المركز الوطني للرقابة على الالتزام البيئي
National Center for Environmental Compliance
المملكة العربية السعودية

نبراس
NPRAS
المنصة الوطنية لاستشراف البحث والابتكار للاستدامة
National Platform of R&I Analytics for Sustainability

وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture

Innovation Trends in the Environment Sector

Pollution Control and Compliance

Foreword

His Excellency Eng. Abdulrahman Abdulmohsen AlFadley

Minister of Environment, Water, and Agriculture

The Kingdom's leadership believes in the importance of research and innovation to build a knowledge-based economy and achieve true diversification of the national resources, especially in the vital, priority sectors of environment, water, and agriculture. The Ministry of Environment, Water, and Agriculture aims to enable partners across the innovation ecosystem to stimulate and localize technologies to provide effective sustainability solutions within the Ministry's sectors.

His Excellency Eng. Mansour bin Hilal Al Mushaiti

Vice Minister of Environment, Water, and Agriculture

The innovation ecosystem enjoys unlimited support and keen interest from our wise leadership, may God support them. The Ministry of Environment, Water, and Agriculture has taken several steps to enable innovation, including establishing a deputyship for research and innovation to help find innovative solutions for issues related to sustainability of natural resources, environmental protection, meeting basic water and food needs, and achieving economic and developmental outcomes.

Foreword

Dr. Osama Ibrahim Faqeeha

Deputy Minister for Environment

The government of the Kingdom of Saudi Arabia has attached the utmost importance to protecting the environment and natural resources, as one of the three main pillars of achieving sustainable development. For this purpose, the National Environment Strategy was adopted, which included 64 initiatives to advance all environmental scopes and restructure their sector. This includes establishing specialized environmental centers and an environment fund that is considered the largest in the region, which will stimulate environmentally friendly practices and technologies. The strategy also aims to adopt a new environmental system compatible with global best practices, another waste management system built on the foundations of the circular economy, and a meteorological system.

The government also launched the Saudi Green Initiative, which includes planting 10 billion trees across the Kingdom. This ambitious goal aims to rehabilitate 40 million hectares of land and restore natural green spaces in accordance with the approved road map. By doing so, the initiative aims to contribute to restoring vital environmental functions, such as reducing dust and sandstorms and improving air quality. This initiative also aims to protect 30% of the Kingdom's terrestrial and marine areas, and manage them in accordance with international best practices.

Preserving the environment, both locally and globally, requires collaboration among all relevant stakeholders. This includes scientific and academic institutions working in tandem with specialized government agencies to provide the necessary knowledge base and scientific research. These efforts help guide initiatives addressing various environmental issues, such as climate change, biodiversity preservation, and restoration of degraded lands. Given the interconnected and expansive nature of the environmental field, leveraging technologies and fostering innovation becomes crucial. This enables the national environmental sector to progress and effectively tackle its challenges.

Technologies are a critical enabling factor to achieve the goals of the National Environment Strategy, which requires innovative methods for monitoring ecosystems, protecting against overgrazing and desertification, improving waste management practices, monitoring and reducing pollution, and improving monitoring and forecasting systems for weather phenomena and fluctuations. These technologies will contribute to enhancing the protection of the Kingdom's environment and its biodiversity, and ready-to-use technologies applied in other places around the world will help provide effective solutions that contribute to achieving environmental sustainability and the goals of environmental protection within the Kingdom's Vision 2030.

Dr. Abdulaziz bin Malik Al-Malik

Deputy Minister for Research and Innovation

The Kingdom of Saudi Arabia has placed increasing emphasis on strengthening its research, development, and innovation (RDI) ecosystem, recognizing the pivotal role that emerging technologies play in maximizing the economic value of the environmental sector and enhancing resource efficiency to ensure sustainability for future generations. This strategic direction reflects the ambitions of the national RDI ecosystem for the coming two decades, placing environmental sustainability and essential needs, namely food and water security, at the forefront of its priorities. These efforts are driven by ambitious targets to achieve Net Zero by 2060 and increase renewable energy production capacity to 50% by 2030.

In light of rapidly accelerating global transformations, accelerating the pace of "Environmental Innovation" has become not merely a strategic option, but a foundational pillar to enable major national initiatives such as the "Saudi Green Initiative," and to transform climate challenges into promising investment opportunities that contribute to diversifying the national economy.

In alignment with this momentum, this report serves as a key output of the National Platform of Research and Innovation Analytics for Sustainability (NPRAS), providing an in-depth analytical perspective on the global and local landscape. The report aims to monitor high-priority technology groups with the highest impact, and understand trends in patents and green investments, thereby empowering decision-makers and investors with accurate, reliable data. This ensures that national efforts are strategically channeled toward areas that secure a global competitive advantage for the Kingdom.

At the Ministry of Environment, Water, and Agriculture, we reaffirm that effective integration between government entities, the private sector, and the research community represents the cornerstone for achieving this desired transformation. We remain committed to fostering an attractive environment for adopting innovations and elevating sector readiness to integrate modern technologies and ultimately realizing a resilient and sustainable environmental ecosystem capable of addressing future challenges, in fulfillment of the goals of Saudi Vision 2030.

Foreword

Ali bin Saeed Al-Ghamdi

Chief Executive Officer of the National Center for Environmental Compliance Control

Amid the significant transformation taking place in the environmental sector in the Kingdom, the Environment System continues to advance through the integration of its regulatory, operational, and technical roles—enhancing efficiency and elevating compliance levels in alignment with the objectives of Saudi Vision 2030.

Building on this integration, this report reflects the system's direction toward embracing innovation and leveraging advanced technologies to address environmental challenges. It is grounded in data analysis, trend foresight, and the development of decision-support tools, while also underscoring the role of knowledge as a fundamental pillar in improving environmental performance and strengthening national capabilities to achieve environmental sustainability.

Within this context, the Center plays an enabling role within the Environment, Water, and Agriculture ecosystem by developing regulatory frameworks, enhancing environmental monitoring and compliance tools, and enabling environmental compliance through data-driven and emerging technology-based solutions. These efforts contribute to institutional integration and improve the overall efficiency of environmental operations across the Kingdom.

The report also emphasizes the importance of partnerships among relevant stakeholders, the integration of efforts between the public and private sectors, and the role of society in supporting environmental initiatives—collectively reinforcing sustainability and delivering the desired positive impact.

In conclusion, this report represents a step within an ongoing journey to advance environmental work through innovation and integration. It reflects the Center's commitment to building a more sustainable future—one that is driven by knowledge, technology, and partnership, under the guidance and support of the Kingdom's wise leadership.

National Platform of R&I Analytics for Sustainability "NPRAS"

نبراس
NPRAS
المنصة الوطنية لاستشراف البحث والابتكار للاستدامة
National Platform of R&I Analytics for Sustainability

The Ministry of Environment, Water and Agriculture has placed research and innovation at the forefront of its priorities to advance its sectors and ensure their long-term sustainability. Through its Executive Plan for Research and Innovation, the Ministry aims to effectively direct research and innovation efforts toward national priorities and strengthen sustainability in support of the Kingdom's Vision 2030 objectives. In line with this commitment, the Ministry recently launched the National Platform of R&I Analytics for Sustainability, "NPRAS", which aggregates accurate and up-to-date data related to the environment, water, and agriculture sectors. The platform analyzes this data using advanced analytical tools such as big data analytics, artificial intelligence, generative AI, agentic AI, and scenario analysis tools. NPRAS relies on more than **10,000** local and international sources, including databases of scientific publications, patents, sectoral reports, and news, and it monitors over **100** million data points updated daily. This enables the platform to deliver precise insights that support evidence-based research and innovation decision-making within the environment, water, and agriculture sectors.

NPRAS serves as an effective model for transforming data into insights with tangible national impact. It supports leaders, decision-makers, and policymakers by providing data-driven guidance and strategic insights that enhance innovation adoption policies and identify promising technologies to address national challenges. The platform also equips investors with information that helps mitigate investment risks and uncover opportunities aligned with national priorities. Moreover, it opens the door for innovators and entrepreneurs to better understand sectoral needs and funding opportunities. For researchers and scientists, NPRAS provides access to a network of scientists and researchers, highlighting innovation and research gaps, and priority areas—thereby enhancing scientific collaboration and facilitating the practical application of research outcomes.

Policymakers and Decision-Makers

- Data-driven and analytical decision-making
- Strategic insights to improve policies
- Identifying promising technologies for national challenges

Investors

- Data that reduces investment risks
- Investment opportunities aligned with national priorities
- Access to data on high-impact projects

Innovators and Entrepreneurs

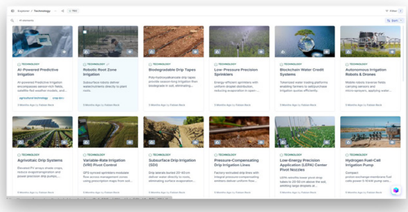
- Access to the needs of national sectors
- Data on partnership opportunities and financing for promising technologies
- Highlighting innovative solutions

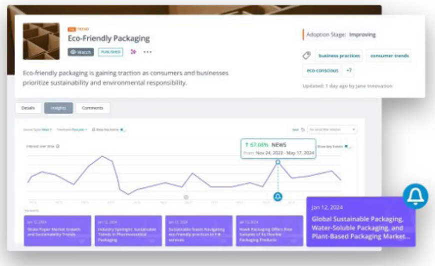
Researchers and Scientists

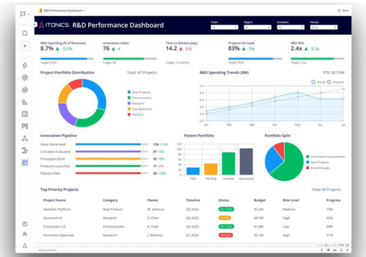
- Data on leading scientists and researchers
- Identifying research gaps and priorities
- Data that strengthens collaboration to apply research outcomes

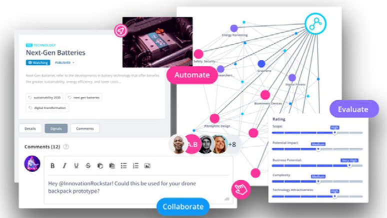
National Platform of R&I Analytics for Sustainability “NPRAS”

NPRAS offers a comprehensive suite of solutions that include platform access as well as specialized value-added services. The platform continuously monitors and anticipates technological trends by tracking the latest global innovations and developments and aligning them with the needs of the Kingdom’s sectors. It also supports decision-making by providing dashboards and analytical methodologies that enable relevant entities to assess technological solutions and select the most suitable ones.



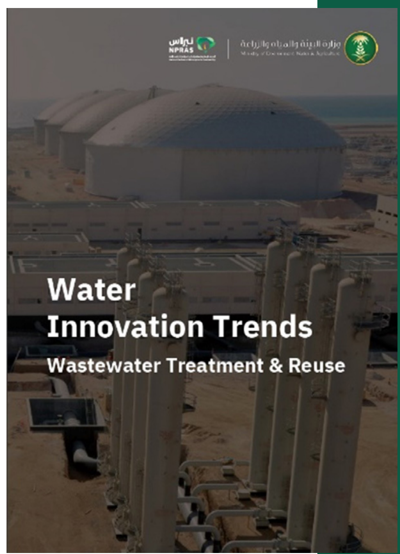






Furthermore, the platform promotes knowledge dissemination, generating analytical reports, and knowledge briefs that help raise awareness of emerging technologies, their impact, and opportunities for adoption. It also enhances scientific collaboration by offering a space for interaction among experts, researchers, and relevant stakeholders to foster joint efforts and knowledge exchange.

NPRAS specialized services also include the development of technology adoption roadmaps in collaboration with various entities, helping them adopt effective technological solutions at lower costs. In addition, the platform publishes periodic sectoral reports highlighting key technologies, trends, and future opportunities, as well as a monthly innovation brief that tracks the most important global and local technological developments in a simplified and practical manner. NPRAS additionally provides knowledge-based and training workshops that support knowledge transfer, clarify practical technology applications, and strengthen technical and innovation-related collaboration.



In September 2025, the platform published its first report, titled “**Water Innovation Trends: Wastewater Treatment & Reuse**” The report examined the most prominent technological innovation trends, innovation-support policies, and investment opportunities in emerging technologies, serving as a strategic reference for policymakers, sector leaders, investors, and entrepreneurs. It included insights from several leaders in the private sector, reflecting the pivotal role of national companies and adding a practical, market-oriented dimension to the report. Additionally, the report provided data-driven insights supported by interviews with innovation leaders, offering a practical framework that supports ongoing efforts to advance innovation in the water sector in alignment with the objectives of Saudi Vision 2030.

Thus, NPRAS Platform serves as the Ministry’s foresight arm, transforming data into insights that support research and innovation decision-making. It aims to support advancing the development of the environment, water, and agriculture sectors, and to strengthen water and food security as well as environmental sustainability—all in alignment with the national priorities for research, development, and innovation.

About the report

The strategic direction of the sectoral innovation system necessitates continuous and comprehensive monitoring of key technology and innovation trends. This is essential to enable stakeholders across various sectors to refine their policies and strategic plans in response to an increasingly complex and competitive global landscape, both technologically and economically. To support this effort, the Ministry of Environment, Water, and Agriculture established the NPRAS Platform, a dedicated platform designed to utilize advanced monitoring tools and analytical methodologies. Its objective is to guide the innovation ecosystem within the environment, water, and agriculture sectors by identifying and prioritizing technologies and innovations with the highest potential impact at the sectoral level.

This series aims to achieve several aspects:

1. **Raising stakeholder awareness** of emerging technologies, market dynamics, best practices, and global policies related to innovation in the environment, water, and agriculture sectors.

2. **Accelerating efforts to localize and deploy environmental technologies** by highlighting the most ready technologies that can enhance the efficiency and sustainability of the environment sector.

3. **Enable strategic decision-making** by providing policymakers, industry leaders, and investors with data-driven insights to guide innovation initiatives.

This report is one in a series of regular sector-specific publications issued by the NPRAS Platform, which is committed to tracking and analyzing innovation trends within the environment, water, and agriculture sectors. This edition focuses on the environment sector, offering a detailed examination of 6 technology priority groups (TPG) that demonstrate strong potential across the sector's value chain. It provides insights into the latest trends, emerging developments, and key opportunities to shape the future of the environment sector.

This report is part of five reports issued by NPRAS on the environment sector. It aims to identify trending technologies that contribute to solving sectoral challenges in the Kingdom of Saudi Arabia.

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Executive Summary

This report examines the future of environmental innovations in Saudi Arabia by analyzing one technology priority group and its alignment with national strategies. It provides stakeholders with actionable insights into challenges, opportunities, and technology pathways that can enhance productivity, resilience, and sustainability across the environmental value chain.

Building on this foundation, the report follows a rigorous, three-stage methodology aligned with global best practices specifically the OECD Framework for Anticipatory Governance ensuring that its insights are not only robust and in-depth but also actionable for driving innovation and policy development. The first stage in the OECD framework is systematic monitoring, where the NPRAS Platform tracks +10,000 sources (scientific publications, patents, industry reports, and news) with 100M+ data points, updated twice daily to identify signals of high-interest technologies. The second stage is technology trend analysis, where technologies are evaluated for momentum, innovation maturity, and relevance to national environmental challenges. Moreover, redundancy is removed by clustering similar innovations. The final stage is technology assessment. Where rapidly evolving, high-impact technologies are selected and then examined in greater depth to assess their strategic significance and inform relevant policy decisions. Additionally, environmental experts were consulted to validate the identified technologies, provide practical insights on adoption and relevance, and ensure the report reflects both data-driven evidence and sector expertise.

The environment innovation trends report builds upon the Innovation in the Environment Sector in Saudi Arabia – Technology Adoption Roadmap report, which will highlight the key technology segments within each technology priority group (TPG), stating relevant technologies under each technology segment from each TPG. A chart will assist in selecting the top technologies, with each one assessed based on Innovation and Interest scores (refer to Figure [4]). This report will highlight and focus on one TPG (Pollution Control and Compliance) following one key selected technology within the TPG: **Dynamic Emissions and Carbon Metering from the Pollution Control and Compliance TPG.**

In the Technology Spotlight section, the report delves into detailed insights for each selected technology, highlighting key players, Capability Readiness Level (CRL), Technology Readiness Level (TRL), technology advantages & disadvantages, key signals & facts, current state, localization, future trajectory, key uncertainties, and local case studies.

The selection criteria used for scoring the four technologies are based on the technology table described in the Appendix. The two criteria are: Technology Readiness level (TRL) and Spotlight Score*

In conclusion, the report incorporates insights gathered from interviews with innovation leaders, providing an overview of key priorities. These insights collectively serve as a guiding framework for policymakers, industry leaders, and investors to foster innovation and advance the sustainable environment sector in alignment with Vision 2030.

