COP 30 Balem

ambition by reaching net-zero emissions earlier than current target dates and by providing new, additional, and concessional climate finance at a scale of trillions rather than billions. It also stressed the importance of affordable and accessible climate technology, highlighting that climate technologies should be free from restrictive intellectual property barriers.

The Government of India has demonstrated that development and environmental stewardship can advance in tandem. According to MoEF&CC, India's emission intensity has declined by over 36% since 2005, and non-fossil fuel sources now account for more than half of the country's total installed electricity capacity (around 256 GW), achieving its NDC target five years ahead of the 2030 timeline. India also announced that it will submit its revised NDCs up to 2035 and the first Biennial Transparency Report on time.[4]

India's global leadership in climate initiatives was also highlighted through platforms such as the International Solar Alliance and the Global Biofuel Alliance. In addition, national initiatives like the Green Hydrogen Mission and Nuclear Mission are contributing to India's pathway toward achieving net-zero emissions by 2070. In line with the objectives of the Paris Agreement regarding the conservation and development of carbon sinks, over two billion trees were planted within sixteen months under a community-led initiative, demonstrating the power of collective climate action.

The Indian government concluded by reaffirming its commitment to global climate cooperation, climate justice, and shared responsibility, calling for the coming decade to focus on implementation, resilience, and collective action to effectively address climate change.[5]

Newspaper Spotlight

What India did to protect its forests and hills in 2025: from Kancha Gachibowli to Aravalli

Citizens' protest to protect environment, their ancestral land, judicial orders impacting natural resources: what Indians are doing to protect their environment

Updated - December 30, 2025 08:03 pm IST

INDRANI PAL

Source: The Hindu

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India notifies first emission intensity targets for carbon-intensive sectors

According to the notification, each facility must reduce the amount of greenhouse gases emitted per unit of output compared to a 2023-24 baseline.

Published - October 10, 2025 11:57 am IST - w Delhi

PTI

HOME / NEWS / INDIA

Source: The Hindu

Parliamentary panel recommends easing clearances for underground coal mining projects

The government has set a target to produce 100 million tonnes (MT) of coal from underground coal mines by 2030

Published - December 14, 2025 11:28 am IST - NEW DELHI

PTI

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A parliamentary panel has suggested simplifying the policy and standardised protocols for allowing underground coal mining, saying that the complex clearance process, similar to large open-cast mines, leads to delays in projects that have low environmental impact.

ETPrime

Mining industry flags retrospective impact of new auction rules; govt says aim is to curb hoarding

By Twesh Mishra, ET Bureau • Last Updated: Nov 11, 2025, 12:39:00 AM IST

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Synopsis

Officials, however, maintain there is no retrospective applicability of law and penal provisions would apply only to future approvals. "The goal is solely to prevent squatters hoarding natural resources, and free assets up for rebidding," a senior official said, adding that any penalties incurred for earlier delays would be adjusted against the auction premium payable if the final milestone is achieved within the stipulated time frame.

Articles by iCED

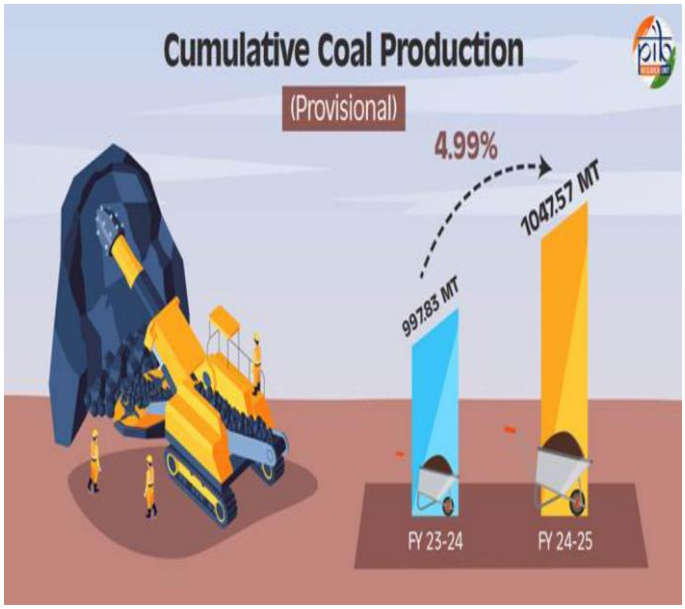
Sustainable Coal Mining: Good Practices in India

Shri Manoj Kumar, SAO
Research Section, iCED

1. Introduction

Mining is essential for economic development but poses environmental and social challenges. Governments worldwide are promoting sustainable mining practices that balance economic growth with environmental protection and social welfare.

In India, the coal industry contributes a significant part towards the mining sector. India achieved a historic milestone by surpassing **one billion tonnes (BT)** of coal production on **20 March 2025**, in **FY 2024-25—11 days ahead of last year's 997.83 million tonnes (MT).** With the **fifth-largest** coal reserves and as the **second-largest** consumer, coal remains crucial, contributing 55% to the national energy mix and fuelling over **74%** of total power generation.[1]



With such a huge contribution, the mining activities of coal in India, certainly ask for good practices for long-term sustainability of the environment.

Innovative mining techniques or technologies assist to reduce environmental and ecological impacts and include:

- Use of surface miners, continuous miners, highwall / longwall mining, etc.
- Increasing installation & usage of First Mile Connectivity (FMC) projects to reduce coal transport via roads.
- Improving energy efficiency across coal mining projects.
- Reclamation and eco-restoration of mined-out areas including development of eco-parks, mine tourism sites, etc.
- Conceptualizing re-purposing of de-coaled areas for sustainable uses like installation of renewable energy generation plants, development of agricultural avenues for surrounding communities, development of mine sumps, etc.
- In order to ensure sustainable mining practices, the compliance of environmental and forestry clearance conditions are being ensured.

In line with India's Panchamrit & Nationally Determined Contribution (NDC) commitments, Ministry of Coal is promoting sustainable coal mining and reduction in carbon footprint by encouraging the following:

- **Greening Initiatives—Bio-Reclamation/Plantation:** Coal/Lignite PSUs have been constantly making efforts

[1] Press Information Bureau, 04 April 2025

to minimize the footprints of coal mining through sustained reclamation and afforestation of areas in and around their operating mines.[2] Ex: Coal & Lignite Public Sector Undertakings (PSUs), namely Coal India Limited (CIL), NLC India Limited (NLCIL) and Singareni Collieries Company Limited (SCCL), have biologically reclaimed and afforested about 55312 Hectares (Ha) of land in and around Coal and Lignite mining areas upto FY 2023-24. The estimated carbon sink potential of the greening initiatives is 2.77 million tonnes CO_2 equivalent. The greening initiatives of Coal & Lignite PSUs contribute to India's Nationally Determined Contribution (NDC) target titled "to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030".[3]

- **Eco-parks:** Coal/Lignite PSUs developed 3 Eco-parks/Mine Tourism sites in various coalfields. This effort of the Ministry of Coal emphasizes the commitment to creating sustainable and engaging spaces for the local communities.
- **Efficient utilization of mine water:** Mine water after the application of appropriate treatment methods is utilized for various purposes such as - community supply for domestic and irrigation purposes; industrial use for dust suppression, plantation, firefighting, machinery washing, sprinkling in UG workings, creation of recreational areas, fish farming, and groundwater recharge etc. Coal/Lignite PSUs have also entered into an MoU with respective State Governments for community water supply. In FY 2023-24, about 4,892 lakh kilolitres (LKL) of mine water was offered for community purposes (Domestic/ Drinking - 2389.5 LKL & Irrigation - 2502.82 LKL).
- **Gainful Utilization of Overburden:** Extracting sand from Over Burden (OB) for construction and stowing

Processed Overburden Plant at Gonegaom Area by WCL & at Srirampur OC Mines by SCCL

[2] Press Information bureau, 02 December 2024
[3] Press Information bureau, 04 December 2024

Overburden to M-Sand Plant at Amlohri Plant, NCL

material supports sustainable development by providing affordable sand and reducing the land required for OB dumps. As of March 2024, Coal/Lignite PSUs have commissioned 4 OB processing plants and 5 OB to M-Sand Plants. This initiative not only helps reduce environmental pollution, improve the riverine ecosystem, enhance water flow, and boost groundwater recharge but also provides a cheaper alternative for construction sand.

- **Energy Efficiency Measures:** Coal/Lignite PSUs have been taking of various energy conservation and efficiency measures over the years. In FY 2023-24, Initiatives such as the replacement of 1.37 lakh conventional lights with LED lights, installation of 2,165 energy-efficient air conditioners, 46,750 super fans, deployment of 153 electric vehicles, and utilization of 531 efficient water heaters, 338 energy-efficient motors for pumps, 1430 auto timer in street lights among others, have resulted in savings.
- **Green Credit Programme**: Coal India Limited (CIL) and its subsidiaries are also participating in extensive plantation under Green Credit Program launched by MoEF&CC. CIL has already registered for restoration of more than 3200 Ha of degraded forest land.
- **First Mile Connectivity (FMC) projects:** Coal PSUs have taken steps to upgrade the mechanized coal transportation and loading system under 'First Mile Connectivity' projects. Commissioning of FMC projects in coal mining areas reduces consumption of diesel significantly and therefore reduces carbon emissions.[4] The Ministry of Coal has planned to set up 102 first-mile connectivity projects having 1092 MT capacity by FY2030 in a continuous manner. Presently, 44 FMC projects having capacity of 429.5 MTY are operational.[5]

[4] Press Information bureau, 02 December 2024

[5] Press Information bureau, 18 August 2025

- **Deployment of Blast free technology in coal mining:** Coal companies are deploying modern equipment having environment friendly features, like Surface Miner in coal, which eliminates the drilling, blasting and crushing operations in coal and hence, in turn, obviates pollution caused due to these operations. Rippers are also being deployed for blast-less removal of Over burden in some mines.
- **Renewable Energy and clean coal initiatives:** Coal PSUs have also started commissioning Renewable Energy power projects. Additionally, they are venturing into various clean coal technologies like coal bed methane (CBM), etc.
- **Scientific Closure of Mines:** Mine Closure Plan is an integral part of the Mining Plan for scientific closure of coal mines.

In order to strengthen the mine closure and repurposing activities collaboration with World Bank and GIZ is being done to implement global best practices. Coal India Limited (CIL) has MoU's with expert agencies of repute like NEERI, ICFRE etc. to assist in taking up various specific assignments of coal sector, research & development and capacity building of CIL executives in various emerging areas of environmental management. CIL has engaged ICFRE for scientific project of "Standardization of Package and Practices for Eco-rehabilitation of Degraded Coal Mines falling under different Agro-climatic Zones of India through Forestry Interventions".

Conclusion:

Sustainable coal mining in India is gradually evolving from a purely extractive activity into a more responsible and balanced approach that integrates environmental protection, social welfare, and economic efficiency. Initiatives led by the Ministry of Coal and Ministry of Mines—such as scientific mining practices, land reclamation, First Mile Connectivity projects, and the effective utilization of District Mineral Foundation funds—demonstrate a strong policy commitment toward sustainability. These efforts are complemented by increasing adoption of cleaner technologies, digital monitoring systems, and progressive mine closure planning. However, challenges such as legacy environmental impacts, illegal mining, and the need for stricter enforcement remain. Going forward, aligning coal mining with climate goals, expanding renewable integration in mined areas, and strengthening community participation will be crucial. Thus, sustainable coal mining in India is not only achievable but essential for ensuring that resource extraction contributes to long-term environmental stewardship and inclusive development.

Closing the Loop in Mining: Circular Economy Pathways for Sustainable Resource Use

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Mining plays a vital role in the global economy especially, minerals such as gold, copper, lithium, nickel, cobalt, and rare earth elements which are crucial for emerging technologies including electric vehicles, wind turbines, and solar panels.

According to the World Gold Council, about 190,000 tonnes of gold have been mined from the Earth throughout human history, with nearly two-thirds of this total extracted in the past few decades. This rapid increase reflects a broader global trend in mineral extraction, where the production of several minerals has risen dramatically sometimes three to ten

With increased extraction, the amount of mining tailings generated globally is extremely large, as only small quantities of metal often just ounces or pounds are obtained from each ton of processed ore. In 2022, it was estimated that more than 14 billion metric tons of mining tailings were produced worldwide each year. At present, the management of these tailings is linked to numerous environmental challenges[1].

According to the International Resource Panel (IRP), the extraction and processing of material resources are responsible for **more than 55 percent of global greenhouse gas (GHG) emissions, 40 percent of particulate matter–related health impacts,** and **around 90 percent of land-based biodiversity loss and water stress**. These figures emphasize the need for more sustainable resource management and circular economy practices[2].

In 2022, India had approximately **1,245 operating mines**. The demand for coal in the country has increased significantly, rising from about **900 million tonnes to nearly 1,200 million tonnes per year**. According to the Ministry of Mines, coal consumption is expected to further increase to **around 1,500 million tonnes by 2040**. Similarly, the metal industry recorded a demand of about **86 million tonnes per year during the 2022 fiscal year**, while the steel sector is projected to grow at a rate of **7 to 10 percent annually**. As a result of this growth, steel demand in India may reach **approximately 230 million tonnes per year by 2030**, reflecting the expanding needs of infrastructure and industrial development[3].

Tailings

When rocks containing minerals are mined, they are **crushed and processed to separate useful metals** such as gold, copper, or iron. After the valuable part is removed, the **remaining finely ground waste material** is called **tailings.**

The concept of the **Circular Economy (CE)** that focus improving resource efficiency and minimizing waste can be a useful approach in

1 Environmental Impact Assessment of Mine Tailings
2 Circular Economy UNDP
3 Sustainability and Circular Economy in Mining

ensuring sustainability by reprocessing mine tailings to recover remaining valuable metals, recycling water and energy within mining operations, and converting mining waste into useful materials such as construction products. In addition, mining activities can be integrated with other industries through industrial symbiosis, where waste from one process becomes a resource for another. Together, these strategies help close the material loop, reduce environmental impacts, and promote more sustainable use of natural resources.

