وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture

Innovation in the Environment sector in Saudi Arabia

Technology Adoption Roadmap

His Royal Highness Prince Mohammed bin Salman

Crown Prince، Prime Minister، Chairman of the Council of Ministers، and Chairman of the Supreme Committee for Research، Development، and Innovation

"Our ambition for Saudi Arabia is to become a global leader in research، development، and innovation with an annual investment equivalent to 2.5% of GDP in 2040. This will diversify and add 60 billion Saudi Riyals (US$ 16 billion) to the economy in 2040 while creating high-value jobs in science and technology."

Statement by His Excellency the Minister of Environment, Water, and Agriculture

The Kingdom's leadership believes in the importance of research and innovation to build a knowledge economy and achieve true diversification of the state's 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. Abdulrahman Abdulmohsen AlFadley

Statement by His Excellency the 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.

His Excellency Eng. Mansour bin Hilal Al Mushaiti

Dr. Osama Ibrahim Faqeeha

Deputy Minister for Environmente Affairs

Statement by the 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 Green Saudi 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

Statement by His Excellency the Deputy Minister for Research and Innovation

Many countries have focused on developing their technical and innovative capabilities, as it is a key enabler for sustainable economic growth. It helps increase the competitiveness and productivity of various economic sectors and provides effective solutions to many pressing challenges. The Kingdom of Saudi Arabia has given remarkable attention to technology and innovation in various fields. HRH Prince Mohammed bin Salman bin Abdulaziz Al Saud, Crown Prince, Prime Minister, Chairman of the Council of Ministers and Chairman of the Supreme Committee for Research, Development, and Innovation, announced the aspirations and national priorities for research, development, and innovation in Saudi Arabia for the next two decades. These are based on four main priorities, including environmental sustainability and basic needs. This reflects Saudi Arabia's commitment to sustainably provide for basic human needs for water and food by developing environmentally friendly technologies for water supply and desalination, and modern and sustainable techniques for food production and increasing green spaces.

The urgent need to adopt technology and innovation in the environment sector in the Kingdom stems from the necessity for environmental sustainability, which includes preserving biodiversity in land and sea, protecting degraded lands, reducing desertification, managing waste, improving air quality, and reducing sand and dust storms.

Recognizing the importance of adopting technology and innovation, the Ministry of Environment, Water, and Agriculture established a Deputyship for Research and Innovation within its organizational structure to activate the Ministry's role within the institutional framework and the national governance model for the research, development, and innovation sector. It has developed an executive institutional plan for research and innovation to make the environment, water, and agriculture system the most ready and capable to embrace and develop innovative technologies and practices. One of the most important components of this plan, which is the focus of our report, is the strategic focus on adopting priority innovative technical solutions to meet the needs in the environment sector. This will serve as a guide for institutional interventions and initiatives to ensure optimal direction of efforts and resources.

The Ministry of Environment, Water, and Agriculture has followed a carefully designed methodology to analyze demand and identify available supplies of the most important innovative solutions for the environment sector that should be focused on in the short and medium term. It detailed the waves of their adoption and widespread dissemination in a technology adoption roadmap for the environment sector in the Kingdom. This methodology relied on a several criteria, including expected impact of technology deployment, its ability to address the challenges facing the environment sector, and ease of adoption, with a focus on the most mature, deployment-ready technologies. After piloting and adaptation to suit local conditions, these technologies can be broadly disseminated in the sector. This roadmap was developed through integration, cooperation, and support from various stakeholders and in alignment with relevant national strategies for the environment, water, and agriculture, and research, development, and innovation sectors. The process involved dozens of policymakers and experts specialized in environmental innovation.

The purpose of publishing this report is to inform all stakeholders in the environmental system, including pioneering and emerging companies, R&D centers, and non-profit organizations, about the Ministry's strategic direction in this sector. This information will assist them in making informed decisions and developing their own customized plans and policies enlightened by the promising opportunities outlined in this report for incorporating technology and innovation in their operations and systems. This will have the greatest impact, God willing, in elevating the national environmental system.

About the Report

This report is part of three reports issued by the Ministry of Environment, Water, and Agriculture on technology adoption in its sectors in the Kingdom. It aims to identify ready technologies that contribute to solving sectoral challenges in the Kingdom and to explain the Ministry's executive plan in this regard.