*a composite score of current research volume (no. of patents & scientific publications in 2024) and growth rate (2019-2024 CAGR of patents and scientific publications) in relation to the leading technology in the priority field. A score of 100 indicates that the technology ranks first among the 15 selected technologies in both research volume and growth rate, whereas a score of 0 indicates that it ranks last in both areas.

Introduction

The environment sector in the Kingdom of Saudi Arabia today stands at the intersection of critical ecological challenges and unprecedented technological opportunities. Globally, environmental systems are facing increasing pressures due to biodiversity loss, land degradation, waste accumulation, and climate change, all of which threaten the sustainability of natural resources and the resilience of ecosystems. In the Kingdom, these challenges are further intensified by vast arid landscapes, limited water and soil resources, and the need for sustainable management of biodiversity and ecosystems.

Nevertheless, these challenges present significant opportunities for innovation, as emerging technologies enable the Kingdom to enhance environmental management, ranging from ecosystem monitoring systems that provide real-time insights into biodiversity and habitat health, to advanced waste management and circular economy solutions, in addition to innovative irrigation techniques for trees and wild plants. These technologies support data-driven decision-making, predictive environmental modeling, and improved resource efficiency, thereby contributing to the protection of natural capital and the reduction of environmental impacts.

Within the framework of the Kingdom of Saudi Arabia's national objectives, **the Saudi Green Initiative aims to ensure that %50 of electricity generation comes from renewable energy sources by 2030,** as part of broader efforts to enhance environmental sustainability and reduce carbon emissions. This is complemented by measures to protect %30 of the Kingdom's land and marine areas, as well as initiatives to plant 10 billion trees to further strengthen environmental sustainability. The report examines the current state of the technologies under the environmental technology priority groups, their national capability maturity, readiness levels, global key players, and potential pathways for local adoption. It additionally presents data on the expected economic and environmental impacts of implementing these technologies, providing a guided framework to support policymakers, investors, researchers, and innovators in adopting innovative and sustainable environmental solutions.

By focusing on innovation, strategic planning, and effective partnerships, the Kingdom can restore and protect its ecosystems, achieve sustainable resource management, and become a global model for environmental stewardship, in line with the objectives of Saudi Arabia's Vision 2030 for sustainable development, environmental protection, and enhancing the quality of life for society.

Scope of the Report [1/4]

This report centers on the advancement of Saudi Arabia's environment sector by examining one technology priority groups (TPG): "Pollution Control and Compliance". It explores global key players, Capability Readiness Level (CRL), Technology Readiness Level (TRL), technology advantages & disadvantages, key signals & facts, current state, localization, future trajectory, key uncertainties, and local case studies.

The report offers actionable insights to guide stakeholders in adopting cutting-edge technological solutions that support the Kingdom's goals for a resilient and innovative environmental future.

Target Audience:
This report is developed for the key stakeholders driving the transformation and sustainability of Saudi Arabia's environmental sector.

Leaders and Decision Makers
Senior officials and executives within Saudi ministries, authorities, and government-affiliated organizations who shape national strategies and lead sustainability initiatives across the Environment, Water, and Agriculture (EWA) sectors.

Policymakers
Government officials and advisors responsible for formulating environmental-related policies and regulations in line with Saudi Arabia's Vision 2030, national priorities, and regional development plans.

Investors
Public and private sector stakeholders, including sovereign funds, local investment firms, and strategic partners committed to financing innovative, high-impact environmental technologies and infrastructure projects within the Kingdom.

Researchers and Scientists
Experts from Saudi universities, research centers (such as KAUST and KACST), and specialized institutes driving R&D to advance sustainable environmental solutions tailored to the Kingdom's unique environmental context.

Innovators and Entrepreneurs
Saudi-based startups, incubators, and technology developers creating localized, scalable innovations to address challenges in environmental productivity, resource efficiency, and sustainability, aligned with national goals for food security and sectoral transformation.

The report outlines key advancements across the four technology priority groups and presents data on their potential economic and environmental impact, highlighting the need for targeted investments and supportive policies. These insights align with Saudi Arabia's Vision 2030 objectives, reinforcing the importance of adopting innovative solutions and strategic planning to enhance environmental productivity, and sustainability.

Scope of the Report [2/4]

Strategic Benefits and Alignment with National Goals

The alignment of environmental innovation with national strategic objectives represents a cornerstone of sustainable development, particularly within the context of Saudi Arabia's transformative Vision 2030 framework. The Kingdom's ambitious environmental agenda encompasses comprehensive ecosystem restoration, sustainable resource management, and circular economy principles that collectively aim to diversify the economy while preserving natural heritage for future generations. Saudi Arabia has committed to achieving 50% of its electricity capacity from renewable sources by 2030 and net zero greenhouse gas emissions by 2060, demonstrating unprecedented environmental ambition. This strategic alignment becomes increasingly critical as Saudi Arabia positions itself as a global leader in environmental stewardship through initiatives such as the Saudi Green Initiative and the Middle East Green Initiative. Within this strategic context, one key TPG emerge as fundamental pillars for achieving these national environmental goals:

Pollution Control and Compliance

Pollution Control and Compliance encompasses technologies and systems designed to prevent, monitor, mitigate, and ensure regulatory compliance related to environmental contamination. It includes solutions for **air pollution prevention and mitigation** (e.g., emission control technologies and air quality management systems), water pollution prevention and mitigation (e.g., advanced treatment and discharge control technologies), and **soil pollution prevention and remediation** (e.g., contamination detection and soil restoration methods). This group also covers **pollution monitoring technologies**, including real-time sensing, remote monitoring, and data analytics platforms that track pollutant levels and support regulatory reporting. Collectively, these technologies enable effective environmental protection, compliance with standards, and informed decision-making to safeguard ecosystems and public health.

Scope of the Report [3/4]

Environment Sector Challenges and Opportunities

Figure 2 provides an analytical overview of the primary environmental challenges and corresponding opportunities within the five areas. This framework serves as a diagnostic tool that identifies the areas requiring immediate attention and highlights where technological and policy interventions can generate the greatest environmental and socioeconomic impact. The environmental sector in the Kingdom faces key challenges such as loss of biodiversity, desertification, overgrazing, waste accumulation, and rising air and water pollution, in addition to limited climate-forecast accuracy and the impacts of global climate change. These issues create opportunities to advance the sector through sustainable technologies and practices, including ecosystem restoration, improved rangeland management, expanded recycling, enhanced pollution monitoring, and strengthened climate-forecast systems. Such efforts are essential to achieving the environmental sustainability targets of Saudi Arabia's Vision 2030. By systematically mapping these challenges and opportunities, the framework provides a foundation for strategic decision-making, and enabling policymakers, researchers, and environmental planners to align national sustainability goals with practical technological applications, ensuring that innovation efforts are data-driven, targeted, and responsive to the Kingdom's environmental priorities.

Figure No. [2] outlines the current challenges and opportunities for the environmental sector, categorized into five main areas in the environmental value chain*: **"Biodiversity", "Land, Vegetation & Desertification ", "Waste Management", "Pollution Control and Compliance", and "Meteorology".**

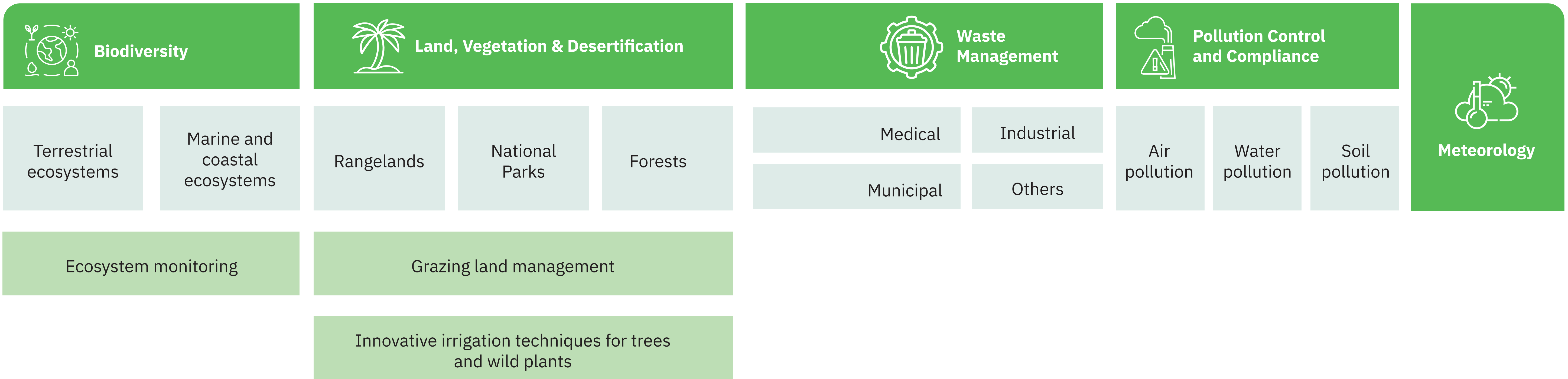
Biodiversity	Land, Vegetation & Desertification	Waste Management	Pollution Control and Compliance	Meteorology
Restore and promote sustainability of terrestrial ecosystems	Protect against overgrazing	Reduce volume of generated waste	Reduce emission levels (incl. CO2, CH4, PM)	Improve climate prediction and early warning capabilities
Restore and promote sustainability of marine and coastal ecosystems	Promote sustainable greening practices	Improve waste treatment	Increase effectiveness of air quality monitoring	Increase automation of meteorological data and reports
Increase protection of biodiversity hotspots	Protect against desertification, soil erosion, and droughts	Reduce mixed waste collection	Increase capacity to monitor environment compliance	Increase geographical coverage
Increase effectiveness of monitoring and assessment	Mitigate spread of invasive species and plant diseases	Improve hazardous waste safety levels	Improve control over soil contamination	Increase meteorological services offered
Increase effectiveness of conservation	Increase effectiveness of land monitoring and sustainable management	Increase capacity to monitor environmental compliance	Increase effectiveness of water quality monitoring	Improve forecasting & simulation techniques

*"Innovation in the Environment Sector in Saudi Arabia - Technology Adoption Roadmap" 2024

Scope of the Report [4/4]

Figure No. [3] presents the technological framework for the environment sector as outlined in the Technology Adoption Roadmap*. The first horizontal level in the diagram is classified as the main areas in the environmental value chain, consistent with those introduced in the previous figure. The second horizontal level further breaks down the areas components into elements. The third level highlights the technology priority groups: “Ecosystem Monitoring”, “Grazing Land Management”, and “Innovative Irrigation techniques for Trees and Wild Plants”. In addition, “Waste Management, Pollution Control and Compliance, and Meteorology” are featured in the framework as a main areas and a technology priority groups and throughout this report. This report will therefore be examining “Pollution Control and Compliance” in greater detail.

Figure 3: Technological framework for the environment sector



*“Innovation in the Environment Sector in Saudi Arabia - Technology Adoption Roadmap“ 2024

Methodology

Specifically, the content of this report is based on a four-stage process for analyzing technology signals.

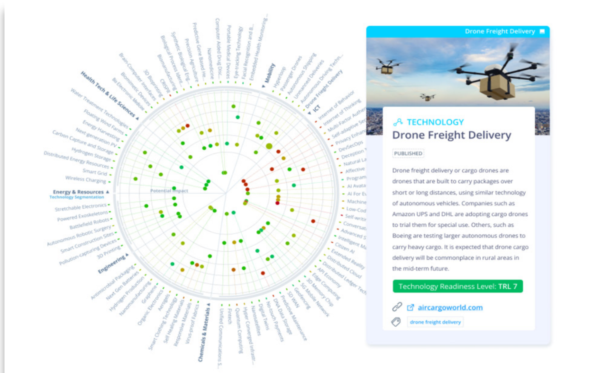
1. Signal Collection & Technology Identification
Considering established practices, such as the Framework for Anticipatory Governance of Emerging Technologies (OECD 2024), the first analysis step involved the systematic collection and evaluation of signals to identify relevant technologies aligned with Saudi Arabia's Vision 2030 environmental objectives and the National Environment Strategy. To achieve this, the team employed a scanning method that combines the advantages of human expertise and machine intelligence, utilizing a signals database that contains over 100 million data points (e.g., patents, industry reports, scientific publications, etc.). Over the past five years, about 45,000 signals related to MEWAs' strategic priorities in the environment sector were sourced. Using Retrieval-Augmented Generation (RAG) AI and human expert validation, a longlist of 200 distinct technologies mentioned in patents, scientific publications, and news articles was compiled for in-depth analysis – comprising each of the four technology priority groups as outlined in the **MEWA Environment Technology Adoption Roadmap.**

2. Technology Assessment & Landscape Creation
In the second step, a comprehensive technology landscape was created from the long list of technologies mentioned in the signals. In the first step, conceptual overlap among the technologies was minimized by subsuming similar or idiosyncratic technologies (e.g., "P-band SAR", "Multi-band Synthetic Aperture Radar", and "High-revisit SAR Constellations"). After that, for each of the four technology priority groups, the 15 technologies receiving the most mentions in signals in 2024 were selected for the technology landscapes. Those 15 technologies were clustered into technology segments based on the purpose of use and functional characteristics. Finally, all technologies included in the landscape were evaluated on technology and national capability maturity (TRL & CRL), impact potential, and ease of implementation following the criteria outlined in the **MEWA Environment** Technology Adoption Roadmap.

3. Detail Analysis & Spotlight Selection
In the final step, the signals for each technology were examined in detail. Based on this, technology descriptions covering information such as global key players, current state of adoption, development outlook, and relevant case studies were created. In this report, one technology in each of the identified segments was selected to be presented as a spotlight in this report. The selection was done by a quantitative assessment of the current innovation activity level and the growth trajectory of innovation activity. To this end, a composite score of current research volume (no. of patents & scientific publications in 2024) and growth rate (2019-2024 CAGR of patents and scientific publications) in relation to the leading technology in the priority field. A score of 100 indicates that technology ranks first among the 15 selected technologies in both research volume and growth rate, whereas a score of 0 indicates that it ranks last in both areas (see the Selection Criteria section in the Appendix for a full overview of the technologies and the scoring).

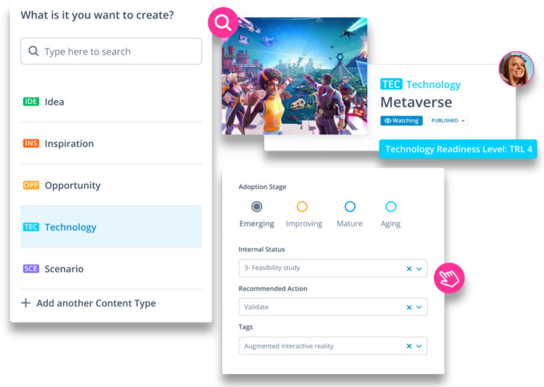
4. Expert Insights & Validation
To complement the quantitative and signal-based analysis, the methodology incorporated insights from environmental experts with extensive experience in technology adoption and sectoral innovation. A group of selected experts were consulted through structured interviews to validate the identified technologies, assess practical relevance, and provide contextual perspectives on adoption barriers, policy considerations, and regional applicability. Expert input was used to refine technology descriptions, verify the accuracy of key players and adoption trends, and identify emerging use cases that may not be fully captured by signals alone. This step ensured that the report reflects both data-driven evidence and practical expertise, enhancing the robustness, relevance, and actionable value of the technology landscape and spotlight selection.

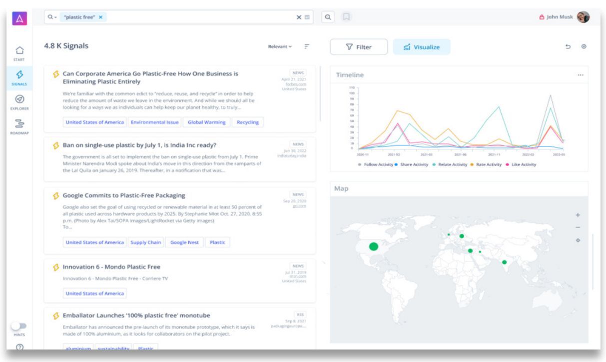
The analyses leading to this report were conducted during the first iteration of MEWA's NPRAS Platform— an AI-enhanced Innovation Operating System that enables the systematic scouting of technology signals, the continuous tracking of emerging technologies and innovation



Technology Radar
In an interactive, visual radar view, emerging technologies can be analyzed and their relevance, maturity level (TRL), and application potential assessed. The Technology Radar helps identify new developments early, strategically prioritize innovation fields, and continuously monitor technology trends.