1. Circular Economy Pathways in Mining Tailings Reprocessing

Tailings often contain valuable metals that were not extracted in earlier mining processes. With modern technologies such as **hydrometallurgy and bioleaching**, companies can recover these metals from waste deposits, reducing environmental impact and improving resource efficiency. This approach not only generates additional economic value but also reduces the environmental footprint of mining by lowering waste volumes, improving water recovery, and supporting circular economy practices in the mining industry[4]. **NRIDigital 2023,** highlights innovative technologies for recovering metals from mine tailings. Microbial bioleaching can extract metals such as copper, nickel, and gold from waste while potentially offsetting **up to 30 percent of mining-related CO_2 emissions**. Nanoparticle "sponges" can selectively absorb metals, improving recovery efficiency and reducing environmental pollution.

Waste-to-Resource Conversion

Mining waste materials such as slag and waste rock can be converted into useful products for other industries. For example, the global **copper slag market** has experienced steady growth in recent years due to increasing demand from construction and industrial sectors. This growth is largely driven by the rising use of copper slag in **cement and concrete production**, where it serves as a durable and cost-effective alternative to natural aggregates. The increasing emphasis on **sustainable construction and waste recycling** has further encouraged its adoption as an eco-friendly material[5]. Similarly, coal mine waste rock can be used in road construction because its physical properties are comparable to natural gravel materials.[6].

Water Recycling and Energy Efficiency

Circular economy strategies aim to minimize water use through recycling and closed-loop systems. Some mining companies are adopting dry processing technologies that eliminate the need for water during mineral processing.

This transition will reduce the generation of **tailings waste**, eliminate the need for new tailings dams, and lower environmental risks.

Digital Technologies and Smart Mining

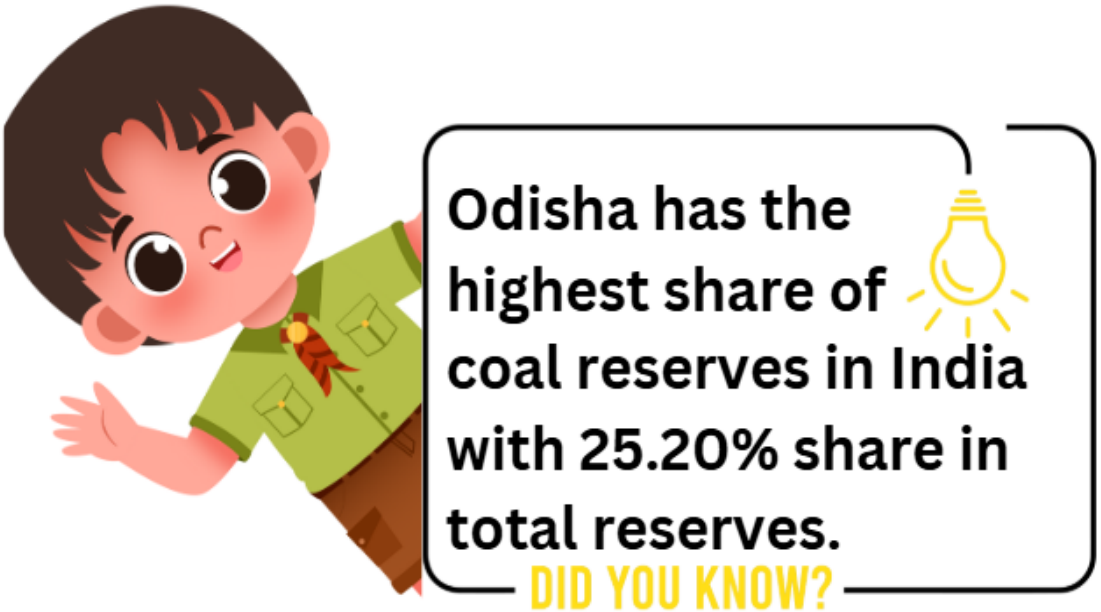
Digital technologies such as artificial intelligence, remote sensing, and predictive analytics are transforming mining operations. **Automation and robotics** enable machines

[4] Unlocking wasted value through tailings reprocessing
[5] Global Copper slag Market
[6] Mining Waste Materials in Road Construction

such as haulage trucks to operate with minimal human intervention. **IoT systems** connect sensors and equipment to monitor operations, worker safety, and tailings dams. **Big data and real-time data** support predictive maintenance and hazard detection. **Artificial intelligence and machine learning** analyse complex datasets to optimise mining processes. **3D printing** is used to produce spare parts and models, reducing downtime and improving logistics in mining operations.

6. Conclusion

The transition toward a circular economy in the mining sector is essential to balance the growing demand for mineral resources with environmental sustainability. With global resource consumption increasing rapidly and only a small percentage of materials currently recycled, the adoption of circular economy strategies has become increasingly important. Practices such as tailings reprocessing, waste-to-resource conversion, water recycling, and the use of digital technologies can significantly reduce environmental impacts while improving resource efficiency. These approaches not only help recover valuable materials from mining waste but also support sustainable industrial growth and reduce pressure on natural ecosystems. Therefore, integrating circular economy principles into mining policies, technologies, and management practices will play a crucial role in ensuring responsible resource use, minimizing waste and achieving long-term environmental and economic sustainability.

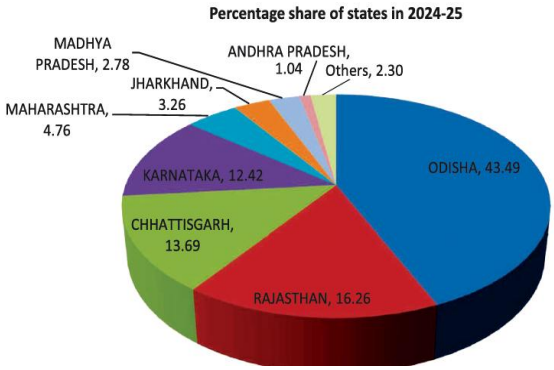


Source: Energy Statistics India 2026

Audit of Extractive Industries: Financial Integrity, Regulatory Compliance and Performance Evaluation

By: Shri Ajay Babu Meena, AAO
Research Section, iCED

Minerals constitute the vital raw materials for many basic industries and are a major resource for development. India produces as many as 95 minerals, which includes fuel, metallic, non-metallic, atomic and minor minerals (including building and other materials).[1]



Share of States in Value of Estimated Mineral Production 2024-25 (Excluding Atomic, Fuel Minerals, minor minerals)

Source: Ministry of Mines, Government of India

Regulatory and Governance Framework

The extractive industry in India requires both Central and State governments to share regulatory duties. The Mines and Minerals (Development and Regulation) (MMDR) Act of 1957 functions as the main regulatory framework which directs the operations of this sector.

MMDR Amendment Act, 2015

The MMDR Amendment Act of 2015 brought about a fundamental transformation to the existing system. The amendment created uniform 50-year lease durations for mining businesses while it established severe penalties to fight against unauthorized mining operations.[2]

The National Mineral Policy 2019

The National Mineral Policy (NMP) 2019 serves as the fundamental legal base for this statutory system. It promotes mining operations that produce no waste materials. The policy demands organizations to create exact sustainability assessment standards which they will use to evaluate their mining operation performance. The Indian Bureau of Mines (IBM) oversees these standards, actively enforcing the Mineral Conservation and Development Rules (MCDR), 2017.[3]

The Pradhan Mantri Khanij Kshetra Kalyan Yojana (PMKKKY) Framework

The PMKKKY guidelines 2024 provides that Gram Sabha/ Local Bodies may aid in preparation of perspective plan. Further, these guidelines also mandates that the utilization of DMF Funds in the scheduled areas shall be guided by the provisions contained in Article 244 read with Schedule V and Schedule VI to the Constitution relating to administration of the Scheduled Areas and Tribal Areas and the Provisions of the Panchayats (Extension of the

[1] Ministry of Mines, Government of India
[2] The Gazette of India published on 27 March 2015
[3] National Mineral Policy 2019 Ministry of Mines, GOI

Scheduled Areas) Act, 1996 and the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006.

PMKKKY mandates DMFs to spend funds on priority sectors viz. Drinking Water, Environment Preservation and Pollution Control measures, Health Care, Education, Welfare of Women and Children, Welfare of aged and differently-abled, Skill Development and Livelihood generation, Sanitation, Housing, Agriculture and Animal Husbandry and other priority sectors which helps in improving the lives of peoples in mining-affected areas. Till November 2024, cumulative amount of Rs 1,02,083.03 Cr. has been collected in DMFs across country, out of which Rs 87,357.28 Cr. has been sanctioned for 3.60 lakh projects. A total 2.01 lakh projects have been completed and an amount of Rs.54,892 Cr. has been spent.[4]

Audit Findings on DMF Utilization

During audit of Pradhan Mantri Khanij Kshetra Kalyan Yojana (PMKKKY) including District Mineral Foundation Trust (DMFT) (Government of Karnataka Report No. 7 of the year 2025 Performance Audit – Civil), the Comptroller and Auditor General of India found shortcomings in the implementation of PMKKKY. Some of the observations are as follows:

- **Idling of Funds:** Districts left massive sums sitting in Personal Deposit (PD) accounts rather than transferring them to high-yield Fixed Deposits, causing direct interest losses.
- **Inadmissible Works:** Officials diverted funds specifically protected for tribal welfare into general state infrastructure, building Police Stations and Superintendent of Police offices instead.
- **Beneficiary Exclusion:** The local trusts failed to conduct baseline surveys. When surveyed, 100% of local Gram Sabhas (village councils) said they were never consulted for project approvals. Even worse, officials deceptively labelled infrastructure built with DMF money as "MLA grants."[5]

Use of Technology in Audit: Geospatial Verification

The SAIs have started to use Geographic Information Systems (GIS) together with Remote Sensing Data (RSD) for conducting audits in the mining sector.[6]

The auditing process involves combining authorized lease coordinates with high-resolution satellite images from Sentinel and Google Earth Pro to monitor how land usage evolves throughout different time periods. As per the performance Audit on illegal mining in Rajasthan (Report no. 08 of 2022) As per the performance Audit on illegal mining in Rajasthan (Report no. 08 of 2022),122 suspicious excavation sites were identified through remote sensing technology which auditors used to verify activities beyond authorized lease boundaries. The illegal mining operations became evident through physical inspections which used handheld GPS devices to track mining activities that reached depths of seventy meters. The system exposed operators who stole 13.37 lakh metric tonnes of minerals through their illegal

[4] PIB District Mineral Foundation (DMF)
[5] Government of Karnataka Report No. 7 of the year 2025 Performance Audit – Civil
[6] Guidance Note on Usage of Remote Sensing Data and Geographic Information System for effective audits

activities which resulted in a ₹ 111 crore loss to the state government.[7]

Conclusion

India's mining sector remains a critical pillar of economic growth and industrial development. Legislative reforms such as the Mines and Minerals (Development and Regulation) Amendment Act, 2015 and the National Mineral Policy, 2019 have attempted to improve transparency, promote sustainable mining practices, strengthen mineral conservation, and ensure that the benefits of mineral extraction reach mining-affected communities.

However, audit findings reveal that substantial challenges persist in the effective governance and utilization of mining revenues. These deficiencies highlight the continuing need for robust oversight, transparency, accountability, and citizen participation in the management of mineral wealth.

At the same time, the successful use of geospatial tools in audits demonstrates the transformative potential of technology in strengthening environmental governance and regulatory enforcement.

Going forward, sustainable and accountable mining in India will depend on a balanced approach that integrates economic development, environmental protection, technological innovation, and community welfare. Strong institutional mechanisms, transparent fund management, active participation of local communities, and technology-enabled audit practices will be essential to ensure that mineral resources are utilized responsibly for the long-term benefit of both present and future generations.

[7] Report No. 8 of the year 2022 Performance Audit on 'Illegal Mining in Rajasthan' - Government of Rajasthan

National Critical Mineral Mission: Securing Strategic Resources for India's Energy Transition

By: Shri Rohit Kirodiwal, AAO
Research Section, iCED

India has pledged to reach net-zero emissions by 2070 and has set targets in its Nationally Determined Contributions (NDCs). By 2030, at least half of the country's installed energy capacity will come from non-fossil fuels, with a goal to cut CO_2 emissions by 1 billion tonnes and reduce carbon intensity by over 45%. This shift will increase the need for critical minerals, which are essential for electric vehicles, renewable energy projects, and battery storage.

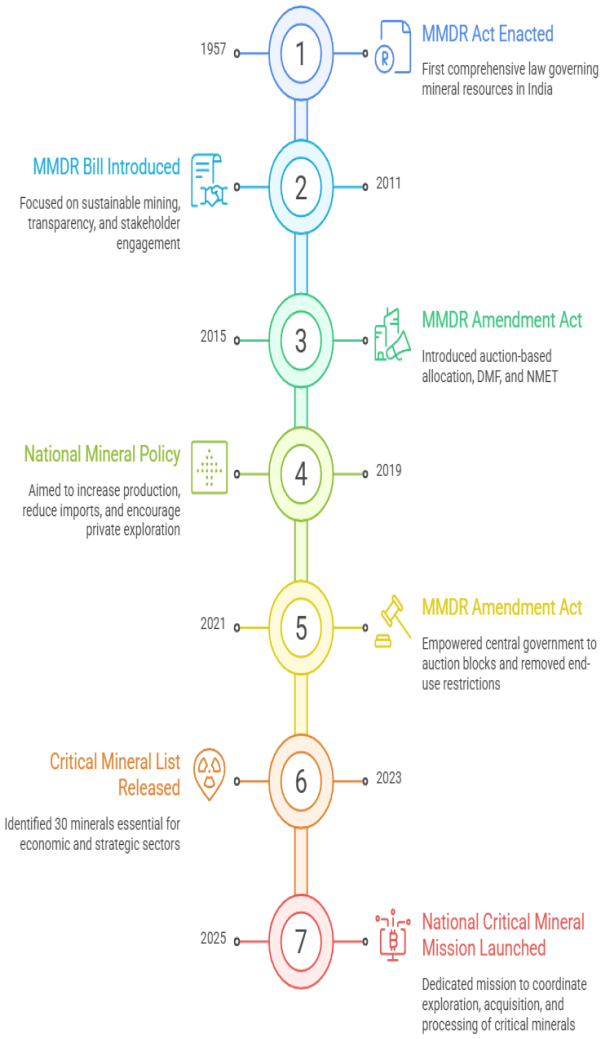
Critical minerals[24] play a vital role in modern clean energy technologies, like batteries, solar panels, wind turbines, and other generating technologies.