Environmental Innovation in the Kingdom of Saudi Arabia

Agricultural Innovation in the Kingdom of Saudi Arabia

Water Innovation in the Kingdom of Saudi Arabia

About the Ministry of Environment, Water, and Agriculture

The Ministry of Environment, Water, and Agriculture in the Kingdom of Saudi Arabia is responsible for regulating and implementing all aspects of the Kingdom's policies in the environment, water, and agriculture sectors. The Ministry implements environmental, water, and agricultural plans and programs at the national level, with a focus on sustainability and value creation. Its contribution to the national economy has increased through various programs, especially in food security, water provision, and environmental protection.

Vision

Sustainable environment and natural resources that achieve water security, contribute to food security, and improve the quality of life.

Mission

The Ministry strives for excellence in developing and implementing comprehensive policies, effective strategies, and improved services. It aims to achieve prosperity and sustainability in the fields of the environment, water, and agriculture by actively involving the private sector and other relevant entities.

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Executive Summary

Technology and innovation is playing an increasing role in achieving national targets in the environment, water and agriculture sectors, such as achieving food and water security and environmental sustainability, increasing significantly. Adopting technology and innovation in the environmental sector has never been more paramount, given the ambitious national goals for this sector. To accomplish these objectives, it is crucial to widely implement innovative technologies and practices to transform sectoral challenges into opportunities.

This report sheds light on the Ministry's executive plan to promote adoption of innovative technologies and practices in the environmental sector, and the strategic focus towards adopting priority innovative products and solutions to meet the most pressing needs in the environment sector. This will serve as a guide for institutional measures and initiatives to ensure the optimal steering of efforts and resources.

The Ministry followed a detailed methodology to select priority technologies in the environment sector. This process began by analyzing the demand side for technology and innovation by examining the challenges faced by the environment sector across the value chain and within subsectors. Additionally, the Ministry considered the expected impact of technology and innovation adoption on addressing these challenges. On the supply side, the Ministry surveyed an extensive list of available technology and innovation solutions and refined them based on several criteria. From this, the Ministry generated a list of technologies and innovations that are ready for adoption and scaling up. These selected technologies have the potential to make the greatest impact and offer quick and effective solutions to the most pressing challenges in the environment sector in the short and medium term.

This effort involved more than a hundred policymakers and technology and innovation experts, identified more than 25 challenges and opportunities, and selected over 100 individual technologies, categorized into 22 technology groups. Based on this, 10 technology families were chosen for the environment sector, half of which will be adopted in a first "high priority" activation wave until 2025, and the other half in a second, subsequent wave. A third, future wave will involve the adoption of broader technologies beyond the initial 10 identified ones. The first-wave technology families are environmental monitoring techniques, grazing land management, waste management, and innovative irrigation techniques for trees and wild plants. This report covers these four groups in detail by introducing them and explaining the demand and supply drivers and current barriers to their widespread adoption. The report further touches on the technologies of the subsequent second and third waves, which the Ministry intends to adopt between 2025 and 2030.

The Ministry aims to implement several institutional initiatives to adopt and disseminate priority technologies in the environment sector in partnership with relevant stakeholders. These initiatives were developed after a comprehensive survey and analysis of existing efforts in the environment sector. The goal is to achieve the ambitious future aspirations for this sector within Vision 2030. This includes aligning with the national research, development, and innovation agenda and understanding the Ministry's role within the institutional framework governing it. Additionally, the initiatives consider the current state of technology adoption and innovation activities in the environment sector, and the state of technology adoption enablers such as available infrastructure, human resources working in the environment innovation ecosystem, and policies and regulations supporting technology adoption and innovation in the sector. It also utilized best practices of sectoral and national innovation policymaking recommended by several international organizations.