Collaborative Evaluation
The platform enables a structured, collaborative evaluation of emerging technologies. The involvement of various experts minimizes subjective assessments and facilitates the efficient identification of innovation opportunities and risk evaluation.





Automated Monitoring
The platform's scouting function utilizes AI-powered analytics to continuously capture technological developments from various sources such as scientific publications, patents, industry reports, and news. Through intelligent filters and algorithms, relevant signals are identified, categorized, and updated in real time.

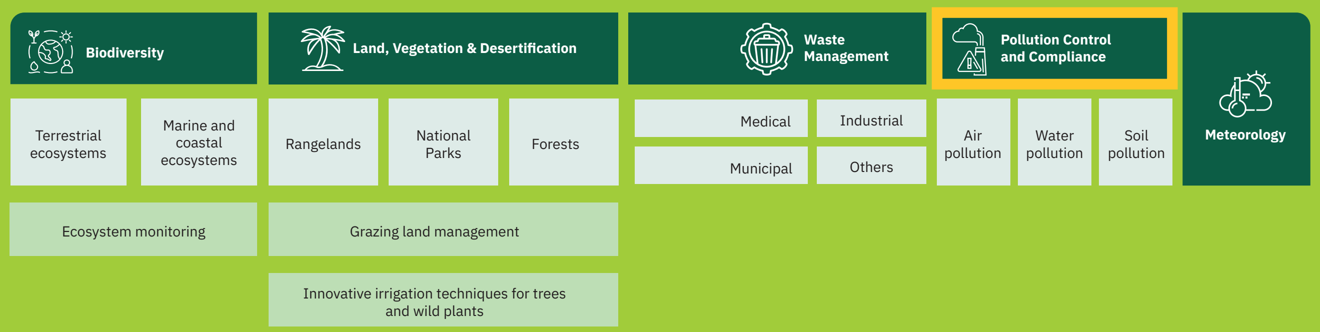
03

Pollution Control and Compliance Technology Priority Group

TECHNOLOGY PRIORITY GROUP FOCUS

3.1 POLLUTION CONTROL AND COMPLIANCE

Pollution Control and Compliance encompasses technologies and systems designed to prevent, monitor, mitigate, and ensure regulatory compliance related to environmental contamination. It includes solutions for air pollution prevention and mitigation (e.g., emission control technologies and air quality management systems), water pollution prevention and mitigation (e.g., advanced treatment and discharge control technologies), and soil pollution prevention and remediation (e.g., contamination detection and soil restoration methods). This group also covers pollution monitoring technologies, including real-time sensing, remote monitoring, and data analytics platforms that track pollutant levels and support regulatory reporting. Collectively, these technologies enable effective environmental protection, compliance with standards, and informed decision-making to safeguard ecosystems and public health.



Frontier Technologies in Pollution Control and Compliance

Aerial Detection Systems	Ground-Based Monitoring Networks	Compliance & Laboratory Analytical Technologies	Digital Intelligence Systems
Autonomous OGI Drone LDAR (TRL 9)	AI Fenceline HAP Detection (TRL 8)	HRMS Non-Target Chemical Screening (TRL 7)	PEMS with Process Digital Twins (TRL 9)
High-Resolution Methane Satellites (TRL 9)	Continuous Methane Monitoring Networks (TRL 8)	High-Throughput PFAS Compliance Analytics (TRL 8)	Automated Environmental RegTech Reporting (TRL 7)
Mobile Plume Mapping and Quantification (TRL 8)	AI-Calibrated Low-Cost Sensor Networks (TRL 8)	Automated Monitoring QA/QC Pipelines (TRL 9)	Integrated Satellite-Model Enforcement Intelligence (TRL 7)
	Open-Path Laser Perimeter Monitoring (TRL 8)		Dynamic Emissions and Carbon Metering (TRL 6)
	ML Odour Sensor Networks (TRL 7)		

The definitions of the listed technologies are in the glossary

Innovation, Interest, and Investment by Technology

To assess the development of each emerging technology, our team collected data on four tangible measures of activity: **news publications, patents, research publications,** and **investment.**

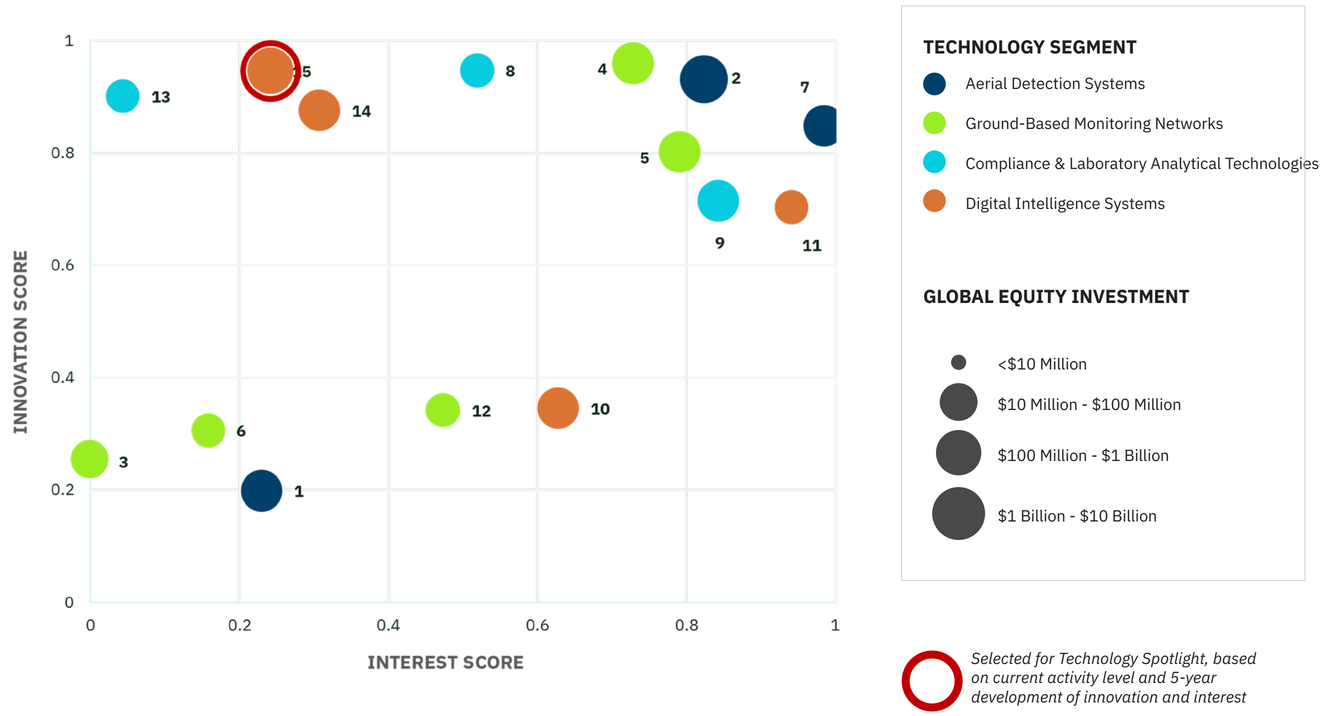
For each measure and in Figure No. [4], we used a defined set of data sources to find occurrences of keywords associated with each of the 15 technologies, screened those occurrences for valid mentions of activity, and indexed the resulting numbers of mentions on a 0–1 scoring scale that is relative to the technologies studied:

The **innovation score** combines the patents and research scores. The patents score is based on a measure of patent filings, and the research score is based on a measure of research publications.

The **interest score** reflects the number of global news publications, relative to the technologies studied (While we recognize that an interest score can be inflated by deliberate efforts to stimulate news coverage, we believe that each score fairly reflects the extent of discussion and debate about a given technology).

Investment depicts the flows of funding into companies linked with the technology, including private-market and public-market capital raises (venture capital and corporate and strategic M&A, including joint ventures), private equity (including buyouts and private investment in public equity), and public investments (including IPOs).

Figure 4: Chart representing Innovation Score vs Interest Score across all 15 technologies



01. Autonomous OGI Drone LDAR
02. High-Resolution Methane Satellites
03. AI Fenceline HAP Detection
04. Continuous Methane Monitoring Networks
05. AI-Calibrated Low-Cost Sensor Networks
06. Open-Path Laser Perimeter Monitoring
07. Mobile Plume Mapping and Quantification
08. HRMS Non-Target Chemical Screening
09. High-Throughput PFAS Compliance Analytics
10. PEMS with Process Digital Twins
11. Automated Environmental RegTech Reporting
12. ML Odour Sensor Networks
13. Automated Monitoring QA/QC Pipelines
14. Integrated Satellite-Model Enforcement Intelligence
15. Dynamic Emissions and Carbon Metering

Based on the scoring methodology of the McKinsey Tech Report

Note: Innovation and interest scores for the 15 trends are relative to one another. All 15 trends exhibit high levels of innovation and interest compared with other topics. While some technologies may have applications outside of environment, this analysis considered only patents, publications, news, and investments in the environmental context.

Technologies Trending in Innovation Output and Public Interest

Static innovation and interest scores snapshot technological vitality, but momentum reveals trajectory. Tracking growth or decline exposes breakouts before rivals, flags waning hypes, guides timing of subsidies, calibrates capacity-building, and aligns infrastructure budgets with future demand. Dynamics safeguard against sunk costs and amplify the impact of the resources in the EWA ecosystem.

Looking into the global growth rates in patents, publications, and news published on the technologies studied over the past 5 years, particularly the growing momentum in the segment Digital Intelligence Systems is evident. In particular, the following technologies display high growth rates across all three measures examined:

PEMS with Process Digital Twins

Predictive emissions monitoring systems integrated with virtual process replicas enabling real-time emissions forecasting and adaptive control optimization.

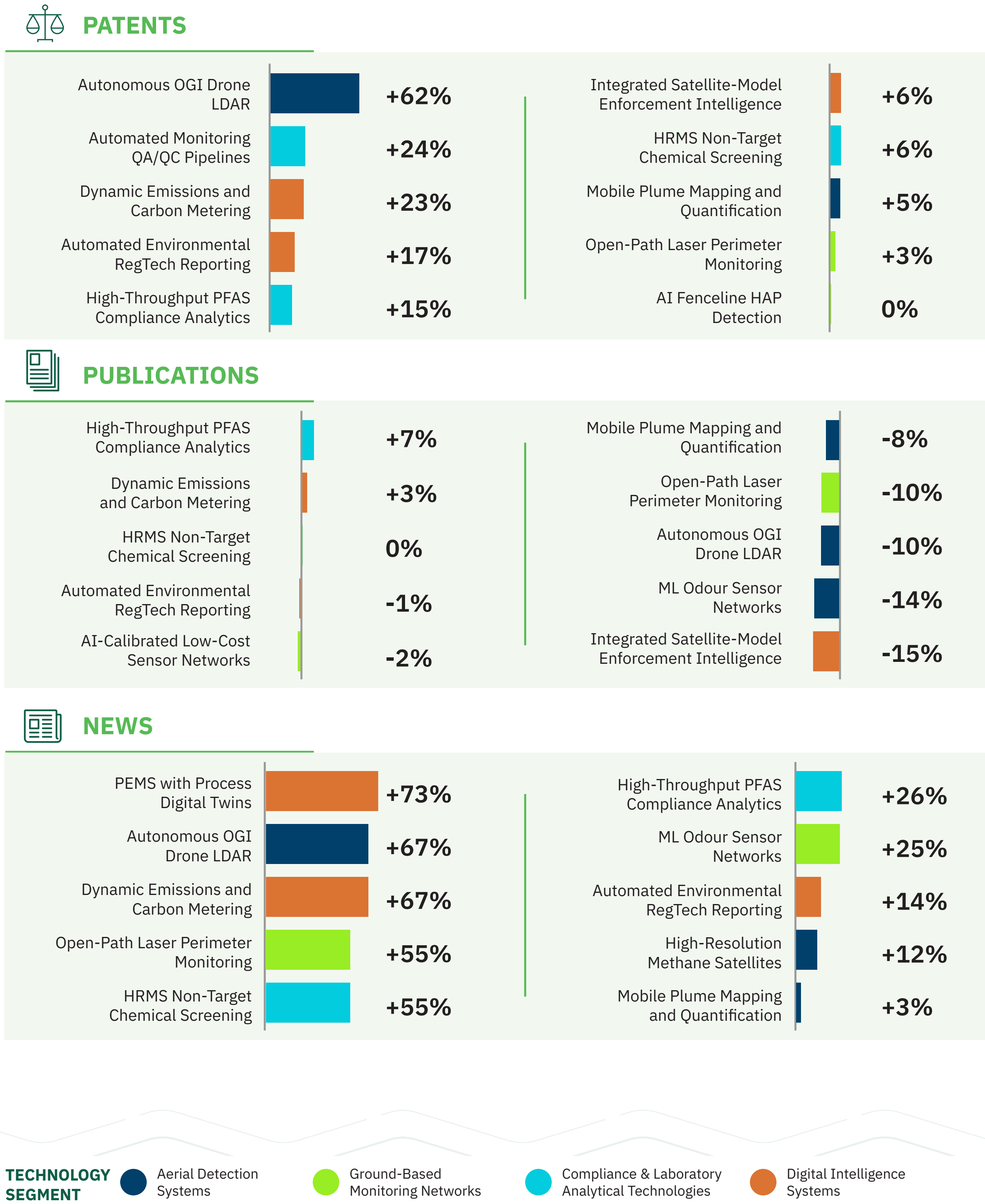
Automated Monitoring QA/QC Pipelines

Systematic quality assurance frameworks that automatically validate environmental monitoring data accuracy, precision, and reliability through standardized protocols.

Autonomous OGI Drone LDAR

Unmanned aerial vehicles equipped with optical gas imaging sensors for automated leak detection and repair inspections.

Figure 5: Continuous Annual Growth Rate of Patents, Publications, and News (2019-2024), Top 5 and Bottom 5 Technologies



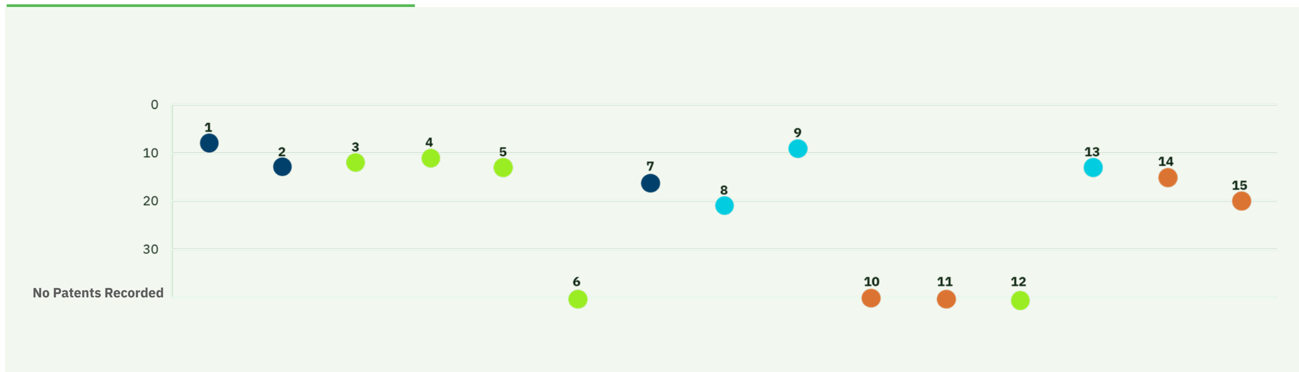
Overview of National RDI Output

Overall, Saudi Arabia is in a promising competitive position in the technologies investigated. Regarding **Patents**, compared to the **overall Global Patent Rank**, our nation ranks in the global Top-10 for only two of the technologies surveyed, and Top-20 in 10 of the key emerging technologies in the field. For the technology “**Autonomous OGI Drone LDAR**”, our country ranks #8 globally in patents registered between 2019 and 2024.

Regarding **Publications**, the positioning is less promising with a Top-20 ranking in only one of the technologies observed. The dominate technology segment where Saudi Arabia holds a mediocre position in “Ground-based Monitoring Networks”.