To achieve the net-zero emission targets, there is need of technological advancement which is dependent on critical minerals such as lithium, graphite, cobalt, titanium and rare earth elements. Identifying this need, Ministry of Mines in November 2022 constituted a seven-member committee to identify the list of critical minerals. The committee in June 2023 identified 30 critical minerals[25].

The committee also identified that India is 100 *per cent* dependent on imports in case of 10 critical minerals which are Lithium, Cobalt, Nickel, Vanadium, Niobium, Germanium, Rhenium, Beryllium, Tantalum, and Strontium.

The key milestones in India's mineral policy are depicted in Figure 1.

Figure 1: Key Milestones in Indian Mineral Policy



[24] Critical minerals are those minerals which are essential for economic development and national security, the lack of availability of these minerals or even concentration of existence, extraction or processing of these minerals in few geographical locations may lead to supply chain vulnerability and disruption.

[25] Critical Minerals of India – Ministry of Mines

National Critical Mineral Mission

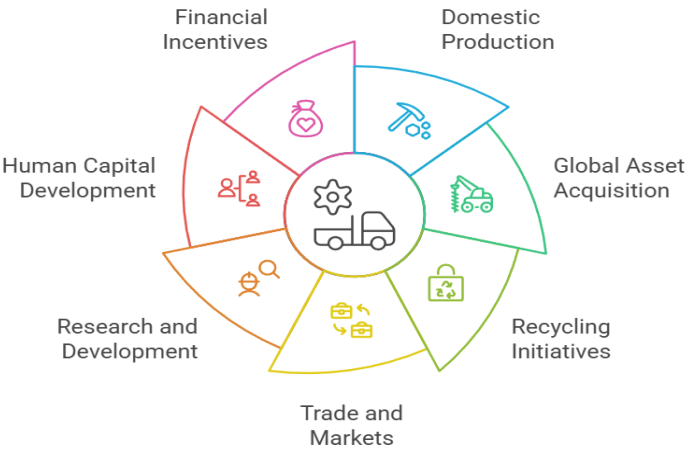
In July 2024, Government of India[26] announced setting up of "National Critical Mineral Mission" for domestic production, recycling of critical minerals and overseas acquisitions of critical mineral assets. The mission is anticipated for seven years from 2024-25 to 2030-31 with proposed expenditure of ₹34,300 crore, comprising ₹16,300 crore in form of government expenditure and ₹18,000 crore from Public Sector Undertakings (PSUs) and other stakeholders.

The mission was launched with two following objectives:

- To secure India's critical mineral supply chain by ensuring mineral availability from domestic and foreign sources.
- Strengthening the value chains by enhancing technological, regulatory, and financial ecosystems to foster innovation, skill development, and global competitiveness in mineral exploration, mining, beneficiation, processing, and recycling.

The National Critical Mineral Mission has following components[27] –

Figure 2: Components of National Critical Mineral Mission



Expected Outcome of Mission

The major outcomes[28] envisaged under the National Critical Mineral Mission are as follows:

A. Expansion of Domestic Mineral Production – To complete 1200 critical mineral exploration projects and auction 100 critical Mineral blocs by 2030-31.

B. Enhancing self-reliance in critical minerals – To meet domestic production of critical minerals up to10 *per cent* of the national annual demand.

C. Acquisition of Overseas Mineral Assets – Secure at least 50 overseas mining assets to meet 5 *per cent* of annual critical demand by 2031.

D. Promoting Circular Economy – recycle at least 10 *per cent* of the nation's annual consumption of critical minerals.

E. Research and Development – Support 100 domestic R&D projects to achieve self-sufficiency in processing of at least 5

[26] Policy Document on National Critical Mineral Mission
[27] Press Information Bureau: 9 April 2025
[28] Policy Document on National Critical Mineral Mission

critical minerals and generating 1000 patents by 2031.

F. Skilled Workforce Development – create 10,000 skilled professionals, specialised in the critical mineral sector.

G. Establishment of Centre of Excellence – establishment of four regional mineral processing parks

H. Establishment of National Stockpile – creation of National Critical Minerals Stockpile comprising of at least 5 minerals.

Governance Framework

Under the Ministry of Mines there is an Empowered Committee on Critical Minerals chaired by the Cabinet Secretary and including members from relevant stakeholders. The committee will monitor and review the activities of the mission, give board directions for investment in foreign countries and minerals, approve guidelines of sub-components, and approve changes in the mission component as may be necessary to achieve the mission objectives.

India's stride towards Critical Minerals

After the launch of National Critical Mineral Mission, Geological Survey of India has intensified its exploration of critical minerals. In 2020-21, GSI executed only 65 critical mineral projects which in 2025-26 increased to 230 (as on 5 March 2026) marking an increase of more than 3 times.

The Ministry of Mines, to conduct high quality research and development activities, has recognised seven institutes – four IITs (IIT Bombay, IIT Hyderabad, IIT-ISM Dhanbad, IIT Roorkee) and three R&D labs (CSIR – IMMT, Bhubaneshwar; CSIR-NML, Jamshedpur; NFTDC, Hyderabad) as Centre of Excellence[29] under the National Critical Mineral Mission.

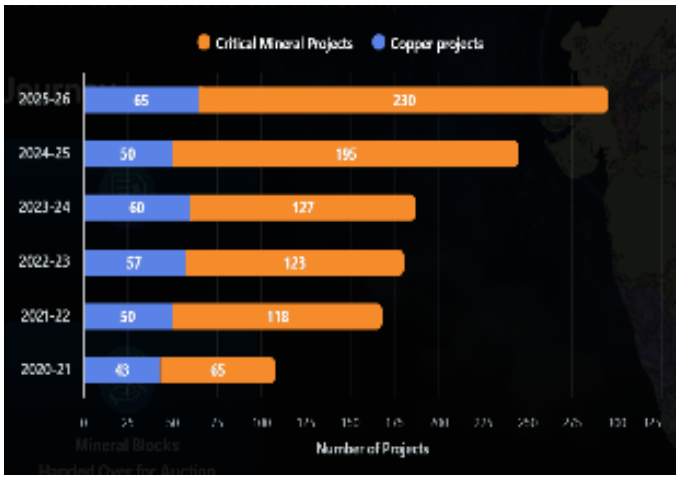


Figure 3: Exploration Projects undertaken by GSI as on 5 March 2026 (Source: Geological Survey of India)

Global Initiatives in the field of Critical Minerals

A. Sustainable Critical Minerals Alliance

In 2022, during the United Nations Biodiversity Conference (COP 15) in Montreal, Sustainable Critical Minerals Alliance[30] was announced between Canada, Australia, Germany, France, Japan, the United Kingdom and the United States.

The Alliance aims to:

- Adopt nature-positive mining practices.
- Support local and Indigenous communities.
- Combat climate change and restore ecosystems.

[29] Press Information Bureau: 1 August 2025
[30] Sustainable Critical Minerals Alliance

- Advance a circular economy.
- Promote ethical corporate practices.

Aligned with the **COP15** outcomes and the **G7 2030 Nature Compact**, the Alliance seeks to halt and reverse biodiversity loss by 2030 while supporting sustainable development.

It encourages collaboration with Indigenous groups, industry, NGOs, and international organizations such as the **United Nations Environment Assembly**, **International Energy Agency**, **World Bank**, and **Organisation for Economic Co-operation and Development**. Key areas of cooperation include sustainable mining standards, supply chain transparency, biodiversity conservation, and inclusive resource-sector initiatives. Members have committed to working through existing multilateral forums and invite other governments to join the Alliance.

B. **Quad Critical Minerals Initiative (QCMI):**

The Quad countries—India, Australia, Japan, and the United States—launched the Quad Critical Minerals Initiative[31] in 2025 to strengthen the security, resilience, and diversification of critical mineral supply chains. The initiative promotes cooperation in mining, processing, refining, recycling, and investment to ensure reliable access to minerals essential for clean energy technologies, electric vehicles, semiconductors, and advanced manufacturing. It seeks to reduce supply-chain vulnerabilities, support sustainable and responsible mineral development, and enhance economic security across the Indo-Pacific region. For India, the initiative supports the objectives of the National Critical Mineral Mission by facilitating access to strategic minerals, technology partnerships, and investment opportunities.

[31] Joint Statement from the Quad Foreign Ministers' Meeting in Washington D.C. (July 01, 2025)

Embedding ESG in Extractive Industries (EI): Governance, Disclosure and Sustainable Value Creation

By: Rahul Yadav, AAO Research
Research Section, iCED

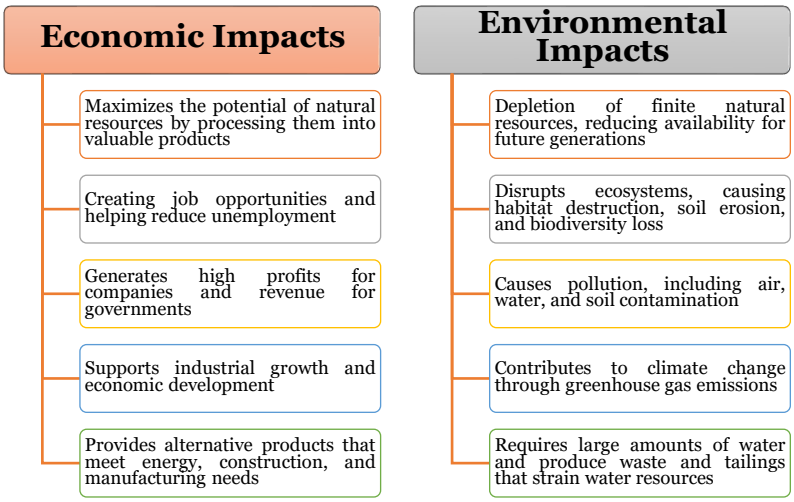
Extractive industries are defined in "***World Investment Report 2007-UNCTAD***" as primary activities involved in the extraction of non-renewable resources.[1]

The growing integration of Environmental, Social, and Governance (ESG) considerations into corporate strategy and public policy reflects a broader recognition that sustainable resource extraction must balance economic benefits with environmental stewardship, social responsibility, and institutional transparency.

The scale of the sector is immense. Minerals play a central role in the economies of **81 countries** that together account for roughly a quarter of global GDP, half of the world's population, and nearly **70 per cent of those living in extreme poverty**.[2] Critical raw materials are required for sustainable development and the transition to a green or circular economy, including renewable energy, industrialisation, mobility and urbanisation.[3]

According to ***UNEP's Global Resources Outlook 2024***, extraction of the Earth's natural resources has **tripled over the past five decades**,[4] and without corrective action, global material extraction could rise by a further **60 per cent by 2060**, seriously derailing international sustainability commitments.[5]

While the extractive industries have immense potential to drive growth and reduce poverty, they are also associated with financial,



economic, governance, social and environmental concerns. On one hand, the EIs support economic development, reducing unemployment and creating revenues for the government, on other hand it depletes the finite natural resources reducing availability for future generations.

ESG in the Extractive Sector: Concept and Evolution

ESG as a framework originated in financial markets, articulated most influentially in the UN Global Compacts' ***Who Cares Wins***

[1] UNCTAD's World Investment Report 2007 Box III.1
[2] UNEP Working Group on Transforming Extractive Industries for Sustainable Development: Introduction
[3] UNECE and SDGs
[4] UNEP Global Resource Outlook: Story
[5] Global Resources Outlook 2024 - Bend the trend: Pathways to a Liveable Planet as Resource Use Spikes

report of 2004, but has since evolved into a comprehensive tool for measuring corporate sustainability performance.[6]

Figure 1: Environmental, Social, and Governance pressures on the extractive industry

In recent years, ESG has emerged as a powerful framework for evaluating how extractive industries manage these risks while creating long-term economic value. Investors, regulators, and civil society increasingly expect companies and governments to demonstrate that natural resources are developed responsibly, transparently, and in ways that contribute to sustainable development. For resource-rich countries, the stakes are particularly high: effective governance of extractive industries can generate revenues that finance development, while poor governance can deepen inequality and perpetuate the well-documented ***"resource curse"*** *or* ***"paradox of plenty"***.

Environmental Dimension: Climate, Biodiversity, and Mine Waste

The environmental dimension of ESG in extractives is perhaps the most technically complex and politically contentious. It encompasses greenhouse gas accounting, water stewardship, biodiversity impact mitigation, and the management of physical waste, including the especially hazardous challenge of tailings.

GHG Emissions and Climate Transition Risk

The oil, gas, and mining sectors collectively account for a major share of global emissions. Beyond Scope 1 and Scope 2 emissions (direct and energy-related), Scope 3, the downstream combustion of extracted fossil fuels, represents the overwhelming majority of the sector's climate footprint and has become a central battleground for investor engagement and litigation. The extraction and processing of materials, fuels and food contribute half of total global greenhouse gas emissions and over 90% of biodiversity loss and water stress.[7]

Tailings, Water, and Biodiversity

Tailings, the slurry waste generated by ore processing, represent one of the mining sector's most material physical risks. Following the Brumadinho and Mariana disasters[8], the **Global Industry Standard on Tailings Management (GISTM)** was developed with input from UNEP and the International Council on Mining and Metals (ICMM). ICMM members' first disclosure against GISTM alignment was required in 2023, with escalating pressure on broader

[6] The Global Compact: "Who Cares Wins" Connecting Financial Markets to a Changing World

[7] https://www.un.org/en/actnow/facts-and-figures

[8] lessons from the Mariana and Brumadinho disasters

industry adoption through the new Global Tailings Management Institute (GTMI).