The priority measures to promote technology and innovation were identified, with the aim of achieving four main objectives:

- Directing and coordinating efforts: This involves overseeing and managing the plans, efforts, and resources allocated to adopting technology and innovation in the environment sector. The focus is on addressing sectoral challenges in line with national research, development, and innovation priorities and the relevant national strategies.
- Enhancing collaboration and partnerships: The goal is to improve connections and cooperation between stakeholders engaged in technology and innovation adoption within the environment sector. This collaborative approach aims to foster partnerships, leverage synergies, exchange expertise, and share knowledge. It also seeks to raise awareness of the environment ecosystem's achievements in integrating technology and innovation into their plans and operations to create positive momentum and ensure the sustainability of these efforts.
- Stimulating technology demand: This involves increasing the interest and demand for technology products and innovative solutions within the environment sector. It includes measures and incentives designed to boost the sector's willingness to adopt available technology solutions, ensuring that the supply of technology aligns with the demand.
- Building research and innovation capacities: This objective focuses on strengthening the research, development, and innovation capabilities within the environment sector. The aim is to ensure a sufficient and continuous local supply of technology products and innovative solutions.

Portable Nucleic Acid Extraction Technology for Marine Conservation, KAUST

Introduction

Technology and innovation are among the most important drivers of economic growth, primarily by enhancing the productivity of various sectors. This significance is particularly relevant to the environment sector, given the challenges of climate change and negative practices such as overgrazing and logging. The call for innovation in the environment sector in the Kingdom is even more pressing due to its unique goals, including the preservation of 30% of its terrestrial and marine areas, and the planting of 10 billion trees as part of the Saudi Green Initiative, in addition to its many programs to preserve biodiversity.[1]

Environmental innovation has several objectives, including traditional economic drivers like increased productivity, competitiveness, and contribution to GDP. It also has strategic objectives, such as achieving environmental sustainability. This requires the collaboration of several parties, on both the demand and supply sides of technologies.

Technology and innovation contribute to the environmental sector in many ways, such as facilitating the monitoring of degraded lands, contributing to land reclamation, reducing desertification, providing supporting tools for environmental monitoring to preserve biodiversity, and increasing the economic feasibility of waste management. It also helps improve air quality by reducing dust storms and sandy areas and provides advanced early warning systems for weather fluctuations.

Technology has profoundly transformed the environmental sector on a global scale. The market value of environmental technologies exceeded $700 billion in 2022, and is expected to reach nearly $1.2 trillion by 2032, at a compound annual growth rate of 5.1%.[2] Advances in waste management technologies have led to a significant increase in recycling rates, reducing landfill waste and pollution globally. In the US, for example, waste recycling and diversion has seen a significant increase from 7% in 1960 too 35% in 2022. In addition, multiple studies have shown the significant benefits of investing in environmental fields. For example, Finland saw a return on investment of $10 for every $1 invested in protecting vegetation in national parks and reserves, and the US achieved a return on investment of $27 for every dollar invested in protecting water sources from pollution.[3]

These global successes underscore the potential benefits of prioritizing technology and innovation in the environmental sector. Studies indicate a direct correlation between GDP per capita and Environmental Performance Index scores, emphasizing the importance of sustainable growth in this sector. To capitalize on these successes, it's essential to implement large scale initiatives. By adopting a structured approach to technology diffusion and adoption, significant improvements in sustainability and resilience can be realized. This approach involves more than just individual innovations; it entails creating an interconnected system capable of adaption and evolution. Such a system ensures the long-term sustainability and efficiency of the environmental sector.

Figure No. (1) shows an overview of the objectives of the environmental sector.

Figure 1: Environment sector goals in 2030

Access to 75% protected biodiversity areas

The number of trees planted and preserved is 450 million

Achieving a 50% diversion rate from landfills

15 days form weather forecast

1 Ministry of Environment, Water, and Agriculture, National Environment Strategy, 2018

2 Remediation Technology, Environmental technology market to reach $1.2 trillion by 2032, 2023

3 UN Environment Programme, Beyond GDP: Making nature count in the shift to sustainability

Figure No. (2) below shows the current aspirations of the environment sector and their classification according to five main areas, developed based on the results of national strategy analyses and intensive meetings with stakeholders.

These aspirations will address the challenges facing the environment sector — in the five areas — and will contribute overall to improving sustainability, cost and accessibility.

Figure 2: Overview of challenges and opportunities for the environment sector

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

However, the environmental sector still needs more investments in research and development; a need shared not only by the Kingdom but by globally. The significance of enhancing local innovative capabilities is heightened by the diverse goals and challenges faced by countries in the environmental sector. Therefore, it is important to channel efforts towards technologies that address local issues and contribute to national objectives. This involves continuously monitoring the national environmental landscape and aligning it with the latest technological advancements and innovations. Additionally, it necessitates coordinating national efforts towards unified goals that enhance the sector's value. Supporting current and future efforts requires continual updates to supporting systems, fostering an environment conducive to innovation, addressing obstacles within the innovative ecosystem, and providing ongoing support and guidance.