Figure 6: Saudi Arabia’s Positioning across Emerging Technologies, Global Rank in No. of Patents & Publications (2019-2024)

PATENTS



PUBLICATIONS

01. Autonomous OGI Drone LDAR
02. High-Resolution Methane Satellites
03. AI Fenceline HAP Detection
04. Continuous Methane Monitoring Networks
05. AI-Calibrated Low-Cost Sensor Networks
06. Open-Path Laser Perimeter Monitoring
07. Mobile Plume Mapping and Quantification
08. HRMS Non-Target Chemical Screening
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11. Automated Environmental RegTech Reporting
12. ML Odour Sensor Networks
13. Automated Monitoring QA/QC Pipelines
14. Integrated Satellite-Model Enforcement Intelligence
15. Dynamic Emissions and Carbon Metering

TECHNOLOGY SEGMENT: Aerial Detection Systems; Ground-Based Monitoring Networks; Compliance & Laboratory Analytical Technologies; Digital Intelligence Systems

TECHNOLOGY SPOTLIGHT

3.1.1 Dynamic Emissions and Carbon Metering

Dynamic Emissions and Carbon Metering refers to advanced monitoring systems that utilize real-time data acquisition technologies, including wireless sensors, satellite imagery, and artificial intelligence, to continuously track, measure, and forecast greenhouse gas emissions with high temporal resolution and accuracy. These systems enable automated, granular monitoring of carbon footprints across industrial operations, replacing static, post-hoc assessment methods with dynamic, performance-based metrics for proactive emission management and verification.

Next-Gen SAR Satellites

Dynamic Emissions and Carbon Metering represents a transformative approach to environmental monitoring that leverages real-time data acquisition technologies, including wireless sensors, satellite imagery, and artificial intelligence, to continuously track and measure greenhouse gas emissions with unprecedented precision. This technology enables organizations to move beyond traditional static, post-hoc carbon accounting methods to dynamic, performance-based metrics that provide actionable insights for immediate operational optimization. (**EMC: Continuous Emission Monitoring Systems | US EPA, The Role of IoT in Real-Time Carbon Emissions Monitoring**)

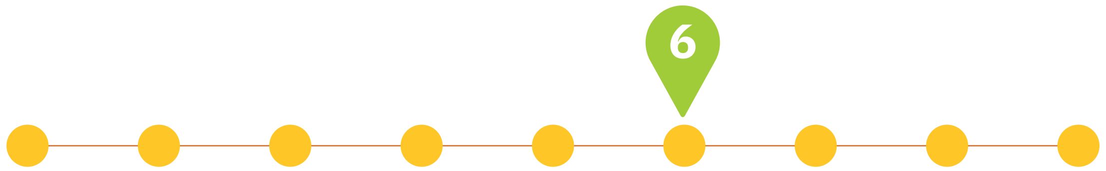
The technology matters because it addresses critical gaps in pollution control and regulatory compliance by providing minute-by-minute, audit-ready measurements that enable proactive intervention rather than reactive reporting. Modern systems integrate IoT sensors, machine learning algorithms, and cloud-based analytics to detect anomalies, predict emission trends, and automatically trigger alerts when thresholds are exceeded, fundamentally transforming carbon management from a compliance burden into a strategic operational tool. (**SensorUp: Leading Oil & Gas Emissions Management Solutions, AI Transforms Real-Time Tracking & Reduction of Scope 3**)

For Saudi Arabia's environmental priorities, this technology directly supports ecosystem monitoring, pollution control compliance, and meteorological applications by providing the high-resolution, verifiable data necessary to meet net-zero commitments while enabling evidence-based environmental stewardship across the Kingdom's diverse landscapes and industrial sectors. (**Continuous Emission Monitoring Systems** (CEMS):-a-strategic-primer-for-industrial-decision-makers)

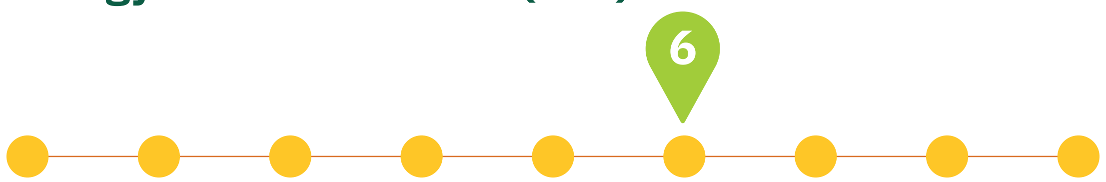
Technology and National Capability Maturity

Dynamic Emissions and Carbon Metering technology demonstrates high maturity (TRL 6) with commercial systems already deployed across industrial facilities globally. The technology integrates proven IoT sensors, AI analytics, and cloud platforms to deliver real-time emissions monitoring with demonstrated accuracy and reliability in operational environments. (EMC: Continuous Emission Monitoring Systems | US EPA, SensorUp: Leading Oil & Gas Emissions Management Solutions). Saudi Arabia shows moderate readiness (CRL 6) with strong government commitment through Vision 2030 and active deployment by major corporations like Aramco, but limited domestic manufacturing capabilities for core sensor technologies. The Kingdom has established research partnerships between KAUST and national agencies like NCEC for environmental monitoring, while megaprojects like NEOM are implementing advanced emissions tracking systems, though most hardware components remain imported. (Partnership advances air quality forecasting and environmental science in KSA, Building on Success: A Pathway for Advancing Local Content in Saudi Arabia).

Capability Readiness Level (CRL)



Technology Readiness Level (TRL)



*Capability Readiness Level (CRL) and Technology Readiness Level (TRL) descriptions are in the Glossary

Global Key Players

01 Siemens Energy

02 ABB

03 Thermo Fisher Scientific

04 Teledyne API

05 Emerson

06 HORIBA

07 Gasmet Technologies

08 CEMTEK

09 Envana

10 Cyanergy

Technology Potential

Dynamic Emissions and Carbon Metering technology offers transformative potential for industrial operations by enabling real-time environmental management, operational optimization, and regulatory compliance through advanced IoT sensors, AI analytics, and cloud-based monitoring systems.

Advantages

- **Operational Excellence Through Real-Time Intelligence:** Advanced CEMS systems deliver minute-by-minute emissions data that enables operators to adjust combustion ratios instantly, optimize fuel efficiency, and detect anomalies hours before they escalate into compliance violations, protecting both revenue and company reputation. Continuous Emission Monitoring Systems (CEMS)
- **Significant Cost Reduction and ROI:** Real-time emissions monitoring systems achieve payback periods of 18-24 months through process optimization, fuel savings, and avoided non-compliance penalties, while PEMS solutions can reduce capital expenses by 50% and operating expenses by 90% compared to traditional hardware-centric alternatives. Why Real-Time Emission Monitoring Is the Key to Safer, Greener Operations
- **Enhanced Safety and Environmental Stewardship:** Continuous monitoring systems provide instant alerts for toxic gas surges and process disturbances, enabling immediate response actions like ventilation or shutdown procedures, while simultaneously supporting decarbonization goals through detailed emissions tracking and carbon offset program verification. 10 Benefits of Continuous Emissions Monitoring for Pharma Compliance

Disadvantages

- **High Implementation and Maintenance Costs:** CEMS installations require substantial capital investment for hardware, software, and infrastructure, with ongoing operational expenses ranging from 3-6% of total installed cost annually, including calibration gases, consumables, and third-party quality assurance services. Understanding Continuous Emissions Monitoring Systems (CEMS)
- **Data Accuracy and Verification Challenges:** Carbon footprint tracking systems face significant data integrity issues, with 83% of companies struggling to access accurate emissions data due to supplier gaps, inconsistent reporting standards, and fragmented systems that complicate comprehensive emissions tracking. Carbon footprint data collection: Common challenges and how to solve them
- **Cybersecurity and Data Privacy Vulnerabilities:** IoT-based emissions monitoring networks face substantial security risks including data breaches, manipulation of emission data, and cyberattacks targeting critical infrastructure, which can erode public trust and create widespread skepticism about system reliability. IoT Networks for Enhanced Carbon Monitoring

Latest Developments

The field of Dynamic Emissions and Carbon Metering is experiencing rapid advancement in 2025, with breakthrough innovations in AI-powered predictive systems, IoT sensor networks, and integrated digital technologies that are transforming real-time emissions monitoring capabilities across industrial sectors.

Key Innovation Signals

- **AI-Powered Predictive Emissions Systems:** Machine learning techniques including LSTM and TCN architectures are revolutionizing PEMS technology, reducing capital costs by 50% and operational costs by 90% while providing continuous data availability and enhanced accuracy for complex non-linear emissions patterns. Researching the landscape of predictive emissions monitoring system
- **Integrated AI-IoT Carbon Management Platforms:** Comprehensive Carbon Management Systems now combine AI, IoT sensors, and data science for end-to-end real-time monitoring, predictive insights, and automated decision-making, replacing traditional periodic surveys with continuous intelligent analysis capabilities. Integrating AI, IoT, and Data Science for a Comprehensive Carbon Management System
- **Edge Computing for Real-Time Processing:** IoT devices with edge computing capabilities enable decentralized data processing for carbon monitoring, reducing latency and enhancing real-time decision-making while supporting early detection of carbon cycle anomalies and automated emission control strategies. Role of IoT, AI, and ML in Carbon Management
- **Machine Learning Pattern Recognition:** Advanced Random Forest classifiers achieve up to 100% accuracy in detecting emission pattern changes and data anomalies across industrial facilities, enabling sophisticated analysis of CEMS data from multiple monitoring parameters simultaneously. Machine learning classifiers to detect data pattern change
- **AI-Enhanced Fugitive Emissions Detection:** Artificial Intelligence-empowered continuous emissions monitoring systems deployed in gas processing facilities demonstrate superior cost-effectiveness and accuracy in capturing both expected and unexpected emissions events through real-time physical detection versus traditional modeling approaches. Leveraging Artificial Intelligence & Fixed, Continuous Methane Monitoring
- **Smart Construction Carbon Monitoring:** IoT-based systems integrated with machine learning analytics achieve high accuracy in real-time carbon emissions monitoring while reducing operational expenses, providing automated continuous tracking with minimal human intervention for construction applications. Real-Time Carbon Emissions Monitoring in Smart Construction

Figure 7: Patents & publications count (2019-2024) for Next-Gen SAR Satellites

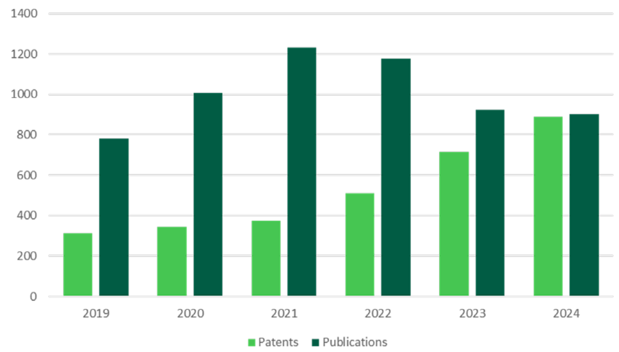
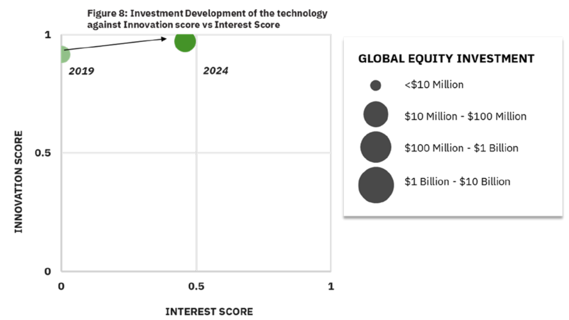


Figure 8: Investment Development of the technology against Innovation score vs Interest Score



Insights and Statistics

Dynamic Emissions and Carbon Metering technology is experiencing unprecedented growth with substantial market expansion, significant cost savings potential, and impressive accuracy improvements driving widespread adoption across industrial sectors.

Key Stats & Facts

- **Carbon Management System Market Growth:** The global carbon management system market expanded from $12.7 billion in 2024 to $14.24 billion in 2025, representing a compound annual growth rate (CAGR) of 12.2%, with projections reaching $21.73 billion by 2029. **Comprehensive Report on the Carbon Management System Market**
- **PEMS Cost Reduction Benefits:** Predictive Emissions Monitoring Systems (PEMS) reduce capital costs by 50% and operational costs by 90% compared to traditional hardware-based Continuous Emissions Monitoring Systems while ensuring continuous data availability and enhanced accuracy. **Researching the landscape of predictive emissions monitoring system**
- **IoT Monitoring Accuracy Rates:** IoT-based real-time carbon emissions monitoring systems achieve superior accuracy rates while reducing operational expenses, making them a cost-effective alternative to traditional human-operated monitoring systems. **Real-Time Carbon Emissions Monitoring in Smart Construction**
- **Industrial Emission Control Market Expansion:** The industrial emission control systems market grew from $21.42 billion in 2024 to $22.78 billion in 2025 at a CAGR of 6.4%, with projections to reach $29.59 billion by 2029 at 6.8% CAGR. **Industrial Emission Control Systems Market 2025-2029**
- **Continuous Monitoring System Precision:** Fixed-point continuous monitoring systems demonstrated high precision in methane emissions quantification, with a 4-week study showing only 4% underestimation (27 kg out of 700 kg released) under complex emission patterns and real-world conditions. **Performance Evaluation of Fixed-Point Continuous Monitoring Systems**
- **Carbon Credit Market Projections:** Carbon credit prices are anticipated to increase dramatically by up to 3000% by 2029, driving demand for carbon measurement and management devices that can help firms save up to 90% compared to purchasing carbon credits from the market. **Comprehensive Report on the Carbon Management System Market**

Technology Adoption

While dynamic emissions and carbon metering systems gain global momentum through regulatory mandates and corporate sustainability commitments, Saudi Arabia's successful deployment depends on establishing robust data governance frameworks, institutional capacity building, and policy alignment with Vision 2030 environmental objectives.

Current State

- **Enterprise-Scale Deployment Accelerating:** Major corporations and government agencies are rapidly implementing AI-powered carbon management platforms like Dcycle and Watershed, with companies reporting 70% reduction in reporting time. **Dcycle**
- **Real-Time Manufacturing Integration Expanding:** Industrial facilities are achieving up to 20% energy savings through IoT-enabled real-time emissions monitoring systems that integrate with existing machinery and exhaust systems, enabling immediate corrective action when anomalies are detected. **nZero**
- **Government Mandate-Driven Adoption:** Public sector organizations are deploying automated carbon analysis dashboards to comply with environmental mandates, with platforms like ICLEI's ClearPath 2.0 launched in spring 2025 helping U.S. subnational governments streamline GHG inventories and climate action planning. **ICLEI USA**

Requirements for Localization

- **NCEC Regulatory Alignment Required:** Saudi Arabia's National Center for Environmental Compliance (NCEC) mandates specialized environmental licensing and monitoring protocols that dynamic emissions systems must integrate with, requiring customization to meet MEWA's air quality standards and real-time reporting frameworks established across monitoring stations in major cities. **National Center for Environmental Compliance - Saudipedia**
- **Sovereign Data Governance Framework:** Vision 2030's emphasis on sovereign AI and data localization requires carbon metering platforms to operate within nationally controlled digital infrastructure, ensuring emissions data remains under Saudi jurisdiction while meeting the Kingdom's $133 billion digital economy targets and ethical AI compliance standards. **Sovereign AI: The Engine Behind Saudi Arabia's $133 Billion Digital**
- **Institutional Capacity Building Gap:** Despite ambitious environmental targets under the Saudi Green Initiative, the Kingdom faces significant institutional readiness challenges for advanced monitoring systems deployment, requiring substantial workforce development and technical expertise building to bridge the gap between Vision 2030 sustainability commitments and operational implementation capabilities. **ESG in Saudi Arabia: The Key to Vision 2030's Success**

Outlook

Dynamic Emissions and Carbon Metering technology is poised for exponential growth through AI-powered predictive systems and IoT integration, though deployment success remains contingent on regulatory harmonization and data governance frameworks.