Social Dimension: Communities, Rights, and Social License

The social pillar of ESG, community relations, labour practices, human rights, and gender equity, is frequently the most volatile source of risk for extractive companies. The *resource curse* is as much a social and governance phenomenon as an economic one: revenues from extraction, if mismanaged, can entrench inequality, fuel conflict, and deepen poverty in host communities.

The UN Guiding Principles on Business and Human Rights (2011) establish a 'protect, respect, and remedy' framework: states must protect against corporate human rights abuses; companies must respect rights even absent state regulation; and both must ensure access to remedies. For extractive companies, this means formal processes for Free, Prior, and Informed Consent (FPIC) from indigenous communities, a standard increasingly codified in national legislation.

Research on the Ghana EITI (2025) highlights an important tension: while global mining firms broadly support EITI, community-level visibility of how their royalty payments are spent remains limited, undermining the social licence argument that transparency builds trust.[9] This points to a broader gap in current ESG reporting: disclosure must translate into tangible community outcomes, not merely satisfy investor information demands.

Artisanal and Small-Scale Mining (ASM): A Social ESG Frontier

An estimated 40 billion people are engaged in artisanal and small-scale mining globally, many in informal and hazardous conditions.[10] The UN Secretary-General's Policy Brief on Transforming Extractive Industries (2021) flagged child labour, mercury use, and absence of safety standards in ASM as urgent social challenges. GRI 14 (2024) includes ASM for the first time in a sector-specific standard, reflecting growing recognition that formalization and ESG integration in this sub-sector is essential for achieving SDG 8 (decent work) and SDG 16 (strong institutions).

Governance Dimension: Transparency, Anti-Corruption, and Public Audit

Governance failures have historically been the defining pathology of the extractive sector in developing nations. Illicit financial flows from Africa's extractive sector alone are estimated at billions of dollars annually. Beneficial ownership opacity enables corruption at licensing stages; transfer pricing erodes tax revenues; and weak public financial management prevents resource rents from reaching citizens.

Beneficial Ownership and Anti-Corruption

EITI now requires beneficial ownership disclosure, identifying the natural persons who ultimately own or control extractive companies, as a cornerstone of anti-corruption governance. The UK achieved 'best practice' status in EITI's 2021 validation specifically for its beneficial ownership

[9] The EITI: Exploring Global Extractive Firms' Interpretation in Ghana's Mining Sector

[10] https://www.worldbank.org/en/programs/egps/brief/emergency-relief-response-for-artisanal-and-small-scale-mining-communities-impacted-by-covid-19

disclosure standards.[11] At the corporate level, the OECD Anti-Bribery Convention[12] and UN Convention Against Corruption (UNCAC) provide the legal framework, while ESG rating agencies increasingly weight governance scores heavily on anti-corruption performance.

The Business Case for ESG Integration

Research published in *ScienceDirect* (2024) on ESG ratings across mining companies demonstrates that **poor ESG scores correlate with higher costs of debt**, as firms neglecting ESG investments are perceived to have greater credit risk from potential cash flow disruptions and reduced reputation capital. A 2023 KPMG survey found that over half of mergers and acquisitions dealmakers had **cancelled deals due to material ESG due diligence findings** in the mining sector. The evidence increasingly supports a virtuous cycle, companies that embed ESG into their strategies reduce operational risk, attract lower-cost capital, strengthen social license, and build durable community relationships, creating what analysts now call ***sustainable value creation***, distinct from short-term extraction rents.

Global Governance Frameworks: Multilateral Architecture for ESG in Extractives

A complex, multi-layered global governance architecture has evolved around extractive industry sustainability. Understanding its components is essential for both public auditors and corporate managers charged with embedding ESG compliance.

The Extractive Industries Transparency Initiative (EITI)

Launched at the World Summit on Sustainable Development in Johannesburg in **2002** and formally constituted in London in **2003**, EITI is the global standard for the open and accountable management of oil, gas, and mineral resources.[13] The EITI Standard, which is currently in effect in **55 countries**, mandates disclosure of the whole value chain, including how contracts and licenses are distributed, how much is produced and paid, and how public funds is used.

The EITI Standard mandates publication of contracts and licenses; production data; revenue collection by government entities; revenue allocation including subnational transfers; and beneficial ownership disclosures.[14]

EITI & ESG Convergence

EITI's multi-stakeholder model, bringing together governments, companies, and civil society, mirrors ESG's own accountability logic. Where EITI has historically focused on financial transparency (the 'G' in ESG), its evolving 2023 Standard now explicitly incorporates environmental governance, gender equity in sector benefits, and indigenous peoples' rights, bringing it closer to a full-spectrum ESG instrument.

UNEP, UNDP and the UN Working Group on Transforming Extractive Industries

[11] UK EITI, What is EITI?

[12] Combating Bribery of Foreign Public Officials in International Business Transactions

[13] Extractive Industries Transparency Initiative

[14] What is EITI? EITI International Secretariat

Responding to the COVID-19-era reassessment of development finance, the UN Secretary-General's *Financing for Development in the Era of COVID-19 and Beyond* initiative launched a dedicated "***Working group on transforming extractive industries***" in **January 2022**. Co-ordinated by **UNDP, UNEP** and the UN Regional Economic Commissions, this body serves as a knowledge hub and policy advisory centre for aligning extraction with the SDGs.[15]

The UN Environment Assembly's Resolution on Mineral Resource Governance (UNEP/EA.4/L.19), *inter alia*, requests UNEP to collect information on sustainable practices, identify knowledge gaps and options for implementation strategies, and undertake an overview of existing assessments of different governance initiatives and approaches on sustainable management of metal and mineral resources, and report to the fifth session of the UNEA.[16]

INTOSAI's Working Group on Audit of Extractive Industries (WGEI)

In the public accountability realm, the **INTOSAI Working Group on Audit of Extractive Industries (WGEI)** was established at the XXI INTOSAI Congress in Beijing in **October 2013**, with SAI Uganda as its inaugural Chair.[17] Its mandate is to *"promote audit of extractive industries within the INTOSAI community in order to support good governance and sustainable development for the UN post-2015 agenda"*, covering oil, gas, and solid minerals.

The WGEI has developed guidance tools for Supreme Audit Institutions (SAIs) to audit the entire extractive value chain, including: financial audits of revenue flows; compliance audits against licensing and contracting regulations; and performance audits of the sector's contribution to national development.[18] SAIs have at least two roles within EITI: following up on discrepancies identified in EITI reconciliation reports, and providing assurance to reported government revenue statistics.

iCED Jaipur, the International Centre for Environment Audit and Sustainable Development, serves as a ***designated Global Training Facility*** *for both INTOSAI WGEA (since March 2011) and WGEI (since August 2016).*

The Role of Supreme Audit Institutions (SAIs)

Given the scale of revenues and the complexity of governance arrangements, independent audit scrutiny is essential to ensure that natural resources are managed in the public interest. SAIs' oversight can extend across the extractive industry value chain, from ***financial audit*** (assurance that government revenues from extraction are properly accounted for), and ***compliance audit*** (whether extractive operations comply with licensing, environmental, and contractual conditions), to ***performance audit*** (whether the sector is delivering optimal public value and contributing to sustainable development). The scope of this role, however, varies across countries depending on the SAI's mandate, institutional capacity, and the maturity of the sector and its regulatory framework.

[15] The Working Group on Transforming the Extractive Industries for Sustainable Development
[16] UNEP Environment Assembly Resolution UNEP/EA.4/L.19 on Mineral Resource Governance
[17] INTOSAI Working Groups, WGEI
[18] INTOSAI WGEI Briefing Note: The Role of SAIs in the Extractive Industries Sector (2019)

The INTOSAI WGEI's Energy Transition Audit Guide, developed by SAI Brazil, adds a fourth dimension: auditing the **governance of energy transitions**, ensuring that the shift from fossil fuels to renewables is equitable, financed appropriately, and aligned with SDG commitments.[19]

Extractive industries are also closely linked to the achievement of the United Nations Sustainable Development Goals (SDGs). The SDGs emphasise economic development, social inclusion and environmental sustainability, three pillars that intersect directly with the governance of natural resources. In this context, SAIs play a critical role in assessing whether extractive sector policies, institutions and regulatory frameworks align with broader sustainable development objectives. Through independent audits, SAIs can help ensure that the management of natural resources contributes to inclusive and sustainable development outcomes.

Challenges and Emerging Issues

Greenwashing and Disclosure Quality

As ESG reporting proliferates, the risk of '***greenwashing***', presenting an overstated picture of sustainability performance has become a critical governance concern. The ISS ESG analysis of the JORC Code reforms in Australia (2024) highlights that early-stage ESG evaluation at the exploration and development phase is essential, since **a number of coal projects were cancelled in 2023 due to inadequate prior environmental impact assessments.**[20] Third-party assurance of ESG data, treated with the same rigour as financial statements, is the emerging standard.

Critical Minerals and the Green Transition Paradox

The global energy transition is driving explosive demand for critical minerals, lithium, cobalt, nickel, graphite, that underpin battery storage and renewable energy systems. This creates a profound paradox: the green economy depends on extractive industries that, if not themselves subject to robust ESG governance, could generate a new curse of critical minerals. The UN Secretary-General's Panel on Critical Energy Transition Minerals (2023-2024) is developing voluntary principles to build trust and guide this transition, supported by UNEP, UNCTAD, and partner agencies.

Just Transition and Equity

The concept of a '***just transition***', ensuring that the movement away from fossil fuels does not leave behind the communities, workers, and developing nations dependent on extractive revenues, is central to the ESG social agenda. INTOSAI WGEI's Energy Transition Audit Guide explicitly addresses the equity dimensions of transition governance, calling on SAIs to audit whether transitions are financed adequately and structured to protect vulnerable populations.

Conclusions and Recommendations

The extractive industries stand at a defining inflection point. Global capital markets, multilateral institutions, civil society, and increasingly host governments are converging on the expectation that oil, gas, and mining companies embed ESG not as a compliance exercise but as a strategic core. The

[19] INTOSAI WGEI's Energy Transition Audit Guide

[20] ISS ESG: ESG at Every Stage, JORC Reforms and Australian Mining, November 2024

governance architecture to support this transition, from EITI's transparency standards to INTOSAI WGEI's audit guidance, and UNEP's sustainable resource frameworks, is more coherent and comprehensive than at any previous point in history. The integration of ESG principles into the governance and operations of extractive industries represents a crucial step toward reconciling resource extraction with sustainable development objectives. Embedding ESG within the extractive sector requires strong regulatory frameworks, transparent disclosure practices, and effective oversight institutions capable of ensuring accountability throughout the extractive value chain. By aligning economic incentives with environmental stewardship and social responsibility, governments and companies can transform extractive industries from sources of risk into drivers of sustainable value creation.

Reimagining Risk Assessment in Extractive Industries through Artificial Intelligence and Advanced Analytics

By: Shri Rohan Sharma, AAO
Research Section, iCED

In recent years, technological advances such as satellite monitoring, big data analytics and artificial intelligence have opened new possibilities for public sector auditing. Supreme Audit Institutions (SAIs) across the world have begun integrating these tools into their audit processes to strengthen risk assessment and evidence collection. These developments provide useful insights for enhancing the effectiveness of extractive sector audits.

Extractive Sector Governance and Audit Challenges

India is one of the leading producers of several minerals including coal, iron ore and bauxite. The mining sector provides essential raw materials for industries such as power generation, steel production and infrastructure development. According to the Ministry of Mines, the sector also contributes significant revenues to state governments through royalties and other levies.[1]

However, extractive industries are also associated with complex governance challenges. These include illegal mining activities, underreporting of mineral production, environmental violations and weak monitoring of lease conditions.[2]

Emerging Role of Technology in Public Audit

Traditional auditing approaches rely heavily on physical inspections, document verification and sample-based analysis. While these methods remain essential, they may not always be sufficient to detect irregularities in sectors that generate large volumes of digital and geospatial data. Technology-enabled audit techniques can help address these limitations by enabling auditors to analyse large datasets and identify patterns of risk.[3]

INTOSAI guidelines emphasise the growing role of data analytics and digital tools in public sector auditing. According to the INTOSAI Development Initiative, advanced data analytics can support auditors in identifying anomalies, detecting fraud risks and improving audit planning through evidence-based risk assessments.[4]

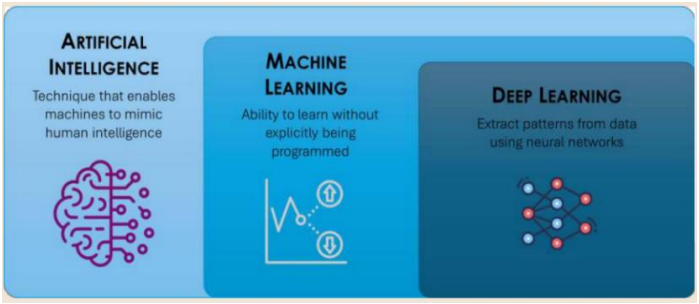


Figure 1 Artificial Intelligence, Machine Learning and Deep Learning
https://cag.gov.in/uploads/media/Artificial-Intelligence-Strategy-Framework-issued-by-CAG-of-India-068515070c7da65-91395536.pdf

uses these datasets to identify trends and detect anomalies in areas such as production reporting and royalty payments. **Deep Learning**, a more advanced form of ML, can analyse complex data such as satellite imagery to detect changes in mining areas or possible illegal mining activities. **Natural Language Processing (NLP)** complements these techniques by analysing large volumes of

[1] Annual Report 2022-23 Ministry of Mines
[2] C&AG Audit Reports
[3] CAG's Auditing Standards 2017
[4] WGITA – IDI Handbook on IT Audit

textual information, including mining leases, environmental reports and regulatory documents. Together, AI, advanced data analytics, ML, deep learning and NLP can create an integrated analytical approach that can assist auditors in examining complex datasets, identifying risks and improving audit planning in the extractive sector.