Recognizing the pivotal role of technology and innovation in driving growth across vital sectors, including the environmental sector, the government of the Kingdom of Saudi Arabia has prioritized innovation within its strategic agenda. Environmental sustainability and essential needs are emphasized among the four national innovation priorities outlined by HRH Crown Prince Mohammed bin Salman. Acknowledging the transformative potential of technology and innovation, the Ministry of Environment, Water, and Agriculture has established a dedicated deputyship for research and innovation. This deputyship aims to enhance the Ministry's role within national frameworks governing research, development, and innovation. The Ministry has embarked on a comprehensive plan, extending until 2030, to integrate technology and innovation into its systems and operational processes across the environment, water, and agriculture sectors. The objective is to position these sectors as leading adopters and developers of innovative technologies and practices.

Underpinned by a commitment to environmental stewardship, the Kingdom has undertaken significant initiatives to manage its environmental system effectively. This includes the launch of the National Environment Strategy and the establishment of five specialized centers dedicated to various environmental aspects: the National Center for Wildlife Development, the National Center for Vegetation Protection and Combating Desertification, The National Center for Oversight of Environmental Compliance, the National Center for Meteorology, and the National Center for Waste Management. In addition, it has established the Environment Fund, which is the largest in the region. The fund aims to contribute to the financial sustainability of the environment and meteorology sectors and provide the necessary capabilities to improve them. The Kingdom has also established natural protected areas to preserve plant and animal species, underscoring its dedication to preserving biodiversity and environmental balance.

The Ministry of Environment, Water, and Agriculture has initiated structural reforms, regulatory policies, and established new entities to drive progress. The next pivotal factor for advancing the Ministry's sectors is innovation. Innovation holds the potential to enhance efficiency, increase productivity, and raise the sector's economic contribution. The case studies in the following pages point to one global and two local examples where innovation was decisive in providing effective solutions.

Global Success Story

Caribbean Community Climate Change Centre partners with global institutions to deploy integrated buoy network

Data Collection Buoy, CARICOM Climate Change Centre partners with global institutions to deploy the integrated buoy network

The Caribbean Community Climate Change Centre plays a pivotal role in bolstering environmental resilience in Caribbean countries through various initiatives. Notably, the center spearheads a project aimed at installing data collection buoys and automated weather monitoring stations in the region, a critical component of its resilience-building efforts. These buoys form part of a specialized network designed to serve as an early warning system for coral reefs in the eastern Caribbean Sea, focusing on monitoring marine environmental conditions and assessing the impact of weather changes on ecosystems like coral reefs.

Achievements

The project has yielded significant outcomes, including enhanced monitoring of weather patterns and environmental conditions facilitated by the deployment of data collection buoys and automated weather monitoring stations. Additionally, the development of an early warning system for extreme weather events such as hurricanes stands as a notable achievement. The collection of valuable data supports strategies aimed at mitigating the impacts of environmental change and informs policy development processes.

Data Collection Buoy, CARICOM Climate Change Centre partners with global institutions to deploy the integrated buoy network

Local Success Stories

Nadec Project transforms agricultural waste into fertilizer

Harnessing composting to convert organic waste into high-quality soil conditioners, Saudi Investment Recycling Company (SIRC) in collaboration with Edamah Organic Solutions

The Saudi Investment Recycling Company (SIRC) joined forces with Edama Organic Solutions Company, a startup from King Abdullah University of Science and Technology, and the National Agricultural Development Company (NADEC) to enhance organic waste recycling infrastructure in the Kingdom.

The project's focus is on promoting responsible and sustainable management of natural fertilizer and agricultural waste on Nadec farms in the Haradh region. Through composting, organic waste is converted into premium-quality soil enhancers, aligning with the broader goal of producing high-quality, locally sourced products to enrich soil quality. These products will be used in the King Salman Park project in Riyadh.

The project aims to transform more than one million tons of organic waste into soil improvers annually. The project will commence operations with the capability to recycle approximately 200,000 tons annually, with potential for scaling up to 400,000 tons.