Future Trajectory

- **Machine Learning Classification Excellence:** XGBoost algorithms in IoT-enabled environmental monitoring systems are achieving approximately 80% accuracy in real-time air quality classification with ROC AUC scores exceeding 0.90, while Random Forest models demonstrate superior performance in predicting carbon concentrations across multiple environmental parameters. **IoT-Enabled Indoor Air Quality Monitoring and Control Using Machine Learning Techniques**

- **Cost-Efficiency Revolution in Smart Construction:** IoT-based carbon emissions monitoring systems integrated with machine learning analytics are delivering accuracy rates between 85-99% while reducing operational expenses by 10-50% compared to traditional manual monitoring methods, enabling automatic continuous emission tracking with minimal human intervention. **Real-Time Carbon Emissions Monitoring in Smart Construction Using IoT and Machine Learning**

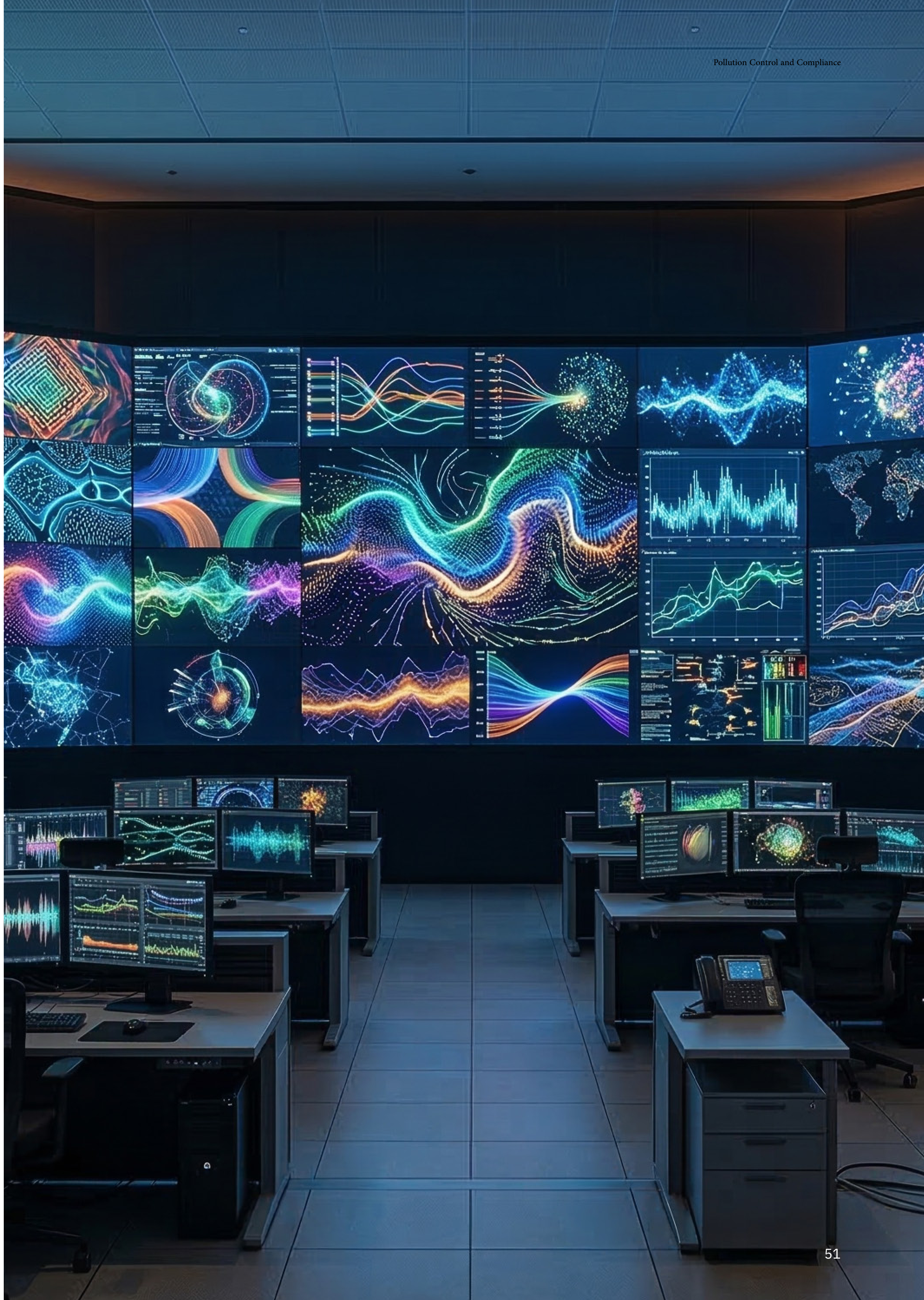
- **Blockchain-ML Fraud Detection Advancement:** Machine learning algorithms including Random Forest, XGBoost, and Neural Networks are being integrated with blockchain-based carbon credit verification systems to process satellite imagery and corporate disclosures, significantly strengthening transparency mechanisms and reducing greenwashing risks in forest-based carbon offset projects. **Discover Sustainability**

Key Uncertainties

- **Sensor Calibration Drift and Data Reliability:** IoT sensors face persistent challenges with environmental sensitivity and calibration drift, with 83% of companies struggling to access accurate emissions data according to the GHG Protocol, potentially undermining the integrity of automated carbon accounting systems. **Carbon footprint data collection: Common challenges and how to solve them**

- **Blockchain Scalability and Energy Paradox:** Digital MRV systems using blockchain face critical scalability bottlenecks when handling massive carbon data volumes, while energy-intensive consensus mechanisms create a paradoxical situation where verification systems consume significant energy to validate carbon reduction claims. **Blockchain for Carbon Removal Verification Scalability Challenges**

- **Interoperability and Standardization Gaps:** The proliferation of incompatible blockchain platforms and carbon credit standards creates fragmentation risks, with different systems using proprietary data formats that hinder seamless integration and could lead to a “software zoo” undermining global carbon market efficiency. **Scalable Blockchain MRV Systems for Verified Carbon**



Source: ESS

Local Case Study

KAUST AirGo Hybrid Air Quality Monitoring System Deployment

King Abdullah University of Science and Technology (KAUST) developed and deployed AirGo, a comprehensive hybrid air quality monitoring system that combines mobile and stationary IoT sensors to track carbon dioxide, carbon monoxide, and other greenhouse gas emissions across urban environments. The system addresses the critical need for real-time environmental data collection in Saudi Arabia's rapidly expanding cities, where particulate matter levels frequently exceed global health standards due to industrial activities, urbanization, and natural dust storms. KAUST's deployment directly supports Saudi Vision 2030's environmental sustainability commitments while providing a scalable model for smart city development across the Kingdom. **KAUST develops hybrid air quality monitoring system for smart cities supporting Vision 2030 environmental goals, Air quality monitoring systems deployed across Saudi cities to address pollution challenges**

The AirGo system delivers significant operational benefits through its modular, solar-powered design that enables continuous monitoring of gases including carbon dioxide, sulfur dioxide, ozone, and nitrogen dioxide, alongside particulate matter measurements. Real-time data transmission via mobile networks feeds into cloud-based databases with automated alert systems, providing immediate environmental health warnings and supporting predictive pollution modeling. The technology demonstrated reliable performance during extensive campus testing, accurately detecting environmental events such as dust storms while generating granular data that enables local-scale forecasting and evidence-based policy development for urban planning authorities.

The implementation leverages GPS-enabled mobile units mounted on vehicles and buses alongside stationary sensors positioned on infrastructure like streetlights, creating a comprehensive monitoring network that covers extensive urban areas with precise geolocation capabilities. KAUST researchers achieved technology readiness level 6 through systematic testing and are actively partnering with manufacturers to scale production for commercial deployment within 18-12 months. The system's adaptability allows deployment in diverse environments including areas with limited infrastructure, while its cost-effective design makes it accessible for widespread adoption across Saudi cities and industrial zones seeking to meet environmental compliance requirements. **Mobile and stationary sensor deployment creates comprehensive urban monitoring networks, Technology readiness level 6 achieved with commercial deployment planned within 18 months**

04

Leadership Insights

Innovating for a Sustainable Future: MEWA in Environmental Technology Advancements

In navigating the evolving landscape of environmental innovation, it is clear that the shift is no longer optional but imperative. The sector is undergoing a transformation driven by the urgency of climate change, water scarcity, and resource constraints, requiring a more integrated and forward-looking approach. Innovation today is not limited to technological advancement alone; it is increasingly about aligning policy, research, and market mechanisms to deliver scalable and sustainable impact. A key insight is the growing importance of cross-sector collaboration where governments, research institutions, and private players must work in tandem to accelerate solutions. At the same time, data and digital technologies are emerging as critical enablers, allowing for more precise monitoring, forecasting, and decision-making. However, the real challenge lies in bridging the gap between innovation development and real-world adoption. Ultimately, success in environmental innovation will depend on the ability to translate ambitious strategies into actionable outcomes, ensuring that efforts are both locally relevant and globally aligned. This requires not only investment in capabilities but also a mindset shift toward agility, experimentation, and long-term resilience.

Dr. Abdullah Alraddadi
Assistant Deputy Minister for International Affairs and Climate

Innovating for a Sustainable Future: Environment Fund in Environmental Technology Advancements

In an arid land with ambitious goals—like planting 10 billion trees and conserving 30% of our ecosystems—technology has become our greatest ally. From AI-driven irrigation that conserves every drop, to satellite monitoring of biodiversity, innovation has turned challenges into catalysts. While mainstream solutions gain traction, I'm closely watching Agrivoltaics, a dual-use model merging solar energy with sustainable grazing—an elegant answer to the food-energy-water nexus. Vision 2030 and the Saudi Green Initiative have made environmental resilience a national priority, with financial and regulatory systems enabling scale. Over the next decade, we will see 'Saudi-Made' solutions built for our climate, a matured environmental credit market, and fully integrated ecosystems where satellites, AI, and smart systems work in harmony. Saudi Arabia isn't just adapting—it's shaping the global future of arid-zone sustainability.

Dr. Abdulrhman Alfawzan
Principle Advisor in Environment Fund

Innovating for a Sustainable Future: MWAN in Environmental Technology Advancements

The waste sector today faces a complex set of environmental challenges that span the entire value chain—from limited treatment technologies and weak data tracking to behavioral gaps, material design issues, and waste surges during seasonal events such as Hajj. Technology is central to overcoming these challenges, particularly where innovation is still lacking, such as the treatment and recycling of lithium-ion batteries, which remain constrained by technical complexity, high costs, and lack of standardization. In Saudi Arabia, the transformation of the sector is being driven by a tailored approach through Waste Master Plans that build on local realities rather than simply importing international models. These plans establish a clear baseline, guide long-term investments, and align sector development with national priorities. Environmental innovation is increasingly driven by clear infrastructure gaps, strong policy direction under Vision 2030, and new PPP models that attract private investment. Over the next decade, innovation will shift from standalone solutions toward optimizing efficiency, cost, and digital integration. By enabling experimentation, strengthening R&D and talent, and fostering collaboration across sectors, Saudi Arabia has a unique opportunity to position itself as a global leader in environmental innovation.

Dr. Mohammed AlAssim
Vice President for Planning and Development in MWAN

Innovating for a Sustainable Future: SIRC & TerraFuel in Environmental Technology Advancements

The defining environmental challenge today is shifting from a linear take–make–dispose model to a fully circular economy at national scale. For us, this means turning waste into value—whether by converting municipal waste into consistent, high-quality industrial fuel, or by using AI and IoT to transform complex waste streams into data-driven resource systems. Beyond what's widely discussed, I'm closely watching biomass pyrolysis for biochar production and the valuation of carbon within the circular economy. These solutions go beyond energy recovery, enabling permanent carbon sequestration and improving soil health, particularly critical in arid regions while unlocking new pathways for project bankability. In Saudi Arabia, environmental innovation is driven by Vision 2030, a clear regulatory roadmap, and growing demand for industrial symbiosis. Over the next decade, the market will evolve from waste management to full resource management, positioning the Kingdom as a global hub for circular petrochemicals, integrated waste hubs, and exportable climate-tech solutions designed for extreme environments.

Sultan Alsaif
CEO, TerraFuel | Executive Director of Technology & Innovation in SIRC

Innovating for a Sustainable Future: FAO in Environmental Technology Advancements

Saudi Arabia’s environmental challenge is no longer ambition, but execution at scale. The binding constraints are weak ecosystem monitoring, fragmented planning, limited institutional capacity, and incentives that are not yet fully aligned with measurable environmental outcomes. Technology is essential—but only when embedded in governance, standard operating procedures, and national ownership. FAO’s experience shows that combining Earth observation, field-validated monitoring, and decision-support platforms can transform environmental management from isolated pilots into coordinated national systems. The real risk lies in unsustainable tech deployment: high-volume data without quality assurance, scenario models without calibration, and platforms delivered without long-term capacity or financing. Looking ahead, environmental innovation in Saudi Arabia will be driven by Vision 2030 and the Saudi Green Initiative, with rapid growth in digital monitoring, water-smart solutions, AI analytics, and results-based financing. Saudi Arabia can position itself as a global leader by institutionalizing monitoring, reporting and verification, integrating water productivity into all land restoration decisions, and linking finance to verified environmental performance—creating scalable, arid-zone solutions transferable worldwide.

Dr. Nizar Haddad
Programme Director in FAO KSA

Innovating for a Sustainable Future: ACWA Power in Environmental Technology Advancements

Saudi Arabia’s environmental innovation story in desalination is fundamentally about breaking the historical link between water and fossil fuels. The Kingdom has moved rapidly from energy-intensive thermal desalination to ultra-efficient seawater reverse osmosis, enhanced by energy-recovery systems, solar integration, and AI-driven plant optimization. These technologies have pushed energy use for desalination to record lows, transforming water production from a carbon liability into a pillar of net-zero strategy. What is less visible, but highly promising, is the emergence of next-generation approaches such as Batch Reverse Osmosis and novel compression technologies that push efficiency toward thermodynamic limits. Investment is driven by water-energy sovereignty, lower cVVVVVosts, and the ambition to localize high-value technologies rather than import them. Over the next decade, the market will evolve toward autonomous, renewables-powered plants and advanced digital control. Ultimately, Saudi Arabia is positioning itself not just as the world’s largest deployer of water technology, but as a global exporter of climate-resilient environmental innovation.

Dr. Ratul Das
Principle Advisor in Environment Fund

05

Appendix

Interviews – Questions for Sector Leader

Dr. Abdullah Alraddadi – Ministry of Environment, Water, & Agriculture
Assistant Deputy Minister for International Affairs and Climate

1. What are the key environmental-related challenges, and how do technologies play a role in overcoming them?

Saudi Arabia faces a wide range of environmental challenges. Some are specific to the Kingdom and the wider region, while others are global in nature. These challenges can be categorized by environmental sub-sector, in line with the technology adoption roadmap issued by the Ministry of Environment, Water and Agriculture. Innovation has a role to play across all of these sub-sectors. However, given the diversity of challenges and the breadth of opportunities, a structured approach is essential. One proposed approach is to link technological opportunities with existing initiatives and declared national priorities. For example, climate adaptation presents a range of technologies that can help address the impacts of climate change. Similarly, the circular economy offers significant innovation potential, including areas such as recycling and resource optimization. The recommendation, therefore, is to align innovation efforts with ongoing national initiatives, ensuring they complement and reinforce existing efforts.

2. What is not yet on everyone's radar, and you are closely following?

Answering this question is challenging due to the lack of full visibility into undisclosed plans across entities. However, several areas can be inferred from existing national initiatives, such as Saudi Green Initiative. For instance, afforestation one of the initiative's key pillars requires advanced and innovative technologies to meet its ambitious targets. This is a particularly relevant domain for Saudi Arabia and a limited number of other countries, given the Kingdom's desert environment.

3. What drives investments in environmental innovation in Saudi Arabia?

Environmental innovation is driven more by necessity than by investment, making it inherently more challenging than in other sectors. As a result, the government's role in fostering innovation within the environmental sector is critical. This role extends beyond regulation and legislation to actively enabling innovation and providing financial instruments that support national environmental priorities. Such support should not be limited to startups alone, but also directed toward large corporations capable of driving meaningful impact in the Kingdom's environmental sector. Importantly, these solutions should be tailored to address local environmental challenges.

4. How do you see the market for environmental innovation evolving in the next 5–10 years?

Saudi Arabia has been among the leading countries in investing in the environmental sector over the past decade and is one of the strongest proponents of innovation as the most effective solution to environmental challenges. The Kingdom has also emerged as an attractive investment destination. By leveraging targeted policies, it is possible to align innovation, investment, and environmental priorities in a way that drives a transformative shift in the sector.

5. How can Saudi Arabia position itself as a global leader in environmental innovation?

Saudi Arabia holds a leading global position in environmental efforts. The Saudi Green Initiative and the Middle East Green Initiative stand as prominent examples of this leadership (for more information, please refer to the initiatives' official websites). At the same time, Saudi Arabia's geographic context makes it one of the regions most affected by climate change and among the most water-scarce areas in the world. These challenges serve as key drivers of innovation. While the Kingdom has distinguished itself internationally through its environmental initiatives, there is significant opportunity to leverage this leadership to advance environmental innovation on a global scale—aligned with Saudi Arabia's position and the local and regional challenges it faces. This opportunity extends across a wide range of sectors, including but not limited to climate change, encompassing other environmental domains that require tailored and context-specific solutions.