Satellite Monitoring and Geospatial Intelligence

Mining activities often occur in remote areas where frequent physical inspection may be difficult. Satellite imagery and geospatial analysis can therefore provide an independent mechanism for monitoring mining operations and verifying compliance with regulatory requirements. Remote sensing data can help identify land-use changes, expansion of mining pits and encroachment into forest areas.

The **Mine Surveillance System (MSS)** developed by the Ministry of Mines in collaboration with the National Remote Sensing Centre (NRSC) uses satellite imagery to detect suspicious mining activities. The system analyses high-resolution satellite data to identify potential illegal mining outside approved lease areas and alerts state authorities for further investigation.[5]

Satellite System	Agency	Possible Audit Application
Cartosat	ISRO	Mine boundary verification[6]
Sentinel-2	ESA	Vegetation and land-use monitoring[7]
Landsat	NASA/ USGS	Long-term environmental changes[8]
RISAT	ISRO	All-weather monitoring[9]

Advance Data Analytics for Extractive Sector

Extractive sector governance generates data across multiple government platforms, including production returns filed with the Indian Bureau of Mines, royalty payments recorded by state mining departments and transportation records of mineral dispatch. Cross analysis of these datasets can reveal discrepancies that may indicate potential irregularities.

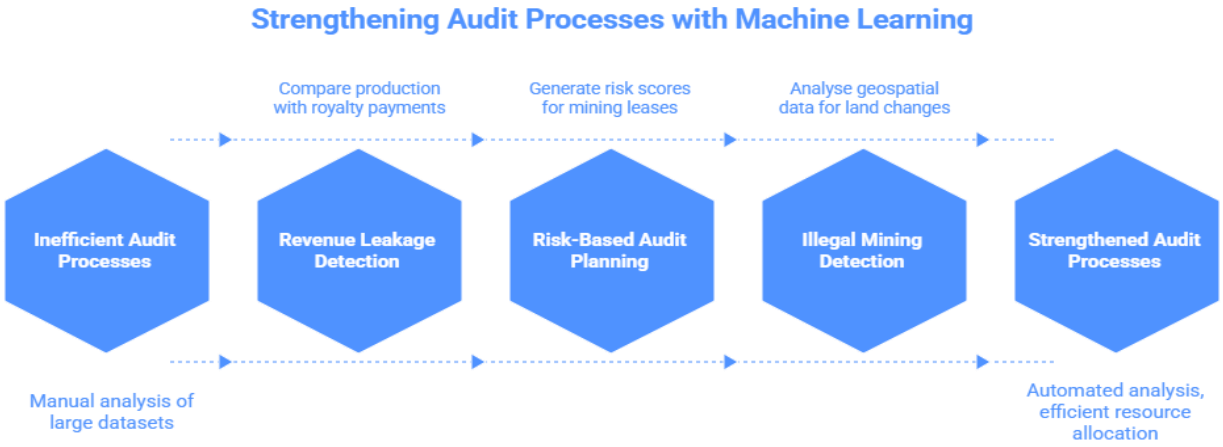
Machine Learning (ML), Natural Language Processing (NLP), and Deep Learning can significantly strengthen audit of extractive industries (mining, oil, gas, coal) by enabling auditors to analyse large datasets, detect anomalies, and monitor activities that are difficult to verify through traditional methods. For audit, these technologies can support risk identification, evidence collection, and audit planning.

a. Machine Learning in Extractive Industry Audit

Machine Learning algorithms can analyse large, structured datasets such as production returns, royalty payments, transportation records, and financial statements to identify irregular patterns.

Machine learning can play an important role in strengthening audit processes in the extractive sector by enabling auditors to analyse large datasets generated across multiple regulatory and operational platforms. One significant application is the **detection of revenue leakage**. Machine learning models can compare mineral production data reported to the **Indian Bureau of Mines**

[5] Annual Report 2024-25 Ministry of Mines
[6] ISRO, CARTOSAT-1
[7] Sentinel online
[8] NASA-Landsat
[9] ISRO, RISAT-1



(IBM) with royalty payments recorded by state governments and mineral transportation records such as railway freight data or e-way bill information.

By analysing patterns across these datasets, the models can identify inconsistencies that may indicate potential irregularities. For instance, if a mining entity reports relatively low production volumes but transportation data reflects higher dispatch quantities, the system can automatically flag the case for audit scrutiny. Such analysis helps auditors detect possible underreporting of mineral production and incorrect assessment or payment of royalties.

Another important application is in **risk-based audit planning**. Machine learning techniques can be used to generate risk scores for mining leases by analyzing multiple indicators such as past audit observations, sudden fluctuations in production levels, instances of environmental non-compliance, or delays in submission of statutory returns. By aggregating these indicators, the system can rank mining entities according to their risk profile. This allows auditors to prioritise high-risk mines for detailed examinations, thereby improving the efficiency of audit planning and ensuring optimal utilization of limited audit resources.

Machine learning can also support the **detection of illegal or excess mining activities** through the analysis of geospatial data. When combined with satellite imagery and remote sensing technologies, machine learning algorithms can identify changes in land use patterns around mining areas. These models can detect indicators such as expansion of mining pits, extraction activities outside approved lease boundaries, or significant alterations in land cover over time. Such automated analysis provides an independent mechanism for verifying mining operations and can assist auditors in identifying cases where mining activities may be occurring without proper authorization or beyond approved limits.

b. Deep Learning in Extractive Industry Audit

In the context of extractive sector auditing, deep learning can assist auditors in identifying patterns and anomalies that may not be easily detectable through conventional analytical methods.

One important application is **satellite image analysis**. Deep learning models can process high-resolution satellite imagery to identify indicators of mining activity such as illegal mining sites, expansion of mining pits, and deforestation associated with mining operations. By comparing satellite images

captured over different time periods, these models can automatically detect unusual land-use changes and flag potential cases of mining beyond approved lease boundaries.

Deep learning can also support **environmental monitoring** by analysing geospatial and environmental data to detect vegetation loss near mining areas, potential water contamination patterns, or the expansion of tailing dams and waste disposal sites. Such insights can assist auditors in verifying whether mining operations are complying with environmental clearance conditions and sustainable mining practices.

Another useful application is **fraud pattern detection**. Deep learning algorithms can analyse large financial datasets of mining companies to identify irregular transaction patterns, abnormal procurement activities, or potential related-party transactions. These capabilities can help auditors detect financial irregularities and strengthen oversight of public sector enterprises operating in the extractive sector.

An effective approach is to integrate these technologies within a broader **AI-enabled audit system**. Machine learning models can detect anomalies in production and revenue data, NLP tools can analyse regulatory documents, and deep learning algorithms can interpret satellite imagery. The integrated analysis can generate risk scores for mining entities, issue alerts regarding potential illegal mining activities, and identify possible revenue leakages. This approach enables auditors to move beyond traditional sample-based audits towards more continuous and risk-based monitoring of the extractive sector.

C. Natural Language Processing (NLP) in Extractive Sector Audit

Natural Language Processing (NLP) is a branch of artificial intelligence that enables computers to analyse and extract insights from large volumes of text-based data. In the extractive sector, auditors can use NLP to review documents such as mining leases, environmental impact assessment reports, compliance filings and legal judgments. This helps auditors quickly identify missing regulatory requirements, compliance gaps and potential risks in mining governance. The extractive sector generates large volumes of textual documents such as mining lease agreements, Environmental Impact Assessment (EIA) reports, compliance filings, court judgments, and parliamentary committee reports. Reviewing these documents manually can be time-consuming for auditors. Natural Language Processing (NLP) can assist by automatically analysing such text-based information and extracting relevant insights.

NLP can be used to review environmental compliance documents such as EIA reports to check whether required sections—such as baseline environmental data, impact assessments, rehabilitation plans and community consultation records—are properly documented. It can also analyse mining lease agreements by extracting clauses related to production limits, environmental obligations and royalty terms, allowing auditors to compare them with standard

conditions prescribed under the **Mines and Minerals (Development and Regulation) Act**.

Additionally, NLP can analyse legal and policy documents, including judgments of the **National Green Tribunal and High Courts**, as well as parliamentary reports, to identify recurring governance and compliance issues in the mining sector. This helps auditors understand systemic risks and strengthens risk-based audit planning.

Conclusion

In conclusion, technologies such as machine learning, natural language processing and deep learning have the potential to strengthen audit practices in the extractive sector. Their use can complement existing audit approaches by helping auditors handle large and complex datasets more efficiently. This makes it easier to identify unusual patterns in areas such as production reporting, royalty payments and financial transactions that may require closer examination. The adoption of such technologies is also consistent with the broader framework promoted by INTOSAI, which encourages Supreme Audit Institutions to use appropriate analytical tools to obtain sufficient and reliable audit evidence.

In addition, these technologies can assist auditors in reviewing large volumes of documentation, including mining lease agreements, environmental reports and compliance filings. By enabling faster and more systematic analysis of such records, they can reduce the time required for manual examination while helping auditors focus on areas that present higher risks or potential irregularities.

Overall, these technologies do not replace the professional judgement of auditors but rather support it. When used carefully, they can make the audit process more efficient, improve the quality of evidence available to auditors and contribute to stronger oversight of the extractive sector.

Deep Sea Mining: Strategic Imperatives, Environmental Risks & Global Governance

By: Shri T. V. S. Kalyan Chakarvarthi, Research Associate (Grade II), iCED

EXECUTIVE SUMMARY

Deep-sea mining (DSM) represents one of the most consequential frontiers in twenty-first-century resource governance. With an estimated USD 16 trillion in polymetallic nodules, cobalt-rich crusts, and seafloor massive sulphide deposits on the international seabed, DSM promises critical minerals essential for the global energy transition at a scale terrestrial reserve increasingly cannot sustain. This study examines DSM through an audit governance lens, assessing the adequacy of ISA oversight, the alignment of national frameworks with international standards, environmental monitoring architectures, and systemic accountability gaps. Drawing on UNCLOS, ISSAI standards, World Bank fiscal frameworks, and independent scientific assessments, it concludes that the current governance architecture is materially insufficient and proposes a comprehensive reform agenda

Introduction

Deep-sea mining (DSM) represents one of the most consequential emerging frontiers in global resource governance. The ocean floor, covering more than 70% of Earth's surface and designated under Article 136 of the United Nations Convention on the Law of the Sea (UNCLOS) as the "common heritage of humankind", harbours mineral concentrations of strategic global significance. The Clarion-Clipperton Zone (CCZ)[1] Alone, spanning approximately 4.5 million km² across the eastern Pacific at depths of 4,000–6,000 metres, is estimated to contain more manganese, nickel, cobalt, and copper than all known terrestrial reserves combined.[2][3]. As the global energy transition accelerates demand for these critical minerals, DSM has advanced rapidly from a speculative prospect to the threshold of commercial exploitation. This trajectory makes robust audit oversight not merely desirable but structurally necessary.

The Seabed Resource Profile

Deposit Types & Spatial Distribution

Three primary mineral deposit types constitute the commercial DSM target universe. Polymetallic nodules, potato-sized concretions at 4,000–6,000 m depth with grade profiles of 27–30% Mn, 1.2–1.5% Ni, 0.9–1.2% Cu, and 0.2–0.25% Co, represent the most advanced commercial target; DOSI estimates the CCZ alone hosts 21 billion wet tonnes.[4]. Seafloor massive sulphides (SMS) form at hydrothermal vents at 1,000–4,000

[1] **CCZ** Clarion–Clipperton Zone — a ~4.5 million km² fracture zone in the eastern Pacific Ocean; primary polymetallic nodule deposit area (4,000–6,000 m depth)

[2] U.S. Geological Survey (USGS). *Mineral Resources of the Deep Seabed*. usgs.gov.

[3] International Seabed Authority (2025). ISA Contractor Database & Annual Reports. Kingston: ISA. isa.org.jm | CCZ

[4] DOSI — Deep Ocean Stewardship Initiative (2024). Deep Sea Mining: State of the Science. DOSI Working Paper Series. dosi-project.org

m, yielding Cu, Zn, Au, and Ag. Cobalt-rich ferromanganese crusts coat seamounts at 800–2,500 m, carrying elevated Co (up to 1%), Pt, REEs, and Te, strategic minerals for which China controls over 85% of terrestrial supply.

The IEA's 2024 Critical Minerals Report projects demand for cobalt will increase by 230%, nickel by 205%, and copper by 55% under its Net Zero Emissions by 2050 scenario, driven by EV batteries, offshore wind turbines, and grid-scale storage. Terrestrial cobalt supply is 70% concentrated in the Democratic Republic of Congo, where governance deficits and geopolitical risk have catalysed strategic reframing of DSM among the EU (Critical Raw Materials Act, 2024), Japan, and South Korea.

Figure 1: Ocean depth zones and DSM deposit types: Polymetallic nodules, Cobalt crusts, and Seafloor sulphides (source: DOSI/ISA data)

Epipelagic zone (0–200 m) *Sunlight zone — fisheries, surface shipping* Photic zone; primary production; no DSM activity		0 m
Mesopelagic zone (200–1,000 m) *Twilight zone — bioluminescence, diel migration* Oxygen minimum zones; limited light penetration	**Gas hydrates** CH_4; depth >500 m	200 m
Bathypelagic zone (1,000–4,000 m) *Midnight zone — low temperature, high pressure* Chemosynthetic ecosystems; hydrothermal vents	**Seafloor sulphides** Cu, Zn, Au, Ag	1,000 m
Abyssal zone (4,000–6,000 m) *Polymetallic nodule-abundant plains (CCZ)* Low temperature (~2°C); high pressure (~600 atm)	**Cobalt crusts** Co, Pt, REE, Te	4,000 m
Hadal zone (>6,000 m) *Trenches — extreme pressure* Limited DSM activity	**Polymetallic nodules** Mn, Ni, Co, Cu	6,000 m
Seabed / benthic substrate		11,000 m

International Regulatory Framework

UNCLOS and the ISA Mandate

The legal foundation for international seabed governance is provided by the United Nations Convention on the Law of the Sea (UNCLOS, 1982), specifically Part XI and the 1994 Implementation Agreement. These instruments declare the seabed beyond national jurisdiction, the Area to be the Common Heritage of Mankind (CHM), to be administered by the International Seabed Authority on behalf of humanity as a whole. The CHM principle carries profound governance implications: resource benefits must be shared equitably, particularly with developing states; exploitation must not occur to the detriment of current or future generations; and the Area must be managed for the benefit of humanity as a whole, not merely licence holders.