These products are used in the construction of King Salman Park in Riyadh, Saudi Investment Recycling Company (SIRC) in cooperation with Edama Organic Solutions

Local Success Stories

Enhancing rainfall through cloud seeding technology

Seeding operations use specialized aircraft equipped with seeding agents, Regional Cloud Rain Program in cooperation with the National Center of Meteorology

The pilot program, spearheaded by the Regional Cloud Seeding Program hosted by the National Meteorological Center, aims to tackle water scarcity using aircraft-based cloud seeding technology to enhance rainfall. By targeting clouds with sufficient liquid content but lacking conditions for heavy rainfall, the project endeavors to stimulate rainfall over wider areas, thereby alleviating pressure on aquifers.

The program focuses on four main actions: cloud identification and evaluation, flight planning, seeding operations, and monitoring and evaluation. First, meteorologists analyze real-time weather observations, radar data, and satellite images to identify clouds suitable for planting seeds. Next, flight paths are accurately planned, taking into account wind conditions, cloud location, and seeding agent dispersion patterns for optimal coverage. Then, the pilot releases the condensation nuclei into the appropriate clouds from specialized aircraft equipped with seeding agents. This is done through icy flare seeding, where ejectable flares are released into the cloud and spot flares are affixed to the aircraft. Finally, radar and other data sources are used to track classified clouds and assess their impact on rainfall patterns.

With 415 successful missions and 36 research aircraft missions collecting valuable data, the project achieved a remarkable 97% success rate, covering 55% of the Kingdom in a short timeframe. Satellite images have shown the positive effect of cloud seeding on vegetation growth and demonstrated the effectiveness of this technique.

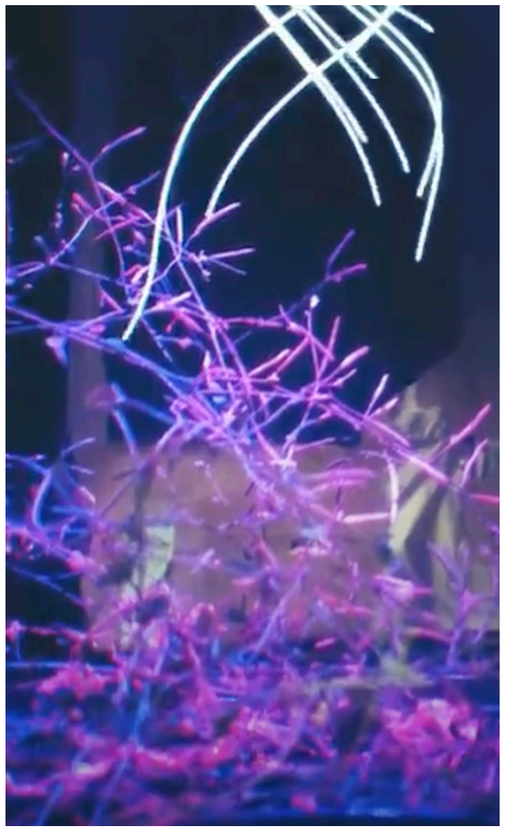
Meteorologists analyze real-time weather observations, radar data and satellite imagery to determine the appropriate clouds for planting seeds, Regional Cloud Rain Program in collaboration with the National Center of Meteorology

Purpose of the Report

The Ministry aims through this work to develop a strategic scope built on the environment sector's needs and oriented towards adopting readily available technical solutions to meet those needs. The Ministry seeks for this scope to guide institutional interventions and initiatives to ensure optimal steering of efforts and resources.

The report thereby presents a roadmap for deployment-ready technologies that the Ministry of Environment, Water, and Agriculture plans to adopt, starting from identifying the problems facing the Kingdom in the environment sector, moving to the technologies addressing them, and ending with executive programs enabling adoption of these solutions.

The roadmap illustrates the path the Ministry aims to take in adopting technologies, with objectives including confirming the availability of solutions for many of the challenges facing the environment sector, and clarifying the Ministry's strategic direction for stakeholders playing vital roles in realizing Saudi Arabia's ambition towards a sustainable environment sector. The next section links stakeholders with this report.



Laser lighting technology for coral reef farming, KAUST

Relevant Parties

The innovative technologies deployment roadmap is the culmination of intensive efforts led by the Ministry of Environment, Water, and Agriculture with support and contributions from all environment system stakeholders, including government institutions, the private sector, startups, research centers and universities, and investors.