Interviews – Questions for Sector Leader

Dr. Abdulrhman Alfawzan – Environment Fund
Principle Advisor

1. What are the key environmental-related challenges, and how do technologies play a role in overcoming them?

The primary challenge we face is the scarcity of resources in an arid environment, coupled with the ambitious scale of our national goals—such as planting 10 billion trees and protecting 30% of our land and marine areas. Traditionally, managing desertification or urban waste at this scale was labor-intensive and reactive. This is where technology came in, which brought about a qualitative shift in this sector and pushed towards effective environmental protection:

- **Ecosystem Monitoring:** Next-Gen SAR Satellites provide real-time tracking of biodiversity and habitat health across our vast, remote terrains.
- **Resource Efficiency:** In a water-scarce region, AI-Driven Smart-Irrigation ensures that every drop is utilized effectively, enabling the survival of native vegetation without depleting non-renewable groundwater.
- **Circular Economy:** Advanced waste management technologies are turning the challenges of urban expansion into opportunities for resource recovery, converting waste into valuable raw material.

2. What is not yet in everyone's radar, and you are closely following?

From my point of view, most of the selected technologies in this report are in the radar, but some are on the edge of the radar and are not being focused on, waiting to be brought to the ground. I am particularly focused on Agrivoltaic "Solar-Grazing" Systems. While many see solar energy and land conservation as competing interests, Agrivoltaics creates a "dual-use" synergy. By placing solar panels over grazing lands, we provide shade that reduces soil evaporation and heat stress for livestock, while the panels themselves generate clean energy. It's an elegant solution to the food-energy-water nexus in our desert environment. Despite its advantages, there are inherent technical challenges to address. This is a standard part of the innovative lifecycle, and the next step is for developers to proactively bridge these gaps through targeted R&D.

3. What drives investments in environmental innovation in Saudi Arabia?

What drives investment in innovation in any country also drives it in Saudi Arabia. **The future vision and the structural framework** are keys:

- **National Strategies:** Vision 2030 and the Saudi Green Initiative (SGI) have turned environmental protection from a "nice-to-have" into a core economic mission.
- **Financial Sustainability:** There are many Financial Institutions (e.g., Environment Fund) which are incentivizing the private sector by reducing the risk of adopting green technologies. They aren't just funding projects; they are building a market where environmental health translates into economic resilience.
- **RDI Missions:** The Research, Development, and Innovation Authority (RDIA) has prioritized "Sustainable Environment & Essential Needs", providing a clear roadmap and funding for high-TRL (Technology Readiness Level) solutions.
- **National Commitment toward Environment Protection:** For example, The Circular Carbon Economy (CCE): Our commitment to the 4Rs (Reduce, Reuse, Recycle, Remove) drives capital toward technologies that can capture emissions and turn them into value.

4. How do you see the market for environmental innovation evolving in the next 5-10 years?

The market for environmental innovation in Saudi Arabia is maturing rapidly. We are moving beyond proof-of-concept into broad-market industrialization. Key drivers for the next 5–10 years include:

- **Market Maturity:** I anticipate a significant maturation of the domestic market, characterized by the establishment of robust environmental credit systems. As the public and private sectors increasingly align their mandates, environment solutions will transition from subsidized initiatives to a primary engine of economic value.
- **Localization of Innovation "Saudi Made":** A shift from importing environmental tech to developing and patenting solutions specifically designed for our climates.
- **Cognitive Environment:** We are moving away from isolated tech silos. Ecosystem data from satellites will automatically feed into AI-irrigation and livestock management, we will create a seamless, self-optimizing ecosystem.

5. How can Saudi Arabia position itself as a global leader in environmental innovation?

Saudi Arabia serves as a global 'Living Lab,' where we turn the challenges of extreme heat and water scarcity into a blueprint for the world's arid regions. Our leadership extends far beyond our borders: we are creating a scalable blueprint for nearly half of the world's landmass facing similar conditions. We are standardizing 'Arid-Tech' for global use, driving regional restoration through the Middle East Green Initiative, and pioneering Anticipatory Governance. By aligning our national strategy with forward-thinking international frameworks, we aren't just reacting to environmental trends, we are defining the future of global environmental policy.

Interviews – Questions for Sector Leader

Dr. Mohammed AlAssim – MWAN
Vice President for Planning and Development

1. What are the key environmental-related challenges, and how do technologies play a role in overcoming them?

The waste sector faces a variety of challenges that can be grouped into five key categories: value chain technologies, digitization and data tracking, seasonal events waste surge (Hajj); awareness, capabilities, and behaviors; and materials design and value. Each of these categories encompasses several challenges that need to be addressed, with each challenge requiring a specific approach. With respect to the value chain technology category, many of the challenges arise from the limited availability of technologies to treat certain types of waste. For example, one important challenge within this category is the limited innovative financially viable solutions to treat lithium-ion batteries.

The treatment and recycling of spent lithium-ion batteries (LIBs) face several limitations, including the complexity of disassembling tightly integrated components, the need for sophisticated technology, and the lack of standardization among manufacturers. This is a potential area for an innovative technological solution that can play a critical role in addressing existing gaps and providing more efficient ways to utilize and extract value from all waste streams.

2. What is not yet on everyone's radar, and you are closely following?

In managing the waste sector, the National Center for Waste Management (MWAN) is orchestrating a distinctive approach through the development of Waste Master Plans aimed at transforming the sector holistically.

The project established a baseline of the existing infrastructure, developed detailed frameworks to guide the evolution of waste management systems, and formulated comprehensive plans for sector-wide investments.

Rather than directly adopting international best practices, the Waste Master Plans identify, adapt, and tailor those practices to align with the Kingdom's existing waste infrastructure and specific national needs across all relevant waste streams.

3. What drives investments in environmental innovation in Saudi Arabia?

The current identified investment opportunities that complement the existing waste management infrastructure create a market opportunity for innovative solutions. Waste management is a perfect microcosm of this dynamic clear infrastructure gap, combined with policy goals circular economy under Vision 2030, creates a market opportunity that is now being filled by private investment, supported by new PPP models and regulations.

This same pattern repeats across energy, water, and industrial sectors. Limitations in treatment capacity and technology availability for specific waste streams highlight the need for advanced, localized technologies. These investment opportunities, combined with the commitment of the National center for waste management to achieve environmental sustainability, incentivize private sector investment aimed at addressing unmet needs and improving overall sector performance.

4. How do you see the market for environmental innovation evolving in the next 5–10 years?

Innovation in the waste sector will continue to evolve alongside the growing waste infrastructure. Over the next 5–10 years, innovations are likely to shift from being primarily solution based to focusing on the optimization of technologies, enhancing efficiency and cost-effectiveness. The market is also likely to see increased adoption of digital tools and systems which will enable better monitoring, decision-making, and regulatory compliance within the waste management sector.

5. How can Saudi Arabia position itself as a global leader in environmental innovation?

Establishing a clear regulatory framework that encourages experimentation and piloting while maintaining environmental safeguards will attract both local and international innovators, resulting in high-impact environmental solutions in waste management.

Strengthening research and development capabilities, investing in talent, and fostering collaboration between industry, academia, and government will further enhance the Kingdom's innovation capacity. Through these initiatives, Saudi Arabia can position itself to be the pioneer in the sector, exporting its influence and expertise globally.

Interviews – Questions for Sector Leader

Sultan Alsaif - TerraFuel & SIRC
CEO and Executive Director

1. What are the key environmental-related challenges, and how do technologies play a role in overcoming them?

The primary challenge is the transition from a linear "take-make-dispose" model to a fully circular economy at a national scale.

- From a TerraFuel perspective: The challenge is ensuring the consistency and quality of waste-derived feedstock. We utilize Advanced Mechanical-Biological Treatment (MBT) to convert municipal waste into high-quality Refuse-Derived Fuel (RDF), providing a sustainable alternative to fossil fuels for heavy industries like cement production.
- From a SIRC perspective: The challenge is managing the complexity and volume of diverse waste streams. We are leveraging AI-driven sorting and IoT-enabled logistics to transform waste collection into a data-driven resource recovery operation.

2. What is not yet on everyone's radar, and you are closely following?

I am particularly focused on Biomass Pyrolysis for Biochar production. While much of the industry focuses on energy recovery, we see a massive opportunity in converting agricultural and organic waste into biochar. This technology supports the Saudi Green Initiative (SGI) by enhancing soil health and providing a permanent method for carbon sequestration in arid environments. Additionally, the Valuation of Carbon in the Circular Economy—integrating waste management into global carbon credit markets—is a frontier that will redefine project bankability.

3. What drives investments in environmental innovation in Saudi Arabia?

Investment is driven by the clear regulatory roadmap provided by the National Waste Management Law and the strategic mandates of Vision 2030. Beyond regulation, there is a growing demand for Industrial Symbiosis. Companies are no longer just looking to dispose of waste; they are seeking energy security. TerraFuel's model of converting waste into industrial fuel offers a hedge against price volatility while helping corporations meet their ESG (Environmental, Social, and Governance) targets.

4. How do you see the market for environmental innovation evolving in the next 5–10 years?

We will see a total shift from "Waste Management" to "Resource Management." The market will evolve into an integrated ecosystem where "waste" is the primary feedstock for new industries. We expect the emergence of a vibrant local Climate-Tech sector, where Saudi startups develop home-grown solutions for water-scarce and high-temperature environments, eventually exporting this expertise globally.

5. How can Saudi Arabia position itself as a global leader in environmental innovation?

By becoming the global hub for "Circular Petrochemicals" and "Integrated Waste Hubs." Saudi Arabia has the unique advantage of having world-class industrial players (like SABIC and Aramco) and a dedicated national circular economy driver (SIRC). By standardizing the use of 4IR technologies (AI, Blockchain, and Robotics) in waste processing, we can export the operational blueprints for modern, sustainable cities to the rest of the world.

Interviews – Questions for Sector Leader [1/3]

Dr. Nizar Haddad – FAO
Programme Director

1. What are the key environmental-related challenges, and how do technologies play a role in overcoming them?

Saudi Arabia's priority environmental challenges are well known. These can be summarized as limited systems and ability to measure environmental conditions consistently, weak coordination of planning and decisions across agencies and mandates, limited institutional and human capacity, weak enforcement and environment compliance, and proven systems to scale out innovative technologies and practices. Most important, technology and innovation must align with policies, standard operating procedures and other enablers. The key environmental challenges are highlighted below:

- **Weak ecosystem monitoring and verification** for land degradation, vegetation condition, biodiversity pressures, and restoration performance. FAO combines cloud-based Earth observation analytics (e.g., SEPAL) with standardized field data collection and validation workflows (e.g., Open Foris). Together, these enable repeatable monitoring, quality assurance, and verifiable reports, allowing interventions be targeted, tracked, and adapted where necessary.
- **Limited human and institutional capacity** to operate environmental data systems, tools, and decision support. In many instances, private contractors fill the gaps but in a fragmented arrangement, thereby lowering technology and innovation ROI. FAO supports targeted training and developing guidelines, protocols, QA routines, and workflows that help Saudi national teams consistently generate and maintain decision maps, environmental indicators, and dashboards.
- **Weak integration of environmental safeguards** into spatial planning and investment decisions. FAO decision support platforms and workflows such as the Hand-in-Hand Platform combined with FAO Earth Observation tools and field validation allow multi-sector spatial overlays that connect ecosystem sensitivity, land degradation risk, and infrastructure setup needs for specific development scenarios. This improves prioritization and reduces costly conflicts by embedding environmental constraints and opportunities into land-use planning upfront.
- **Severe degradation of vast rangelands** driven by multiple factors but mostly attributed to rangeland grazing governance gaps including unsustainable grazing pressure, weak enforcement, unclear access rules, and limited range management mechanisms. FAO's Pastoralist Knowledge Hub advocates "Digital grazing management" as an operational system including SOPs, indicators, compliance triggers, seasonal mobility/corridor mapping, and participatory agreements on grazing access rules. FAO support digital grazing management with Earth Observation monitoring and structured field verification, thereby using technology to makes conditions and compliance visible and allowing governance mechanisms to make behavior change possible.
- **Misaligned state incentives,** especially in grazing system remain a binding constraint, even as Saudi Arabia strengthens regulation, permitting, and sector restructuring. FAO supports the design of results-based incentive packages that have potential to link permits and operational SOPs to measurable KPIs, risk-based inspections, tiered penalties/fees, and pay-for-outcomes contracts backed by MRV. This would allow Saudi Arabia to reward compliant actors and discourage non-compliance.
- **Agri-food and biomass waste** in Saudi Arabia is under optimized by fragmentation, weak planning integration, and financing constraints. FAO can support circular bioeconomy planning that maps biomass supply (food loss/waste, residues, manure), identify optimal processing nodes (composting, anaerobic digestion, biochar), and connect these to land restoration and soil improvement. Based by MRV performance metrics, Saudi can move to service models and PPP ready investments with clean environmental, greening, and land rehabilitation benefits.
- **Severe hyper-arid constraints and water stress,** recently being exacerbated by increased exposure to climate shocks. FAO tools such as WaPOR can help quantify water productivity and evapotranspiration patterns, supporting smarter irrigation scheduling and accountability. Further, scenario tools such as AquaCrop can support testing of water-deficit strategies under heat stress. Additionally, FAO early-warning and risk mapping tools such ASIS help translate drought and vegetation stress signals into trigger-based contingency actions to protect investments and livelihoods.

FAO provides range suitable technologies to address Saudi environmental challenges. However, these require to be embedded in workflows and governance and further strengthened through standardized monitoring and MRV, inter-agency coordination, spatial decision support, enforceable compliance systems, and results-based financing. FAO added value is in enabling the full chain, from tools and protocols to capacity building to and operationalization. The result will be faster, more coordinated, and measurable and effective environmental decisions at scale across Saudi Arabia.

2. What is not yet on everyone's radar, and you are closely following?

FAO strengthen is in supporting technology implementation especially through selection, piloting, and scaling of environmental technologies in Saudi Arabia. From our work, the operational gap between environmental ambitions and what will work on the ground sustainably is one of the concerns always on our radar. Here, we identify and follow some areas on concern as summarized below.

Interviews – Questions for Sector Leader [2/3]

Dr. Nizar Haddad – FAO
Programme Director

- **Coordination bottleneck:** Agencies have overlapping mandates in land rehabilitation, biodiversity, and monitoring and can run parallel interventions without benefiting each other and without sharing data and information to guide prioritization of actions. This increases technology costs and may dilute impact.
- **Technology sustainability:** Contract focused delivery without complementary institutional capacity development can be a sustainability trap. Without national ownership, institutional capacity, clear data governance, and long-term operating financial arrangements, platforms and apps delivered through well intended contracts may not survive.
- **Data quality:** Mobile apps and digital tools are being adopted faster than the required technical capacity for quality control and assurance, calibration, and data collection. This is especially so and these tools tend to replace costly field verification. The risk is high volume of data with limited quality for solid planning and decision support.
- **Scenario models:** With tools for complex scenario modelling being available to everyone, simulations are increasingly used for planning, design, and implementation support. Unfortunately, in most cases, calibration and validation efforts are thin either because of urgency to deliver or because quality field data to is not available for calibration and validation.
- **Community engagement:** Within the environment sector, local institutions and communities are not strongly involved mostly because of limited structured participatory governance including resource use agreements, access rules and incentives. The vital stakeholders remain observers while they should be active environmental and land resource co-managers.

These insights come from FAO ongoing engagement in the environment sector through the Sustainable Rural Agriculture Development (SRAD) Project designed together with Ministry of Environment, Water and Agriculture (MEWA) and implemented in collaboration with the National Center for Vegetation Cover and Combating Desertification (NCVC). Through the SRAD project, FAO supported evidence-based planning and implementation across forests, rangelands, national parks, land desertification, and geospatial systems, utilizing range of FAO environmental technologies. In forests, the project surveyed and mapped 613,132 hectares across 492 forest sites in 5 regions, produced 5 regional forest atlases, and developed and piloted the National Forest Inventory in Al-Baha, scaling it out across the Kingdom. In rangelands, 26 priority sites covering approximately 8 million hectares were surveyed, assessed, and mapped. For land desertification control, sand encroachment control was piloted in 1 region, protecting 22,176 hectares and 616,650 trees.

For national parks, field-based assessments informed 1 model national park and supported nationwide national park planning processes. Across data and geo-spatial, FAO provided sustained technical support and delivered more than 80 technical outputs and supported development of a digital platform and standardized data collection tools for forests, rangelands, vegetation rehabilitation, and land degradation monitoring. To ensure sustainability, FAO backed these activities by capacity building for over 300 office and field staff of NCVC. From FAO perspective, the priority is to align deployment of environmental technology and innovation with coordinated operational systems. FAO tools such as Hand-in-Hand Platform), range of open-source Earth Observation tools such as SEPAL and Open Foris, and simulation and scenario models tools such as WaPOR and ASIS coupled with field validated MRV workflows and participatory community engagement provide a solid foundation for sustainable application of rapidly development environmental technology and innovation in Saudi Arabia.