The ISA, headquartered in Kingston, Jamaica, and comprising 170 member states and the European Union as of 2025, is simultaneously the regulator, the administrator of the common heritage, and, through its Enterprise arm, a potential commercial operator. This structural conflict of interest represents a foundational governance vulnerability that external auditors and civil society organisations[5] have repeatedly highlighted as incompatible with international best practices for regulatory independence[6].

[5] UNCLOS (1982/1994). | ISA 30th session summary

[6] World Bank (2023). Due Diligence Assessment of Deep-Sea Mining Governance. Washington, D.C.: World Bank Extractive Industries. worldbank.org

ISA Contracts & Licensing Architecture

The ISA has developed separate regulatory frameworks (Regulations) for each deposit type: polymetallic nodules, seafloor massive sulphides, and cobalt-rich ferromanganese crusts. These Regulations govern the 31 active exploration contracts awarded to state enterprises, research institutions, and, through sponsoring state arrangements, private sector entities. The unadopted Mining Code governs the transition from exploration to commercial extraction, and its completion has been repeatedly delayed, most recently following the 2023 ISA sessions that exposed deep divisions among member states over environmental standards, benefit-sharing rates, and the enforcement mechanism[7].

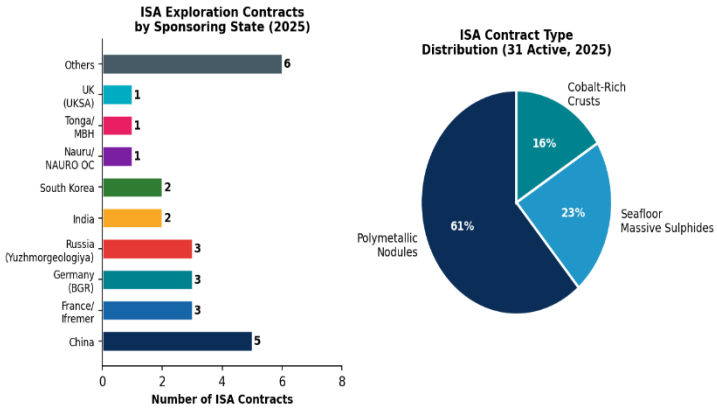


Figure 2: ISA exploration contracts by sponsoring state and deposit type — 31 active contracts as of 2025 (Source: ISA Contractor Database)

India's Deep Sea Mining Technology: State of Readiness (2025)[8]

India has made significant technological strides in deep-sea mining capability, with two landmark developments demonstrating operational readiness. The design and systems engineering of MATSYA-6000. India's first indigenous human submersible capable of carrying three aquanauts to 6,000 metres depth has been completed by the National Institute of Ocean Technology (NIOT), Chennai; all subsystems have been realised, wet tests were successfully conducted at L&T Harbour, Katupalli (January–February 2025), and NIOT scientists gained pilot experience aboard the French submersible NAUTILE in August 2025. Complementing this, India's seabed mining system, designed to collect polymetallic nodules from the seabed and crush them for hydraulic pumping, has been developed and tested for mobility and system-powering at 5,270 metres depth in the Central Indian Ocean (2021), with exploratory mining trials subsequently conducted at Andaman Sea sites in 2024. The SAHAV portal, launched in 2025, further strengthens India's ocean governance infrastructure as a real-time digital platform integrating oceanic data for evidence-driven governance, marine resource tracking, climate forecasting, and disaster early warning

Environmental Risk & Impact Assessment

Ecosystem Vulnerability

The abyssal and hadal zones targeted by DSM harbour biodiversity of extraordinary complexity and endemic character. Scientific surveys in the CCZ have identified more than 5,000 species, most of which are undescribed. Vent-associated SMS deposit areas host unique chemosynthetic ecosystems, including tubeworms, giant clams, and

[7] ISA Regulations 2015 revised

[8] India's Deep-sea mining

thermophilic microorganisms whose biodiversity and ecological functions are only partially understood. Critically, the sediment plumes generated by collector vehicles and discharge pipes, potentially extending hundreds of kilometres from mining sites based on modelling by the National Oceanography Centre (UK) and MBARI (USA), represent the most broadly distributed impact pathway, with effects on pelagic filter feeders, lateral oxygen minimum zones, and potentially on deep-water fisheries extending far beyond the contracted areas.

Environmental Management Plans: Audit Assessment

ISA regulations require contractors to submit Environmental Management Plans (EMPs) and annual environmental monitoring reports under the framework of the International Seabed Authority (ISA) and its draft exploitation-phase rules. The ISA's Environmental management plan for the Clarion-- Clipperton Zone (CCZ)* (ISA, 2023) provides a regional-scale[9] biodiversity and monitoring framework, including nine APEIs and a recommendation that the Legal and Technical Commission (LTC) periodically review the effectiveness of the management plan. The World Bank's 2023 Due Diligence Assessment of DSM governance concluded that existing Environmental Impact Assessment (EIA) requirements fall materially below the standards applied to analogous mining operations in terrestrial jurisdictions, specifically OECD Environmental Due Diligence Standards, the Equator Principles, and the IFC Performance Standards, creating a structural governance arbitrage that effectively externalises environmental risk onto the global commons.[10]

Governance challenges of DSM[11]

- **The ISA's Regulatory and Financial Gridlock:** The International Seabed Authority (ISA) is partially functioning due to its conflicting roles as a multilateral forum, mining regulator, royalty distributor, and environmental protector. The transition to commercial mining is stalled because the ISA's 170 members cannot agree on the "Mining Code," particularly regarding complex financial mechanisms. Unresolved issues include determining whether to charge profit-sharing royalties and whether to redistribute these funds through direct disbursements to member states or via a global Seabed Sustainability Fund.
- **Corporate Circumvention and the Threat to Multilateralism:** Because of the ISA's slow progress, some mining entities are exploiting jurisdictional gaps to bypass the UN Convention on the Law of the Sea (UNCLOS) entirely. For example, Canada's The Metals Company has announced intentions to seek commercial permits under the domestic laws of the United States, which is not a signatory to UNCLOS. This unilateral approach threatens to make the multilateral governance system irrelevant before it is even fully developed, directly

[9] ISA regularity frameworks
[10] World Bank (2023). Due Diligence Assessment of Deep-Sea Mining Governance. Washington, D.C.: World Bank Extractive Industries. worldbank.org
[11] Insight brief DSM

challenging the designation of the deep seabed as the "common heritage of mankind".

- **Scientific Deficits and Severe Legal Risks for Investors:** The deep ocean remains profoundly unexplored; in the heavily targeted Clarion Clipperton Zone, over 90% of known species are new to science. This extreme lack of baseline data makes it nearly impossible to accurately monitor environmental harm or enforce liability, driving widespread calls from nations, major corporations, and insurers for a moratorium on mining. Furthermore, investors and offshore engineering firms backing unauthorised unilateral mining face vast regulatory risks. Civil society and concerned parties could use national courts to enforce international law against entities attempting to profit from mining outside the established UNCLOS framework.

Key International Frameworks & Policy Recommendations

UNCLOS Part XI and the 1994 Implementation Agreement constitute the foundational legal framework. The ISA's Mining Regulations (available at isa.org.jm), Environmental Management Plan framework, and the 2011 Environmental Management Plan for the CCZ provide the primary regulatory reference. The BBNJ Agreement (High Seas Treaty, 2023 ratification ongoing) introduces marine protected area provisions that will materially constrain DSM in the high seas' context. The ISA's Strategic Plan 2019–2023 and its successor framework articulate institutional priorities and performance benchmarks.[12]

Scientific & Technical Resources

The Deep Ocean Stewardship Initiative (DOSI) maintains the most comprehensive and independent synthesis of DSM science, with working groups on ecology, geochemistry, physical oceanography, and socioeconomics. GRID-Arendal's DSM knowledge portal provides accessible visualisations of resource distributions and environmental risk assessments. The Clarion-Clipperton Zone Environmental Management Plan Area (CCZEMP) database, maintained by the ISA, provides contractor-reported monitoring data, though coverage and quality remain inconsistent. The MIT Sea Grant Centre for Coastal Resources maintains an independent technical assessment capacity.

Policy recommendations[13]

- **Moratorium & Corporate Circumvention:** The scientific evidence is unequivocal that DSM would cause irreversible damage to deep-sea ecosystems — recovery, if it occurs at all, would take centuries to millennia. The UN Special Rapporteurs on Human Rights have concluded that, together, scientific uncertainty, potential environmental harm, and human rights risks require a precautionary pause under international law. With The Metals Company (TMC) bypassing the ISA by seeking exploitation permits directly from the US government, the Coalition urges ISA member states to

[12] UNCLOS
[13] Deep-sea conservation

support a moratorium publicly, prohibit approval of any Plan of Work for exploitation unless key environmental and equity conditions are met, reject flawed exploitation regulations without a new completion timeline, and issue a robust collective response to corporate attempts to circumvent the UNCLOS framework.

- **Governance Reform & Environmental Policy:** The ISA Assembly is urged to adopt a binding General Environmental Policy rooted in UNCLOS and international environmental principles, applicable across all ISA organs, building on the support already expressed by 70 member states during the 30th Session. Critically, the ISA's mandatory five-year governance review under UNCLOS Article 154 is now overdue by three years; its immediate initiation in a transparent, inclusive, and comprehensive manner is essential to restoring institutional credibility. Together, these two actions, a moratorium grounded in the precautionary principle and an overdue governance review, represent the minimum necessary response to prevent irreversible harm to the global commons before commercial exploitation begins

Financial & Economic Resources

The IMF Fiscal Affairs Department's technical assistance reports on seabed mineral taxation (2024) and the World Bank's Governance of Extractive Industries Program provide fiscal governance benchmarks. The IEA Critical Minerals Market Review (annual) provides demand projections. The OECD Responsible Mineral Supply Chain Due Diligence Framework provides supply chain audit standards applicable to DSM contractors. Bloomberg NEF's deep-sea mining investment-tracking database provides financial market analysis. Independent financial modelling of the CCZ project's economics by analysts at Imperial College London and the University of Exeter provides a peer-reviewed cost-benefit analysis.

Table 1: DSM governance framework comparison — ISA/UNCLOS vs OECD mining standards vs EITI (Source: ISA, OECD, EITI Secretariat 2024)

Governance Dimension	UNCLOS/ ISA	OECD Mining	EITI Standard
Environmental EIA	Partial	Full	Full
Revenue Transparency	Voluntary	Mandatory	Mandatory
Independent Audit	None	Periodic	Annual
Community Consent	Not required	Required	Required
Monitoring Frequency	Annual (self)	Quarterly	Quarterly
Enforcement Powers	Weak	Strong	Moderate
Benefit Sharing	Proposed	Established	Established

Findings & Recommendations

Principal Audit Findings

Finding 1 — Structural Conflict of Interest

The ISA's simultaneous roles as regulator, CHM administrator, and potential commercial operator constitute a material conflict of interest violating regulatory independence principles. Resolution requires structural separation or establishment of an independent Technical Regulatory Authority[14], as recommended by the 2022 ISA Independent Review Group.[15]

Finding 2 — Inadequate Environmental Baseline

Of 31 active exploration contracts, only 7 have completed baseline surveys meeting ISSAI-compliant evidential standards. Commercial exploitation decisions based on existing baselines would lack the scientific foundation[16] required to implement the precautionary approach under UNCLOS Article 145[17]

Finding 3 — Revenue Transparency Gap

No standardised, independently audited financial disclosure exists for DSM contractors, creating conditions for systematic underreporting of economic benefits, transfer pricing manipulation, and failure to realise the CHM benefit-sharing mandate[18].

Finding 4 — Enforcement Deficit

The ISA has issued no formal compliance notices against any contractor for environmental monitoring failures over the past 30 years, despite documented non-compliance in multiple inspection reports. This finding is materially inconsistent with effective regulatory oversight[19].

Finding 5 — Climate Governance Linkage Gap

No systematic assessment exists of the implications of large-scale seabed sediment disturbance for carbon release. Preliminary NOC/MBARI research suggests abyssal sediment disturbance could generate CO_2 releases not captured in existing DSM environmental assessments[20].

Reform Recommendations

1. Establish an independent DSM Technical Regulatory Authority with financial independence from the ISA Council, funded through a contractor levy.
2. Mandate ISSAI-compliant environmental baseline surveys as a prerequisite for any exploitation licence, with data deposited in a publicly accessible ISA Open Data Repository.
3. Adopt EITI-aligned mandatory financial disclosure for all DSM contractors, including transfer pricing documentation, independently audited within 6 months of each financial year.
4. Establish a DSM Enforcement Office with legal standing to issue binding compliance notices, suspend operations,

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and refer violations to ITLOS, funded through contractor bonds held in escrow.

5. Commission, through DOSI and IOC-UNESCO, a comprehensive ocean carbon accounting framework specific to DSM sediment disturbance, integrated into EIA requirements before any commercial extraction licence is granted.

6. Implement the overdue UNCLOS Article 154 Periodic Review immediately, a treaty obligation and precondition for credible governance reform.