More than 120 experts and specialists from relevant entities, representing about 30 organizations, contributed to this report. The project team analyzed over 50 survey responses on sectoral technologies, aligned these technologies with more than 10 national strategies, and organized several workshops and meetings to gain a deeper understanding of stakeholders' perspectives.

Various entities can benefit from this report, including:

1 **Government institutions:** These are responsible for providing regulatory and strategic support, enabling an environment for innovation, and ensuring policy and standard alignment with sustainable environment growth objectives. While this report provides an overview of technologies expected to be adopted in the Kingdom over the next few years, several governmental entities play a role in facilitating the adoption of these technologies in various aspects, such as enabling technology providers to enter the Kingdom, and ensuring regulatory tools enable implementation of these advanced technologies.

2 **Private sector:** The private sector is a key partner in this endeavor, playing various roles in adopting advanced technologies, including importing mature technologies into the Kingdom, localizing and developing them, and propagating them locally. Additionally, the environment private sector is targeted to implement these technologies in its systems and operations. As a major representative of the demand side targeted in this report, it is the driver towards environment sector sustainability and increased effectiveness.

3 **Innovative startups:** These small emerging enterprises have sufficient knowledge to comprehend advanced technologies and implement them on the ground. They have the agility to absorb medium-term technology investments with economic impact. They can also access specialized innovation financing tools like venture capital funds. Such enterprises play an essential role in introducing technologies into markets, since innovation is at the core of their sectoral activity, and their intermediary position between scientific and sectoral systems.

4 **Research centers and universities:** They contributing to creating and developing technologies in the environment sector. They play various roles, including researching on applied advanced technologies, adapting these technologies to suit the local environment, and developing them to increase their effectiveness in the future.

5 **Investors:** These include national and private investment funds, angel investors, financial institutions, and more. They play pivotal roles in technology adoption, such as financing and monetary support. They mitigate risks for innovators by enabling them to introduce new products despite high uncertainty. They provide expertise and guidance for innovators using their market experience, facilitate market access through commercial and industrial networks, and lend credibility to innovators with markets by adopting their innovations. They also enable innovators to scale locally and internationally.

Sea Coral Monitoring Technology, KAUST

Methodology for Technology Adoption Roadmap

Designing an accurate and adaptable technology deployment roadmap is a complex task for several reasons, including the accelerating pace of technological advancement and market demands. Developing a roadmap for adopting innovative technologies requires anticipating future technology trends and aligning them with long-term national ambitions, which poses a challenge in the fast-changing technology landscape.

Several factors contribute to this complexity. These include the necessity to anticipate emerging technologies and seamlessly integrate them with existing systems. Effective resource allocation, along with the capacity to remain flexible in response to new information or market shifts, adds another layer of complexity. Additionally, ensuring alignment among stakeholders introduces further organizational complexities. Consequently, the technology deployment roadmap must balance future visions and adaptability with the sector's current state, making its design a delicate process.

Overview

The comprehensive approach to developing a technology deployment roadmap consists of three core components: First, assessing the scale and nature of demand for technology solutions through close communication with sectors to understand their challenges and demands. Second, identifying technologies suitably matched to sectors at large, resulting in more than 100 technologies across 22 groups or families for the environment sector. Third, agreeing on technology priorities based on two key criteria: impact on challenges, for instance the technology's ability to address sectoral challenges, and ease of adoption of these technologies in the Kingdom. Adoptability is critical, since a key goal of the technologies is to address the most pressing challenges. Therefore, how quickly a technology could be deployed was an important factor in prioritizing technology adoption, resulting in waves for adoption. The following subsections focus on these three components.

Demand Side for Technologies

Demand for technical solutions in the environment sector is driven by several factors, including the challenges for this sector, most notably the harsh environmental conditions, including water scarcity and hot weather, as well as the Kingdom's vast geographic area and its environmental and geographical diversity. Transforming this sector also requires finding technologies that can facilitate this transformation. Additionally, the sector has witnessed the introduction of several regulations in recent years aimed at organizing it, and it needs innovative solutions in the coming years to align it with national ambitions. Finally, this sector plays an important and strategic role for the Kingdom as it is concerned with environmental sustainability, which requires national entities to work together and consider all available solutions.