3. What drives investments in environmental innovation in Saudi Arabia?

Investments in environmental innovation in Saudi Arabia are most consistently triggered by delivery against national targets such as Vision 2030 and the Saudi Green Initiatives. Within the sector, investments are highly geared towards high tech solutions, international best practices and standards, and reducing risks and improving efficiency.

FAO's value is to connect investments to deployable national systems to provide shared planning layers, so innovations align with national priorities, remain sustainable beyond projects, and produce verified outcomes that will unlock further financing and scaling.

4. How do you see the market for environmental innovation evolving in the next 5–10 years?

Saudi Arabia's environmental innovation market is expected to expand rapidly, driven by government commitments and investments through flagship projects such as the Saudi Green Initiative. It is important to note that the kingdom has high commitment in the sector and requires all projects to mainstream the protection of the environment. Based on current trends, Key areas of environmental innovation will focus on water management including renewable water harvesting, grey water use, and water use efficiency, climate action and climate-smart technologies, and environment sector digitalization among others.

Use of digital monitoring, AI Analytics, and IoT will be scaled up for rangelands, forests, and protected area management. Cloud based Remote sensing and Earth Observation tools will play important roles in climate actions, smart irrigation systems, and water use efficiency modelling and scenarios including for land rehabilitation and urban greening.

Interviews – Questions for Sector Leader [3/3]

Dr. Nizar Haddad – FAO
Programme Director

Progress will be made in developing, testing, and adapting models for integrating private sector investments in land resources rehabilitation and payment for ecosystem services, especially at local community and land user levels. Recent development will allow effective integrated environmental data systems through crowd sources and citizen data, which will facilitate embedding of environmental intelligence into business, infrastructure development, land-use planning, and in policy design. Further, establishment of innovation hubs will support testing, adaptation, and scaling up of environmental innovations and technologies.

5. How can Saudi Arabia position itself as a global leader in environmental innovation?

This section looks at how Saudi Arabia can take advantage of FAO technology and solutions to position itself as a global leader in environmental innovation. The key strategy would be to build a national environment "system" that allows single, coordinated delivery model. With FAO support, this can be anchored in shared spatial planning and targeting layers using tools such as Hand-in-Hand Platform coupled with decision-ready visualization using tools like Earth Map.

The model would be simple - one common view of priorities, interventions, and risks across agencies, with dashboards that translate data into decisions for leaders, technical teams, and field enforcement. Saudi can strengthen its global position by institutionalizing Monitoring Reporting and Verification that combines satellite analytics with field-validated evidence. For this, SEPAL would be ideal for scalable Earth Observation processing while Open Foris would provide standardized field data collection, verification, and QA. However, FAO's value would not only be in the tools, but the operationalization of SOPs, sampling approaches, indicator definitions, quality control points, and national capacity development so that systems remain functional beyond specific projects.

Water is the binding constraint in Saudia Arabia and the Kingdom position as a global environmental leader with be strengthened by becoming reference country for water-smart environmental solutions including land restoration and vegetation cover establishment. FAO can support water management approach that links operational protocols to measurable evidence using tools such as WaPOR to track evapotranspiration and water productivity patterns, and AquaCrop to test deficit irrigation and heat-stress scenarios. This is crucial for assessment of how technologies would perform when scaled out to different water-constraint environments.

This will turn "smart irrigation" from a market claim into enforceable guidance and performance accountability. In the rangelands, Saudi can lead by demonstrating that sustainability is achievable through a practical mix of governance and technology. FAO can help translate grazing policies into a digital grazing management framework with clear SOPs, indicators, and compliance alerts, supported by seasonal planning, mobility and corridor mapping, and participatory agreements on grazing land access rules.

These actions will make conditions and compliance visible and translate range governance mechanisms into behavioral change. Another action that would strategically position Saudi Arabia as a global leader is by scale what works in specific pilots and environment using financing models tied to verified outcomes.

FAO can help package programmes into performance-based service models and pay-for-results mechanisms that use MRV evidence to trigger payments, remove or reduce private sector risk, and crowd sourced green finance. The model would be repeatable with plug and play components including strong coordination, verified outcomes, disciplined water management, enforceable rangeland governance, and finance that rewards impact, focused on arid and hyper-arid realities and transferable to similar environments worldwide.

Interviews – Questions for Sector Leader

Dr. Ratul Das – ACWA Power
Executive Manager, Research and Development

1. What are the key environmental-related challenges, and how do technologies play a role in overcoming them?

The primary environmental challenge for Saudi Arabia's desalination sector is its historically high energy intensity, which has traditionally relied on the combustion of hundreds of thousands of barrels of oil daily to power thermal plants. To mitigate this, the Kingdom has aggressively transitioned to Sea Water Reverse Osmosis (SWRO), a process that requires significantly less electricity. By 2026, this shift is being optimized through the widespread installation of Energy Recovery Devices (ERDs), such as pressure exchangers, which recycle up to 98% of the energy from waste streams, and the integration of dedicated solar farms to decouple water production from the carbon-heavy grid. These advancements, combined with AI-driven load management, have slashed the energy required to produce a cubic meter of water to record lows—approaching 2.7 kWh/m^3—effectively transforming desalination from a fossil-fuel-dependent liability into a core component of the Kingdom's net-zero ambitions.

2. What is not yet on everyone's radar, and you are closely following?

What's currently flying under the mainstream radar but gaining serious momentum in the Kingdom is the shift toward Batch Reverse Osmosis (Batch RO). While standard RO is the current king, Batch RO—being piloted through partnerships like the one with Harmony Desalting (from MIT)—uses a "closed-loop" pressure cycle that avoids the energy waste of continuous flow, potentially pushing efficiency toward the theoretical thermodynamic limit.

3. What drives investments in environmental innovation in Saudi Arabia?

Investment in Saudi Arabia's desalination innovation is primarily propelled by the strategic need to decouple water production from fossil fuel consumption, effectively freeing up millions of barrels of crude oil for export while lowering the Levelized Cost of Water. Under the dual mandates of Vision 2030 and the Saudi Green Initiative, the Kingdom is prioritizing "water-energy sovereignty" by transitioning to high-efficiency, solar-integrated Reverse Osmosis to meet its aggressive Net Zero targets.

Furthermore, there is a powerful push to transform the sector from a technology importer into a global exporter; by localizing the manufacturing of RO membranes and integrating Industrial AI, the Kingdom is building a knowledge-based economy that treats water security as a high-tech industrial asset. This shift not only secures a sustainable supply for giga-projects but also positions KSA as the primary "testbed" for the world's next generation of climate-resilient water tech.

4. How do you see the market for environmental innovation evolving in the next 5–10 years?

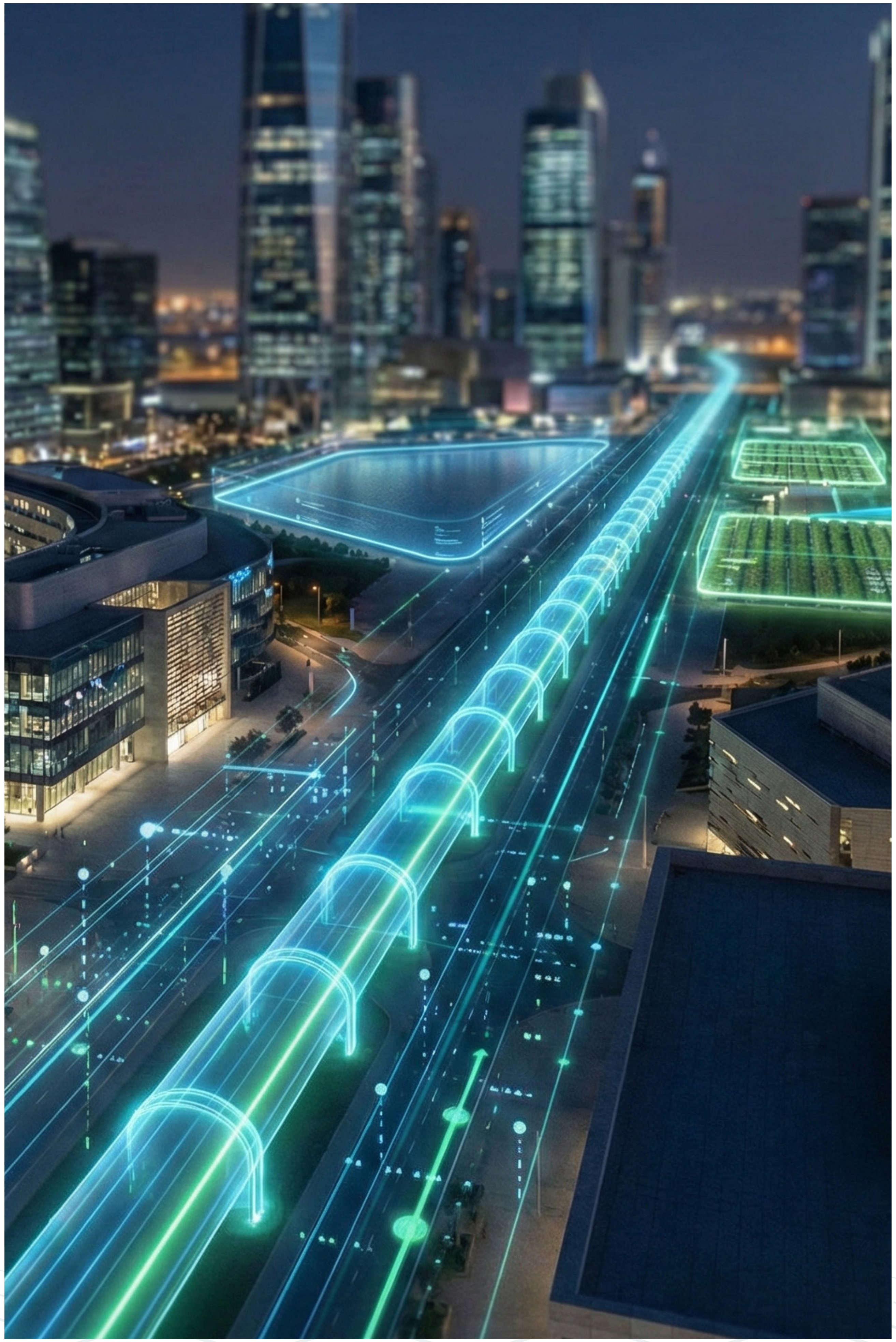
In the next 5–10 years, Saudi Arabia's desalination sector will shift from merely scaling up production to achieving "energy-neutral" water through radical technological integration. By 2030, the Kingdom aims to have 50% of its desalination capacity powered by renewables, while the subsequent five years will likely see the deployment of Small Modular Reactors (SMRs) to provide consistent, carbon-free baseload power. This energy evolution is being managed by a "digital-first" market where Autonomous Plants—run by predictive AI and digital twins—optimize every kilowatt-hour in real-time. Ultimately, the focus is transitioning from being the world's largest consumer of water tech to its primary exporter, localizing the manufacturing of core components like membranes and high-pressure pumps to turn water security into a high-tech industrial engine.

5. How can Saudi Arabia position itself as a global leader in environmental innovation?

Saudi Arabia is positioning itself as the global leader in environmental innovation by shifting from a consumer of technology to a primary "scaling engine" and IP builder. A major takeaway from the 2026 Innovation Days in Riyadh was the signing of 27 strategic partnerships specifically designed to bridge the gap between lab research and industrial deployment. Key insights from the event highlight a move towards "disruptive efficiency": the Kingdom will now pilot Batch Reverse Osmosis (via MIT's Harmony Desalting) to push energy recovery to its thermodynamic limit, and Gravitational Vapor Compression (with WGA), a green technology that moves beyond the traditional thermal and membrane limits, all these to dramatically lower the cost of water production. By integrating these deep-tech solutions with Industrial AI to automate energy loads and utilizing advanced anti-fouling membranes, KSA is not just securing its own water future but is actively packaging these localized innovations as a high-tech export for the global market.

Selection Criteria Scorecard

	Technology	Segment	Technology Readiness Level	Spotlight Score
		TPG 1		
1	Autonomous OGI Drone LDAR	Aerial Detection Systems	9	32
2	High-Resolution Methane Satellites	Aerial Detection Systems	9	46
3	AI Fenceline HAP Detection	Ground-Based Monitoring Networks	8	11
4	Continuous Methane Monitoring Networks	Ground-Based Monitoring Networks	8	51
5	AI-Calibrated Low-Cost Sensor Networks	Ground-Based Monitoring Networks	8	40
6	Open-Path Laser Perimeter Monitoring	Ground-Based Monitoring Networks	8	8
7	Mobile Plume Mapping and Quantification	Aerial Detection Systems	8	31
8	HRMS Non-Target Chemical Screening	Compliance & Laboratory Analytical Technologies	7	56
9	High-Throughput PFAS Compliance Analytics	Compliance & Laboratory Analytical Technologies	8	51
10	PEMS with Process Digital Twins	Digital Intelligence Systems	9	21
11	Automated Environmental RegTech Reporting	Digital Intelligence Systems	7	48
12	ML Odour Sensor Networks	Ground-Based Monitoring Networks	7	7
13	Automated Monitoring QA/QC Pipelines	Compliance & Laboratory Analytical Technologies	9	53
14	Integrated Satellite-Model Enforcement Intelligence	Digital Intelligence Systems	7	24
15	Dynamic Emissions and Carbon Metering	Digital Intelligence Systems	6	76



Glossary

Technology Readiness Level (TRL)

TRLs are used as methods of assessing the maturity of a technology being developed. It has a scale from 1-9 (from basic principles and research to actual proven systems and full commercial application)

TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
Basic Technology Research	Applied Research	Critical Function	Laboratory Testing of prototype component or process	Laboratory Testing of Integrated system	Prototype System Verified	Pilot System Demonstrated	Commercial Design	Full Commercial Deployment

Capability Readiness Level (CRL)

CRL is a scale that assesses the market readiness and economic viability of a technology, ranging from 1 to 9. It focuses on the business model, market validation, and the commercial need for the technology, ensuring that the solution meets market demands and has a viable business case. Unlike TRL, CRL is more subjective and requires detailed market analysis.