Conclusion

Deep-sea mining stands at a critical inflection point where the urgency of the global energy transition collides with the irreversibility of deep-ocean ecological harm. The current ISA governance architecture is structurally compromised, marked by conflicts of interest, an inoperative enforcement mechanism, absent financial transparency, and scientific baselines inadequate for sound regulatory decisions. Corporate circumvention of the UNCLOS framework, exemplified by The Metals Company's 2025 US permit application, threatens to render the multilateral regime irrelevant before commercial exploitation even begins. For India, simultaneously a Pioneer Investor since 1987, a co-architect of the 1994 Implementation Agreement, an active ISA Council member, and a technology investor with MATSYA-6000 trials completed and a ₹4,077 crore Deep Sea Mission underway, the governance stakes are both strategic and constitutional. India possesses the standing, leverage, and obligation to champion accountable DSM governance internationally; while ensuring its own Deep Sea Mission is subjected to the same ISSAI-aligned audit scrutiny it advocates at the ISA. The common heritage of humankind demands nothing less.

Experiences from Other SAIs and Faculties

Making Europe's Electricity Grid Ready for a Net-Zero Future

Sara Pimentel, Principal Auditor – European Court of Auditors

Ms. Sara, esteemed faculty at iCED Jaipur, delivered session on Making the EU Electricity Grid for Net-Zero Emissions: An Audit Case Study from the European Court of Auditors (ECA) during the International Workshop on "Renewable Energy Sector and its Audit"

The global transition towards clean energy is accelerating and electricity grids are becoming the backbone of this transformation. During the International Workshop on *"Renewable Energy Sector and its Audit"* held on 16-20 February 2026 at the International Centre for Environment Audit and Sustainable Development (iCED), discussions focused on how electricity grids must evolve to support a net-zero emission future.

The presentation, delivered by Sara Pimentel, senior auditor, European Court of Auditors highlighted the growing pressures on electricity infrastructure across the European Union and examined the investments, policies, and reforms required to modernize the grid system.

Why Electricity Grids Matter

Electricity demand in the European Union is expected to rise significantly in the coming decades, with electrification increasing from 23% in 2022 to a projected 57% by 2050. Electrification is considered one of the most important pathways for decarbonisation.

However, electricity cannot exist without grids. Modern electricity systems are becoming increasingly complex as they must accommodate a rapidly growing share of renewable energy sources such as wind and solar power. Unlike conventional energy systems, renewable generation is highly variable and intermittent, requiring grids to become smarter, more flexible, and more resilient.

The transition is transforming the traditional electricity system, characterised by single-directional energy flow, into a far more complex system involving intermittent generation, smart transmission and distribution grids, energy storage facilities and bidirectional energy flows. This shift demands investments and presents challenges for grid planning and deployment of new technologies.

About the Review

The exercise conducted by the European Court of Auditors was a review rather than a performance audit. Unlike audits, reviews do not provide formal conclusions or recommendations. Instead, they analyse existing policies, challenges, and opportunities using publicly available information and consultations with relevant stakeholders.

The review covered the key challenges and opportunities associated with making electricity grids fit for net-zero objectives and examined the initiatives undertaken at both EU and national levels to address them. Matters related to the security of the internal electricity market, including cybersecurity and data protection, were excluded from the scope. At the EU level, the review assessed policies related to electricity grids and provided an overview of EU funding available for grid infrastructure investments during the 2014–2020 and 2021–2027 programme periods, including the CEF, ERDF, CF, JTF, RRF, and the Modernisation Fund. At the national level, the review examined planned grid investments by grid operators, the regulatory schemes used for their remuneration, and the measures adopted to improve the electricity system's ability to respond to changes in supply and demand.

Review approach:

The review was conducted through seven modules covering the Commission's actions for grid modernisation, regulatory schemes, grid planning and investment needs, and the financial capacity of grid operators. The approach included reviews of legislation and documentation, questionnaires to national regulatory authorities, analysis of grid development plans of TSOs and major DSOs, and financial analysis using Moody's and ORBIS data. It also involved information visits to Germany and Italy, discussions with key European energy organisations and stakeholders, and consultations with external experts.

Observations:

Grid Investments in the EU

One of the key observations was that the scale of future investment requirements is substantial. Current planned investments by grid operators (around EUR 1.9 trillion) remain below the European Commission's estimated requirement of EUR 2–2.3 trillion by 2050 and are roughly twice historical grid investment levels in the EU. Uncertainty nevertheless increases over time and across underlying grid scenarios.

At the same time, grid infrastructure projects often take significantly longer to complete than renewable energy projects themselves. Planning and permitting alone can consume nearly half of the total project timeline. Grid planning currently involves more than 260 plans prepared at different levels with varying time horizons, while permitting procedures involve multiple authorities and jurisdictions, extended consultations, and legal challenges.

The availability of specialised equipment, raw materials, and skilled labour has also emerged as a growing concern across Europe.

Optimising grid investment

Flexibility measures can significantly reduce the need for additional grid infrastructure investments. Greater flexibility can be achieved through smart technologies, stronger interconnections between neighbouring countries, storage solutions, demand-response measures, and adaptable generation capacity.

As demand-side management and storage technologies continue to develop, electricity systems are becoming better equipped to

manage fluctuations in supply and demand. These measures can improve system reliability while reducing the pressure for large-scale grid expansion.

Funding grid investments

Regulatory frameworks determine grid operators' revenues by balancing policy goals such as investment, cost control, and efficiency. They play a crucial role in incentivising efficiency and innovation, although no single regulatory approach is optimal in every context.

The review highlighted that:

- several EU funding instruments exist but remain underutilised;
- returns on equity for grid operators are declining;
- Distribution System Operators (DSOs) generally face higher credit risks than Transmission System Operators (TSOs); and
- regulators must strike a balance between encouraging investment and keeping electricity prices affordable for consumers.

This balance is particularly important for households and energy-intensive industries already facing rising energy costs.

Key Challenges Identified

Three major categories of challenges:

Accelerating grid investment: Challenges include ineffective, complex, and fragmented grid planning, lengthy permitting procedures, limited public acceptance, and shortages of equipment, materials, and skilled labour.

Optimising grid development and reducing investment needs: Key issues include the slow roll-out of smart meters in some member states and storage solutions, such as batteries and renewable hydrogen, that are either insufficiently advanced or remain too expensive.

Funding investments: Major concerns involve balancing investment needs with affordable electricity prices for consumers, particularly households and energy-intensive industries, maintaining grid operators' access to finance, and accelerating investments while limiting the risk of spending on projects that may later prove unnecessary or underutilised.

Emerging Opportunities

Accelerating grid investment: Opportunities include better coordinated and integrated grid planning practices, streamlining permitting procedures and enhancing public engagement, greater use of modern technology solutions and transparent tools such as capacity maps, as well as training and upskilling initiatives to address labour shortages.

Optimising grid development and reducing investment needs: Key opportunities lie in strengthening interconnections between member states, expanding the use of advanced grid technologies, applying demand-response measures to reduce demand peaks, developing and scaling up new storage solutions, and increasing the role of prosumers and energy communities.

Funding investments: Opportunities include the use of appropriate regulatory frameworks to incentivise efficient investments and making full use of available EU funding initiatives.

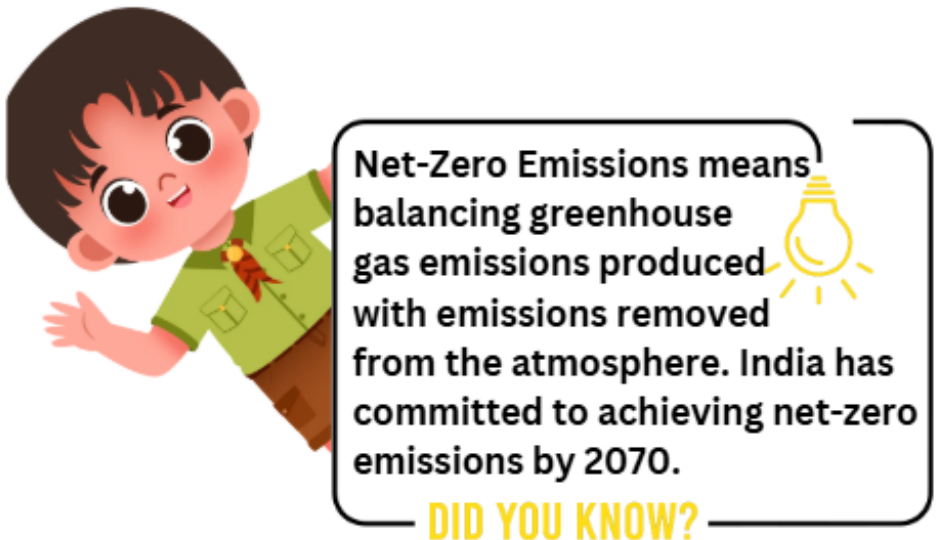
Conclusion

The transition to a net-zero future is not only about generating clean electricity; it is equally about building the infrastructure capable of delivering it reliably and efficiently.

Europe's electricity grids are entering a period of unprecedented transformation. While the investment needs and implementation challenges are substantial, the opportunities offered by smart technologies, better planning, flexible systems, and coordinated policies are equally significant.

The discussions at the iCED workshop underscored that modernising electricity

grids are essential for ensuring energy security, supporting renewable integration, and achieving long-term climate objectives. The success of the clean energy transition will ultimately depend not only on producing green energy, but also on building grids capable of sustaining the energy systems of the future.



Auditing Renewable Energy: Guiding the Energy Transition of Indonesia

Laode Nusriadi (Director General of Audit VI/Acting Director General of Audit IV) and Normas Andi Ahmad (Senior Auditor)
The Audit Board of the Republic of Indonesia

Mr. Normas, esteemed faculty at iCED Jaipur, delivered session on Audit of Renewable Energy Sector: A Case Study from SAI Indonesia during the International Workshop on "Renewable Energy Sector and its Audit"

The global energy sector is currently contributing more than 70% of total greenhouse gas emissions and is undeniably at the frontline of the battle against climate change. However, the transition from fossil fuels in Indonesia extends beyond the environmental mandate to being a fundamental strategy for achieving long-term and resilient national energy security anchored on four critical pillars of Availability, Accessibility, Affordability, and Acceptability (4As). The development of the renewable energy infrastructure is identified as the definitive key to unlock each of these pillars and is presented as follows:

a. **Availability**: The achievement of energy security requires a reliable supply that can consistently meet increasing national demands. Traditional fossil fuels are finite and vulnerable to eventual depletion, but renewable sources such as solar, wind, and geothermal offer an abundant and inexhaustible supply. Therefore, significant investment in these sustainable technologies can guarantee perpetually available power reserves for Indonesia towards ensuring an indefinite supply.

b. **Accessibility**: Energy needs to be physically reachable by all segments of the population, and this is a significant hurdle for an archipelagic country. The hurdle is transformed by renewable energy and modern infrastructure at two levels. At the localized level, decentralized generation such as off-grid solar installations allows the country to bypass traditional limitations by ensuring direct transmission of reliable power to isolated and rural communities. Indonesia is also planning to develop an interconnected national super grid at the macro level. This ambitious infrastructure is expected to connect the main islands with the aim of bridging the massive geographical divide between resource-rich regions and high-demand population centres. The purpose is to ensure clean energy is accessible across the entire archipelago.

c. **Affordability**: A secure energy system needs to maintain equitable and stable prices for both daily consumers and businesses. The initial infrastructure for renewables requires significant startup investment but current operational costs are exceptionally low because the "fuel" harnessed from the sun and wind is completely free. The continuous reduction in the costs of renewable technology allows the shift to clean

energy to effectively insulate the Indonesian economy from the volatile price spikes of global fossil fuel markets. This subsequently leads to the securing of cheaper and more predictable long-term energy costs.

d. **Acceptability**: The increase in global awareness of environmental degradation leads to the rejection of power sources that significantly pollute society or the planet. The transition to clean energy guarantees that power generation produces zero harmful greenhouse gases or toxic pollutants. This important shift protects public health, preserves fragile ecosystems, and ensures the national energy strategy is fundamentally in line with crucial international climate targets.

Indonesia has established aggressive national targets to scale its renewable capacity in line with the need to secure the four pillars. An example is the National Energy Policy which mandates renewables to constitute more than 70% of the National Energy Mix by 2060.

The achievement of these targets requires anchoring national policy in the framework of Just Energy Transition. The trend shows the need for a truly successful shift away from fossil fuels to be beyond emission reductions to the distribution of the associated risks, opportunities, and socio-economic benefits equitably across society. There is also the need to ensure the transition considers all stakeholders by safeguarding vulnerable communities and fossil-dependent workers from bearing the brunt of the shift while actively advancing inclusive economic development and the creation of high-quality green jobs.

A core challenge of the transition is the determination of the energy mix that secures both the energy independence and social resilience of Indonesia. Historically, national energy policies have been predominantly demand-driven but the achievement of true self-reliance requires Indonesia to move towards a balanced demand-and-supply-driven model. This method dynamically satisfies national energy needs while strategically maximizing the utilization of the diverse and localized natural resources owned by the country. The aim is to ensure the deployment of clean energy directly empowers local economies and communities rather than to only feed centralized demand.

The ability to successfully leverage the 4As through the transition can drive the long-term strategy of the country for low-carbon development towards ensuring a secure and sustainable pathway to net-zero emissions by 2060.

The Audit Board of the Republic of Indonesia (BPK) is very important in monitoring the energy transition of the country by evaluating the utilization of renewable energy and biofuel. Over the past several years, BPK has conducted performance audits to assess different facets of this transition which are presented as follows:

- In 2017, BPK audited the renewable energy policy landscape and infrastructure development initiatives.
- In 2019, the focus shifted to assessing efforts aimed at improving the investment climate for renewable energy businesses.
- In 2020, an audit specifically examined the utilization of the Palm Plantation Fund for biodiesel provision.

- In 2022, management of coal, natural gas, and renewables was evaluated to ensure the availability, affordability, and sustainability of energy.
- In 2023, the focus moved towards assessing the preparedness of renewable energy adoption with a significant emphasis on electricity provision and grid technology development.