Therefore, it was necessary for the technology adoption roadmap to be based on these national challenges and urgent needs (demand side) as well as the opportunities available at the same time (supply side). To that end, extensive efforts were undertaken, in close cooperation with the sector stakeholders, to identify and characterize the most important challenges. Existing aligned national strategies tailored to local requirements as well as sectors' ongoing efforts greatly facilitated the work.

To reach the scale and nature of demand for technical solutions, the report began by characterizing the sectors and dividing them into several segments according to their segments. In the environment sector, these lists were biodiversity, afforestation, land protection from desertification, waste management, pollution, and environmental commitment. The report then precisely determined the challenges for each list, assessing the potential of technical solutions for each. Finally, the report connected the challenges with the corresponding technologies, concluding in the creation of maps that represent the demand for technical solutions.

Mangroves, Ministry of Environment, Water and Agriculture

Supply Side for Technologies

Efforts to find technical solutions for the environment sector have been ongoing for decades, and these solutions vary according to regional needs and national orientations. Many attempts have been made to align available environment technologies with these needs. Since there are a large number of available environment technologies and some may not be suitable in all cases for national needs, it was necessary to develop an approach that enables classifying readily available technologies and matching them with sectoral needs in the Kingdom, to identify priority technologies, and then design strategic initiatives to enable their adoption.

To facilitate classifying these technologies, the approach used identified an extensive list of environment technologies, then categorized them into groups of technology families, with each family addressing similar challenges. For example, all technologies that provide solutions for waste management are clustered in one group, even if they differ in their technical fields, such as materials science,

Figure 3: Technology framework for the environment sector

Biodiversity		Land, Vegetation & Desertification			Waste Management		Pollution Control and Compliance			Meteorology
Terrestrial ecosystems	Marine and coastal ecosystems	Rangelands	National Parks	Forests	Medical	Industrial	Air pollution	Water pollution	Soil pollution	
1. Conservation techniques		4. Plant improvement technology (biotechnology)			11. Collection devices, systems and vehicles		16. Air pollution prevention and mitigation	17. Water pollution prevention and mitigation	18. Soil pollution prevention and mitigation	20. Data acquisition methods and monitoring
2. Protected areas management		5. Horticulture technology			12. Automated sorting					21. Weather and climate forecasting
3. Ecosystem monitoring		6. Support for Natural Regeneration of vegetation cover			13. Waste Treatment (incl. recycling, composting and energy recovery)					22. Weather augment technology
		7. Protection from desertification			14. Disposal technology		19. Pollution monitoring			
		8. Innovative irrigation for wild trees and shrubs			15. Waste monitoring					
		9. Grazing land management								
		10. Land monitoring								

Source: Technological Foresight Center at King Abdulaziz City for Science and Technology

digital applications, biotechnology, or others. More than 100 technologies in the environment sector were reviewed by specialized experts, who contributed to classifying them into 22 technology groups, before these technologies were evaluated according to the urgency and priorities of the challenges they address and the ease of their adoption.

When determining technology priorities and waves — which is necessary to ensure that the most relevant technologies are adopted for the most pressing challenges — demand and supply for each technology were considered. During this process, technologies that are easier to adopt were prioritized, particularly those with the potential for growth and expansion within the Kingdom. Thus, this report assessed the enablers associated with these technologies based on available facts and information, with the results reviewed by experts and stakeholders.

Figure No. [3] below shows the technological framework, categorized in 22 families — organized by key environmental sector areas. The framework provides a comprehensive picture of the uses of environmental technologies in the specific areas, and ensures comprehensive coverage of all innovative technologies in the environmental sector.

Technology Assessment

In the technology assessment stage, it was important to first determine the criteria for evaluation. After studying several technology evaluation methods and applying them to current national requirements, it was clear that the two most important criteria to achieve the desired purpose were expected impact of technology deployment, and ease of adoption in the Kingdom. The impact of technologies is measured through indicators like contribution to achieving sector strategy targets, potential to address local and global challenges, and potential role in the Saudi market (for instance, increasing productivity or competitiveness). Ease of implementation is measured through indicators like the ability to adopt these technologies in the Kingdom based on current infrastructure, availability of supply chains, presence of supporting regulations, potential for localization through human capabilities, awareness of the technologies' functions and benefits, and capacity to absorb the technology.