CRL1	CRL2	CRL3	CRL4	CRL5	CRL6	CRL7	CRL8	CRL9
Basic science capabilities and facilities are limited in KSA	• Small-scale basic science completed in KSA, by local and foreign personnel • Necessary lab equipment physically located in the KSA; with limited dependence on out sourcing	• Multiple KSA labs are fully capable of conducting appropriate basic science. • Research output from local labs widely published and cited in Int'l peer reviewed journals	Functional applied science applications of relevant tech completed at a small scale in either Saudi labs, or by tech-focused KSA companies (e.g., MNCs and National Champions)	• Functional tech. modules built in several Saudi labs and/or companies. • Findings widely published. • Large group of skilled Saudi scientists, engineers, and technologists enabled	• Saudi labs or companies have produced Minimum Viable Products (MVP) of fully functional tech components. • MVPs demonstrated in public forums and conferences	• In-country manufacturing capacity exists at scale. • If it is a Technology-based service, it can be deployed and provisioned nationwide	• In-country manufacturing capacity exists at cost levels comparable to similar systems. • Tech-based service, it can be deployed and provisioned worldwide	• In-country manufacturing capacity has produced scale quantities sold nationwide and internationally • Tech-based service deployed in multiple countries.

sources:

1. TRL – Definition is designed by NASA **https://esto.nasa.gov/files/trl_definitions.pdf**.There is detailed description for hardware and software **https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf**
2. CRL – Definitions are designed by RDIA National Mission Guidebook

Glossary

3.1 Pollution Control and Compliance

	Terminology	Description
1	Autonomous OGI Drone LDAR	"Drone-in-a-box" systems equipped with Optical Gas Imaging (OGI) automate leak detection and repair (LDAR) by running scheduled missions, capturing geo-tagged visual evidence of emissions, and generating regulator-ready inspection records. The emerging leap is autonomous operations (remote launches, repeatable flight paths, standardized evidence capture) combined with automated analytics and work-order integration. For MEWA, this is high-impact for industrial clusters and oil/gas-adjacent sites where episodic leaks drive disproportionate emissions and public complaints. The compliance value is speed, auditability, and reduced dependence on manual site walks.
2	High-Resolution Methane Satellites	New satellite systems detect and quantify methane plumes at facility-scale, enabling independent identification of "super-emitters," cross-checking self-reported emissions, and targeting inspections where they matter most. Emerging value comes from higher spatial resolution, improved retrieval algorithms, faster revisit cadence, and open/accessible data portals. For MEWA, the same monitoring logic generalizes beyond methane: satellite-driven detection of industrial plumes and land-atmosphere interactions can strengthen evidence chains for enforcement and policy. The compliance shift is from reactive inspections to intelligence-led regulation with credible third-party measurement.
3	AI Fenceline HAP Detection	AI-enabled fenceline monitoring uses distributed sensors around industrial sites to detect spikes in hazardous air pollutants (HAPs) such as VOCs (e.g., benzene/toluene), then applies anomaly detection and inference models to flag likely releases and support rapid investigation. The emerging edge is real-time analytics (low latency), automated event classification, and integration into compliance workflows (case creation, evidence packages, prioritization of inspections). For MEWA, it's directly relevant to industrial corridors and sensitive receptors (urban edges, schools, hospitals). Done right, it reduces community exposure and turns complaints into measurable, actionable enforcement data.
4	Continuous Methane Monitoring Networks	Continuous methane monitoring (CMM) networks use fixed sensors (point or open-path) plus analytics to detect, localize, and increasingly quantify emissions 24/7. The emerging shift is the move from "detection only" to measurement-informed reporting and reconciliation frameworks, including guidance on how continuous monitoring can support emissions estimation and compliance. For MEWA, CMM is relevant where leaks are intermittent and easy to miss in periodic LDAR. It also supports proactive compliance—operators see issues early, regulators get improved transparency, and enforcement resources focus on high-impact events. Standards and acceptance are evolving, which is exactly why it's a watchlist item.
5	AI-Calibrated Low-Cost Sensor Networks	Dense networks of low-cost air sensors can map neighborhood-scale pollution gradients, industrial edge impacts, and episodic events—if calibration is robust. The emerging technology is ML-based calibration and transfer learning that corrects drift, location biases, and meteorological dependencies, pushing low-cost data closer to decision-grade performance. For MEWA, this enables broader coverage than reference stations alone, supports equitable exposure management, and helps prioritize inspections and mitigation in rapidly growing urban areas. The risk is misuse: without QA/QC, low-cost data can be challenged. The opportunity is pairing ML calibration with co-location protocols and governance to make it defensible for operational decisions.
6	Open-Path Laser Perimeter Monitoring	Open-path laser spectroscopy (e.g., TDLAS and related optical methods) measures gas concentrations along a beam path across facility perimeters or corridors. It's powerful for continuous detection of diffuse emissions and can support event reconstruction when paired with meteorology and inverse modeling. The emerging edge is compact, multi-gas capable systems, better stability, and increasing deployment patterns that integrate with compliance analytics (alerts, localization, evidence packages). For MEWA, it's relevant to petrochemical zones, fertilizer/ammonia value chains, and large facilities where point sensors miss emissions between equipment. Adoption is growing, but widespread regulator-standardized use is still developing.
7	Mobile Plume Mapping and Quantification	Mobile plume mapping uses vehicles, portable systems, drones, or aircraft to rapidly locate and quantify emissions using mass-balance methods, flux planes, or plume inversion. The emerging value is faster quantification (not just detection), lower deployment cost (portable methods), and improved uncertainty characterization that can hold up in compliance contexts. For MEWA, it's a pragmatic bridge between satellites (broad detection) and component-level inspections (fine detail), especially for industrial clusters and waste facilities. It enables rapid "find–quantify–fix" cycles and helps regulators prioritize the worst sources. Quantification methods and standardization are still evolving.
8	HRMS Non-Target Chemical Screening	High-resolution mass spectrometry (HRMS) non-target screening (NTS) detects chemicals beyond fixed target lists—crucial for emerging contaminants, unknown byproducts, and mixture exposures. The emerging capability is standardized data archiving, retrospective screening ("re-check old samples for new suspects"), and regulator-oriented workflows that connect detections to risk prioritization and source investigations. For MEWA, NTS strengthens water/effluent compliance, industrial discharge investigation, and early detection of new pollutants before they become widespread. The hard part is operationalization: libraries, QA/QC, and legal defensibility. Several countries are moving from research into systematic regulatory use now.

	Terminology	Description
9	High-Throughput PFAS Compliance Analytics	PFAS monitoring is accelerating globally as new limits and reporting requirements take effect. The emerging technology layer is high-throughput lab workflows (improved sample prep, LC-MS/MS pipelines, suspect screening add-ons, automation) plus data systems that handle large monitoring volumes and produce regulator-ready reporting. For MEWA, PFAS capability matters for drinking water protection, industrial discharge oversight, landfill leachate, and firefighting foam legacy sites. Even if national standards differ, global supply chains and reputational risk are converging on PFAS transparency. The near-term gap is cost and capacity—so scalable analytics and prioritized monitoring design are key.
10	PEMS with Process Digital Twins	Predictive Emissions Monitoring Systems (PEMS) estimate emissions from process/operational data using calibrated models—often positioned as a cost-effective complement or alternative where direct continuous measurement is difficult. The emerging frontier is integration with process digital twins, improved model governance, and stronger QA/QC for audit defensibility. For MEWA, PEMS can reduce compliance blind spots in complex facilities (power, refineries, industrial boilers) and enable continuous anomaly detection that triggers maintenance or investigation before limits are exceeded. It's not "new," but the compliance-grade digital-twin integration and expanding industrial partnerships are making it a rapidly evolving area.
11	Automated Environmental RegTech Reporting	Environmental RegTech automates compliance workflows: data ingestion from sensors/DAHS, validation, anomaly detection, automated calculation of regulatory metrics, and machine-readable submissions with audit trails. The emerging value isn't "dashboards"—it's compliance-by-design: minimizing manual handling, reducing late/missing reporting, improving evidence integrity, and enabling risk-based inspections. For MEWA, this reduces enforcement friction and accelerates corrective actions by creating consistent, traceable records across facilities. It also supports scalable oversight as industrial activity grows. This space is emerging because standards for machine-readable reporting, interoperability, and automated controls are still forming.
12	ML Odour Sensor Networks	Odour is politically sensitive because it drives complaints but is hard to prove. Emerging "e-nose" sensor networks combine chemical sensor arrays with ML classifiers and drift compensation to identify odour signatures and associate them with facility events and meteorological conditions. For MEWA, odour tech matters around landfills, wastewater plants, industrial zones, and fast-growing urban edges—where nuisance issues become social pressure and public health concerns. The technology remains emerging because long-term stability, calibration, and legal defensibility are not fully standardized. However, momentum is strong in sensor materials and AI methods, making this a high-leverage area for compliance modernization.
13	Automated Monitoring QA/QC Pipelines	Automated QA/QC pipelines for continuous monitoring focus on data integrity: validation rules, automated flags, gap handling, secure storage, and standardized reporting outputs. The emerging part is certified and security-conscious digital handling that makes emissions data legally defensible and reduces opportunities for manipulation or "accidental" reporting errors. For MEWA, this is foundational: strong enforcement requires strong data. Modern DAHS solutions align with standards for DAHS performance and can integrate directly into regulator reporting systems. While DAHS exists, the trend toward certified, auditable, cyber-aware pipelines integrated with analytics is still evolving and critical as monitoring shifts to continuous compliance.
14	Integrated Satellite-Model Enforcement Intelligence	This fuses satellite observations, ground sensors, and air-quality models to generate enforcement-ready insights: plume detection, source probability mapping, episode forecasting, and prioritized inspection targeting. The emerging aspect is operational integration—moving beyond research prototypes to decision-support systems regulators can use daily. For MEWA, it supports management of industrial episodes and urban exposure while optimizing inspection resources. The approach improves transparency by documenting why inspections target specific sites using multi-source evidence. It remains emerging because data fusion methods, uncertainty communication, and governance for enforcement use are still developing, and many implementations are not yet standardized or widely institutionalized.
15	Dynamic Emissions and Carbon Metering	Dynamic emissions/carbon metering measures emissions and carbon intensity in near real-time using context-specific data (operating conditions, energy mix, process states), rather than static factors and end-of-period estimates. The emerging value is compliance alignment with tightening reporting requirements and market mechanisms, plus faster operational control (detect abnormal emission patterns early). For MEWA, the relevance is indirect but growing: as industrial reporting becomes more granular and machine-readable, dynamic metering can improve credibility and reduce disputes. It also aligns with broader national sustainability targets. This remains emerging because standards, interoperability, and verification methods are still evolving, and many implementations are early-stage or sector-specific.

Glossary

Abbreviation

	Abbreviation and Terms	description
1	SAR	Synthetic Aperture Radar (SAR) is a radar imaging technique that creates high-resolution images by processing signals from a moving antenna to simulate a larger aperture.
2	P-band	P-band radar frequency is a radar frequency range of 0.3-1 GHz that provides deep forest penetration for biomass and subsurface monitoring applications.
3	L-band	L-band radar frequency is range of 1-2 GHz used for soil moisture monitoring and moderate vegetation penetration in SAR applications.
4	S-band	S-band radar frequency is range of 2-4 GHz providing high-resolution surface monitoring with limited vegetation penetration in SAR systems.
5	JAXA's ALOS-4	JAXA's ALOS-4 (Advanced Land Observing Satellite-4) is Japan's L-band SAR Earth observation satellite, designed for environmental monitoring and disaster management.
6	NASA-ISRO's	NASA–ISRO Synthetic Aperture Radar Mission is a joint US–India satellite mission for climate monitoring, carbon assessment, and natural disaster observation.
7	NISAR	NISAR is NASA-ISRO Synthetic Aperture Radar, a dual-frequency satellite mission for global Earth observation and deformation monitoring.
8	R&D	(Research and Development) refers to innovative activities undertaken by corporations or governments to develop new services or products, or improve existing ones.
9	ESA's	Refers to the European Space Agency's - Europe's intergovernmental space organization comprising 22 member states, responsible for coordinating European space activities and missions.
10	BIOMASS mission	BIOMASS mission is ESA's Earth Explorer satellite using first space-based P-band radar to measure global forest biomass and carbon stocks.
11	geosynchronous	Orbit matches Earth's rotation, allowing satellites to stay in the same position relative to the ground to provide persistent, continuous coverage of one area.
12	Sentinel	Sentinel is the European Space Agency's satellite constellation providing systematic Earth observation data through the Copernicus program for environmental monitoring.
13	RADARSAT	RADARSAT Satellite Program is Canada's synthetic aperture radar (SAR) satellite program, providing all-weather Earth observation capabilities for environmental monitoring and resource management.
14	LEO	Low Earth Orbit(LEO)is the satellite orbital region between 160-2000 kilometers altitude enabling frequent Earth coverage with shorter orbital periods
15	Shakuntala	Shakuntala is a pathfinder hyperspectral satellite launched by the Indian startup Pixxel. Weighing under 15kg, it captures detailed Earth data across 150+ spectral bands at 10-meter resolution
16	Hyperspectral Imaging	Hyperspectral imaging is a captures electromagnetic spectrum data across hundreds of narrow wavelength bands, enabling precise material identification and spectral analysis

	Abbreviation and Terms	description
17	PV-livestock	Refers to systems that combine photovoltaic solar panels with livestock grazing on the same land, optimizing dual land use for energy production and agriculture.
18	Megawatt (MW)	Megawatt (MW) Is a unit of electric power equal to one million watts, measuring the instantaneous rate of energy generation or consumption.
19	photovoltaic (PV)	Refers to solar technology that converts sunlight directly into electricity using semiconductor materials, typically silicon-based solar panels or cells.
20	Agriculture and Applied Economics Association (AAEA)	Refers to a professional organization for agriculture economists, researchers, and policy analysts focused on food, agriculture, and resource economics.
21	Levelized Cost of Electricity (LCOE)	Refers to the average cost per unit of electricity generated over a power plant's lifetime, including all capital and operating expenses.
22	Kilowatt (kW)	Refers to a unit electrical power equal to 1,000 watts, measuring the rate of energy consumption or generation capacity.
23	INR	Refers to the official currency of India, Indian Rupee.
24	Mollification	Refers to the softening or reducing the severity of climate change impacts through mitigation and adaptation strategies.
25	ACWA Power	a Saudi Arabian renewable energy developer and the world's largest private water desalination company, leading energy transition and green hydrogen.
26	Badeel	A water and Electricity Holding Company, a wholly owned subsidiary of Saudi Arabia's Public Investment Fund (PIF) focused on renewable energy projects.
27	Saudi Aramco Power Company (SAPCO)	Saudi Aramco's power generation subsidiary developing electricity infrastructure and renewable energy projects supporting Saudi Arabia's agriculture and industrial development.
28	Gigawatt (GW)	Gigawatt (GW) is a unit of electrical power to one billion watts or 1,000 megawatts, commonly used to measure the capacity of large-scale power generation facilities.
29	Afif1	A 2-gigawatt solar photovoltaic power plant located in Riyadh Province, Saudi Arabia, developed as part of the kingdom's renewable energy expansion under Vision 2030.
30	Afif2	A 2-gigawatt solar photovoltaic power plant located in Riyadh Province, Saudi Arabia, developed as part of the kingdom's renewable energy expansion under Vision 2030.
31	Electrochemical slag	Refers to metallurgical waste processed using electrical current to extract valuable metals through controlled electrochemical reactions and oxidation.

Glossary

Abbreviation

	Abbreviation and Terms	description
32	EU's Critical Raw Materials Act	EU's Critical Raw Materials Act is a European legislation establishing supply chain resilience targets and recycling benchmarks for strategic materials essential to green transition.
33	Bioleaching	Bioleaching is a biotechnology process using microorganisms to extract metals from ores and waste materials through biological oxidation and dissolution.
34	Biological metal extraction processes	Biotechnological methods using living organisms like bacteria and fungi to recover metals from ores and waste materials.
35	Virgin mining	Virgin mining is the extraction of metals and minerals directly from natural ore deposits in the earth's crust using traditional mining methods.
36	IoT	(Internet of Things) is a network of interconnected physical devices embedded with sensors and software that collect and exchange data wirelessly.
37	Metallurgy	Metallurgy is the science and technology of extracting, refining, and processing metals from ores to create useful materials and alloys.
38	Aramco	(Saudi Aramco) is the Saudi Arabian national oil company and the world's largest integrated energy.
39	Ma’aden	(Saudi Arabian Mining Company) is a state-owned multi-commodity mining giant and one of the world's fastest-growing mining companies, focusing on gold, phosphate, and aluminum.
40	AI	Artificial Intelligence is the simulation of human intelligence processes by computer system, including learning, reasoning, problem - solving, perception, and language understanding to perform tasks that typically required human cognitive abilities.
41	Black-box systems	Computational models whose internal decision-making processes remain opaque and incomprehensible to users, despite producing observable outputs from given inputs.
42	Weather forecasting APIs	Refers to application programming interface that provide standardized access to meteorological data services, enabling real-time integration of weather predictions into agriculture systems.
43	Multi-sensor fusion system	Refers to integrated technological frameworks that combine data from multiple sensor types to create comprehensive, real-time environmental monitoring for precision agricultural applications.
44	IoT-enabled edge computing system	Refers to distributed computing architectures that integrate internet of things sensors with localized processing capabilities to enable real-time data analysis and automated responses.
45	Nano-agriculture technology	Refers to advanced agricultural systems utilizing nanoscale materials and devices to enhance crop productivity, optimize nutrient delivery, and improve precision farming applications.
46	Nanotechnology	Nanotechnology is the scientific manipulation and engineering of materials at the nanoscale (1-100) to create novel properties and applications enhanced functionality.
47	ISOA-ASVM algorithm	Refers to an algorithm that combines Improved Swarm Optimization Algorithm with Adaptive Support Vector Machine for enhanced agricultural decision-making and precision irrigation system optimization.

	Abbreviation and Terms	description
48	LightAgro	LightAgro is a lightweight blackchain-based agricultual security platform utilizing secp256k1 cryptographic authentication to protect IoT irrigation data with machine learning-enhanced threat detection capabilities.
49	Secp256k1	Secp256k1 is a specific elliptic curve cryptographic standard used for digital signatures and authentication, proving 256-bit security for blackchain applications.
50	Machine Learning (ML)	(ML) is a computational method enabling systems to automatically learn patterns from data and make predictions without explicit programming instructions.
51	GIS	Geographic Information System (GIS) is a spatial analysis technology that captures, stores, analysis, and visualizes geographic data for agricultural mapping and resource management.
52	M&A	Mergers and Acquisitions
53	IPOs	Initial Public Offering
54	EWA	Environment, water and Agriculture sectors
55	RAG AI	RAG AI Retrieval-Augmented Generation [RAG] AI technique combining search and AI responses

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