The efforts to ensure a comprehensive evaluation motivate the BPK to engage a diverse array of stakeholders. These include government ministries, the private sector such as power producers and operators, non-governmental organizations, and independent experts providing scientific validation. Rigorous procedures such as document reviews, site inspections of several power plants, and focus groups were used by BPK to identify several critical hurdles slowing the energy transition process. These are further considered in making the following recommendations:

- **Harmonizing Policy and Regulation:** There is a clear opportunity to streamline cross-sectoral regulations in order to accelerate the deployment of clean energy. Moreover, the simplification of complex licensing procedures across the forestry, trade, and industry sectors can resolve administrative bottlenecks and provide a more efficient and predictable environment for developers.
- **Refining Resource Data for Strategic Planning:** The updating of baseline data on national renewable resources can significantly improve project planning. Furthermore, the accurate differentiation of practical and accessible capacity from theoretical potential such as excluding geothermal reserves located in legally protected conservation areas is capable of allowing policymakers and investors to make more reliable and evidence-based decisions.
- **Empowering the Domestic Supply Chain:** The active development of capacity for the domestic industries is a very important next step for a self-sustaining transition in addition to the current local content policy. The provision of targeted support for local manufacturers can also assist in gradually reducing the current dependence on importing 70 to 80% of solar power plant components which is capable of improving the national economy and creating green jobs.
- **Upgrading and Interconnecting Grid Infrastructure:** The efforts to overcome the archipelagic geography of Indonesia require modernized and interconnected grid solutions. Therefore, the immediate upgrade of high-voltage transmission lines and substations can safeguard grid stability and proactively bridge the spatial gap between the vast untapped renewable potential in the eastern regions and the high-demand industrial centers in the west.
- **Strengthening the Financial Framework:** The navigation of the transition successfully requires proactive economic management because the shift to clean energy is projected to temporarily increase electricity production costs by approximately 32.79%. Therefore, the government can carefully manage national energy subsidies by formulating

comprehensive funding schemes and restructuring tariffs while mobilizing concrete capital to achieve high-profile pledges such as the Just Energy Transition Partnership (JETP). This financial clarity is needed to enable both large-scale infrastructure development and early retirement of legacy coal-fired plants.

- **Ensuring Fully Sustainable Supply Chains:** There is a critical need to elevate the environmental standards of the domestic nickel mining industry as high-capacity battery storage becomes very important for managing intermittent renewable energy. Therefore, the implementation of stricter and sustainable practices in the extraction and processing of these vital components is required to prevent ecological degradation and deforestation towards ensuring the energy transition is truly green from start to finish.

The risks are recommended by the BPK to be resolved through the following:

1. Update renewable energy policies to provide long-term certainty for developers.
2. Improve cross-sectoral coordination through formal inter-ministerial mechanisms.
3. Streamline one-stop service licensing processes to reduce bureaucratic friction.
4. Enhance data accuracy through a centralized and legally verified online dashboard.
5. Refine pricing mechanisms and streamline fiscal incentives.
6. Update grid codes and accelerate the deployment of smart grids and advanced metering systems.
7. Mobilize funding to support domestic research and development.
8. Strengthen oversight mechanisms to keep infrastructure development on schedule.
9. Formulate comprehensive financial frameworks to manage rising production costs and coal retirement.

The audit interventions have served as a catalyst for significant progress in ensuring the steady growth of the renewable energy capacity installed from 9,833 MW in 2018 to 15,630 MW in 2025. This physical expansion was fortified by new forward-looking regulations directly influenced by the findings of BPK. Moreover, the key legislative updates include Presidential Regulation No. 112 of 2022 regarding the acceleration of power plant development, Presidential Regulation No. 11 of 2023 empowering local governments, and Government Regulation No. 40 of 2025 which updates the National Energy Policy to optimize renewable resources. The continuous refinement of the legal landscape and the insistence on rigorous oversight allow the audit process to ensure that the momentum of energy transition in Indonesia is matched by transparency, accountability, and the resilience needed to achieve net-zero emissions by 2060.

Waste-to-Energy Technologies: Current Landscape, Challenges and Future Pathways

Shri Pravinjith K P
Managing Director, Paradigm Environmental Strategies Pvt. Ltd

Mr. Pravinjith delivered session on Waste-to-Energy Technologies: Current Landscape, Challenges, and Future Pathways during the International Workshop on "Renewable Energy Sector and its Audit"

Waste-to-Energy (WtE) technologies are becoming an essential component of sustainable solid waste management systems across the world. Rapid urbanization, industrial growth, and changing consumption patterns have significantly increased municipal solid waste (MSW) generation. According to global estimates, municipal waste generation may reach 3.75 billion tons annually by 2050. Traditional landfill-based waste disposal practices are no longer environmentally or economically sustainable due to increasing land scarcity, methane emissions, groundwater contamination, and public health concerns. As a result, countries are increasingly shifting toward integrated waste management systems that combine recycling, composting, and Waste-to-Energy technologies.

WtE technologies convert waste materials into usable forms of energy such as electricity, heat, and fuel. These systems not only reduce waste volume but also support renewable energy production and contribute to climate-change mitigation. Advanced WtE plants can reduce waste volume by over 90%, significantly reducing the burden on landfills.

Global Waste Scenario and Environmental Concerns

The growing waste crisis has become a major environmental challenge for both developed and developing countries. In 2016 alone, solid waste treatment and disposal generated approximately 1.76 billion tons of carbon dioxide emissions, accounting for nearly 5% of global CO2 emissions. Open dumping and uncontrolled burning of waste are major sources of air pollution, particulate matter, and greenhouse gas emissions.

The environmental impacts of conventional energy generation further strengthen the case for renewable and waste-derived energy systems. A typical 1 MW renewable energy plant can save nearly 1,000 tons of coal annually while avoiding significant emissions of sulphur dioxide, nitrogen oxides, carbon dioxide, and fly ash. Waste-to-Energy systems therefore contribute not only to waste management but also to cleaner energy production and reduced dependence on fossil fuels.

Major Waste-to-Energy Technologies

Waste-to-Energy technologies can broadly be classified into thermal and biological processes. Thermal technologies include incineration, gasification, pyrolysis, plasma incineration, and co-incineration. These systems are generally suitable for non-recyclable and combustible waste streams.

Incineration remains the most widely used WtE technology globally because of its ability to handle large quantities of mixed municipal waste.

Biological technologies mainly include biomethanation and anaerobic digestion processes. These methods are suitable for biodegradable waste such as food waste, agricultural residues, animal dung, and organic municipal waste. During anaerobic digestion, microorganisms break down organic matter in the absence of oxygen, producing biogas containing methane and carbon dioxide. The biogas can be used for cooking, electricity generation, vehicle fuel, and industrial heating applications.

Technology Trends and Innovation

The WtE sector has witnessed significant technological advancement in recent years. Artificial Intelligence (AI) and Internet of Things (IoT) technologies are increasingly being integrated into waste management systems for automated segregation, process optimization, and emission monitoring. Smart robotic systems are now capable of identifying and separating recyclable materials with high precision.

Modern WtE facilities are also focusing on higher energy recovery efficiency and stricter environmental compliance. Countries such as Japan and several European nations have adopted advanced flue-gas treatment systems that significantly reduce harmful emissions. In addition, new decentralized waste processing models are being explored for smaller cities and rural areas where centralized infrastructure may not be economically feasible.

Biogas and Bio methanation Systems

Biogas technology is particularly important for countries like India where organic waste constitutes a major portion of municipal solid waste. Biogas mainly contains methane (60–75%) and carbon dioxide (25–35%) along with traces of hydrogen and hydrogen sulphide. It is considered a clean and renewable fuel with multiple applications including domestic cooking, electricity generation, street lighting, and compressed biogas (CBG) production. Biomethanation systems can be categorized into wet and dry anaerobic digestion systems. Wet digestion requires dilution of biomass with water and is commonly used for food waste and slurry-based feedstocks. Dry digestion systems operate at higher solid concentrations and are suitable for agricultural waste and solid organic materials. Technologies such as Valorga, Dranco, Kompogas, and Bekon processes are examples of modern dry digestion systems.

Challenges in Waste-to-Energy Development

Despite the numerous benefits, WtE technologies face several technical, financial, and institutional challenges. High capital investment requirements remain one of the major barriers, particularly in developing countries. Large thermal WtE plants require significant infrastructure investment along with advanced pollution-control systems.

Another major challenge is poor waste segregation at source. Mixed waste streams reduce the efficiency of both thermal and biological processes and increase operational complexity. Emission management is also a critical concern, especially in incineration-based systems, where flue gases may contain harmful pollutants if not properly treated. In addition, many WtE projects face financial viability issues due to subsidized

conventional electricity tariffs and inadequate policy support.

Future Pathways and Policy Recommendations

The future of Waste-to-Energy development depends on stronger policy frameworks, public awareness, and technological innovation. Governments need to promote segregation of waste at source, improve collection systems, and encourage private-sector participation in waste management projects. Carbon-credit mechanisms and renewable-energy incentives can improve the economic viability of WtE projects.

Decentralized bio methanation systems, cleaner thermal technologies, and integrated solid waste management approaches are likely to shape the future of the sector. In addition, research and development in advanced recycling, hydrogen recovery, and carbon-capture technologies may further enhance the sustainability of WtE systems. Waste-to-Energy technologies therefore

represent a critical pathway toward achieving circular economy goals, clean energy transitions, and climate resilience.

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Green Campus & Sustainability Corner

Biodiversity at iCED Campus[1]

Brahminy Starling (*Sturnia pagodarum*)

Image Source: Captured by Shri. Rahul Yadav, AAO

Its adaptability to moderately disturbed habitats makes it a familiar yet ecologically important species in many parts of India.

Belongs to the family Sturnidae and is a distinctive passerine bird widely distributed across peninsular and central India.

Easily identified by its warm buff to orange-brown body, contrasting grey wings, and a glossy black crest with elongated feathers that sweep backward, giving it an elegant appearance. The pale bluish-white iris stands out prominently against the darker head, the bill is yellow with a bluish base, and the overall plumage presents a smooth, silky texture.

This species is commonly found in open woodlands, dry deciduous forests, agricultural landscapes, and urban gardens, often seen perched conspicuously on tree branches in pairs or small groups. It feeds on a mixed diet of fruits, insects, and nectar. The breeding season typically extends from March to June, during which it nests in tree cavities or abandoned woodpecker holes.

Bougainvillea (Araucaria heterophylla)

Image Source: Captured by Shri. Rahul Yadav, AAO

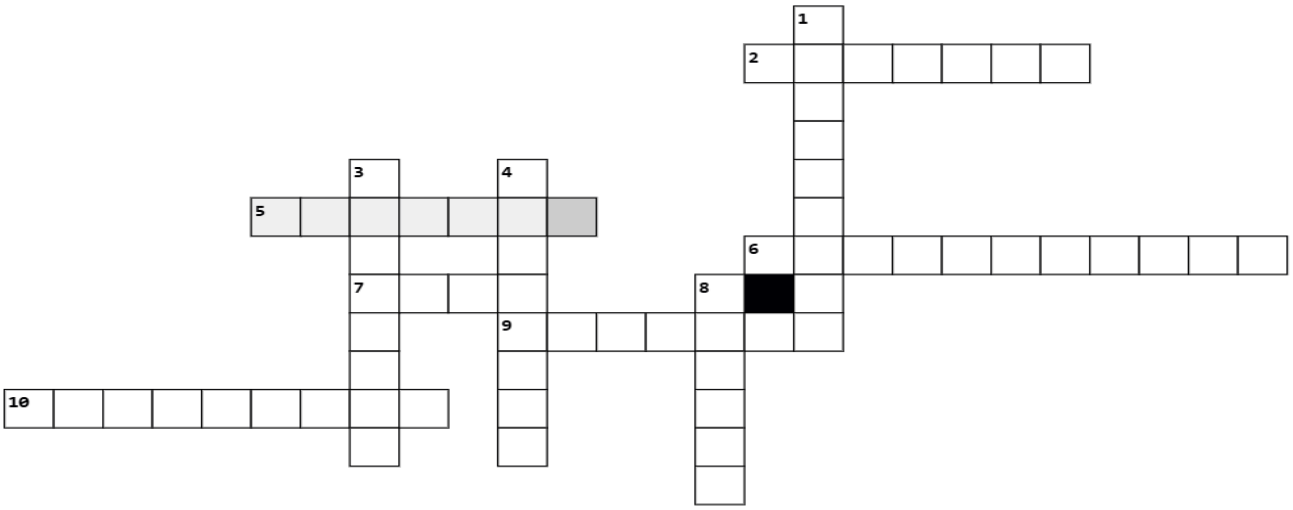
Commonly called “Paper Flower” is a hardy ornamental climber from the family Nyctaginaceae. It is recognized for its bright, papery bracts in shades of pink, purple, red, orange, and white, which surround small, inconspicuous flowers. In India, it blooms mainly from winter to summer, with peak flowering in dry conditions. It thrives in full sunlight and well-drained soil, requiring minimal water. Regular pruning encourages bushy growth and more blooms. Its drought tolerance, thorny stems, and low maintenance make it ideal for Indian gardens, fences, and urban landscaping.

Fertilize the plant every two to four weeks during the growing season with a balanced, water-soluble fertilizer formulated for houseplants.

[1] Picture is captured in the iCED Campus by Shri Rahul Yadav, AAO Research Section, iCED

Knowledge Corner

Crossword Puzzle



Across

2. Greenhouse gas heavily emitted during oil and gas extraction activities.

5. Toxic heavy metal often released through mining activities

6. Process of restoring mined land to usable condition.

7. black fossil fuel widely used in thermal power plants

9. Mineral commonly used in rechargeable batteries and electric vehicles.

10. Open excavation method used for surface mineral extraction.

Down

1. Fossil fuel extracted through offshore drilling and widely used for energy production.

3. Method of extracting oil and gas by injecting high-pressure fluid underground

4. Process of boring deep holes for extraction of oil or natural gas.

8. Process of digging and removing valuable minerals from the earth

Answers of the crossword puzzle

Across
2. Methane 5. Mercury 6. Reclamation 7. Coal 9. Lithium 10. Quarrying
Down
1.Petroleum 3. Fracking 4. Drilling 8. Mining