A comprehensive assessment of the identified techniques was carried out, focusing on the expected impact and ease of implementation of those techniques. The impact criteria measure the role that specific technology will play in the sector's strategy, addressing challenges and meeting market demands, while the ease of implementation criteria examine the time required for the technology to enter the market, barriers to its entry and localization possibilities. As shown in Figure No. (4) below.

Figure 4: Evaluation of technology families

Impact potential		Ease of implementation	
Assessment at technology family level		Assessment at technology level, aggregation at technology family level	
Strategic fit to KSA	• Alignment with sector strategies (objectives.programs. initiatives) and priorities • Contribution to solve sector challenges	**Time to market**	Assessment of total time to market for technologies
Global challenges	Contribution to solve global pressing challenges	**Entry barriers**	Assessment of technology -related entry barriers: • Existing Infrastructure and Supply Chain • Regulatory • Deployment complexity
KSA market demand	Potential contribution to KSA market: • Revenue increase • Cost reduction • Productivity improvement	**KSA localization potential**	Assessment of localization potential: • Adaptability • Existing capabilities • Awareness

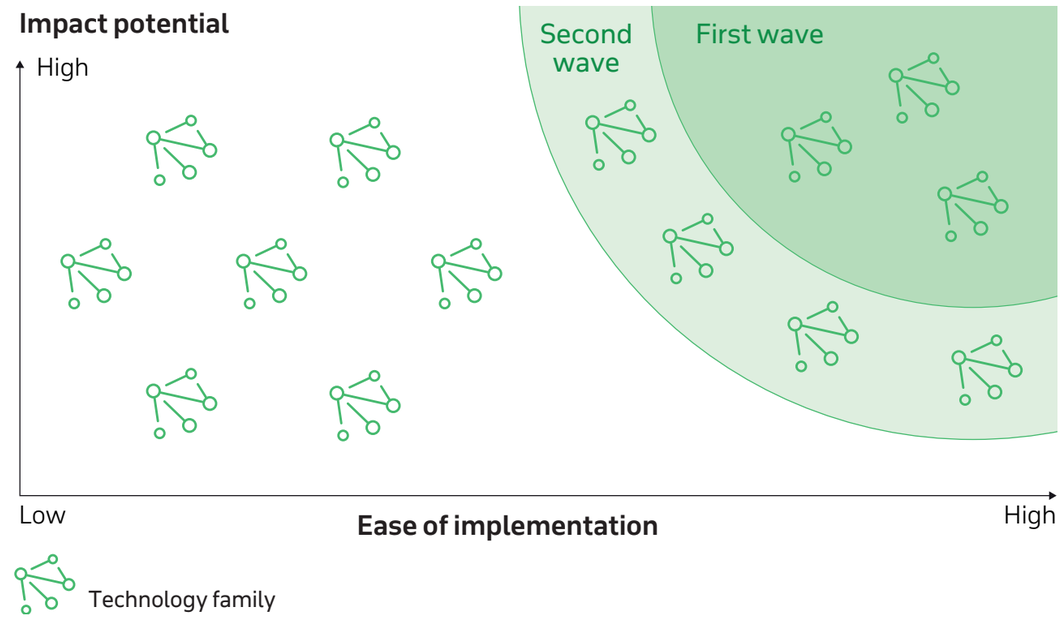
Based on these two criteria, all technology groups were evaluated by experts across the aforementioned metrics, and these assessments underwent several analyzes, subsequently categorizing the technologies into four groups according to impact level (high or medium) and ease of adoption (easy to implement or implementable) — starting with the high impact, easy to implement group, while the other groups would follow after addressing factors affecting their evaluation.

After developing a preliminary list of high priority technologies for adoption, this list was extensively reviewed and validated by specialists and stakeholders to ensure evaluation accuracy and alignment with sector expectations — scientific experts evaluated the technical considerations, and stakeholders looked at regulatory and industry perspectives. This stage utilized several review methods according to the metrics and reviewers, including individual meetings, specialized surveys, and workshops where multiple parties could come together for discussion.

It is worth mentioning that all these methods compiled reports from workshops, minutes of meetings, and survey data for the purpose of utilizing them in future projects or when re-evaluating technologies in the future if necessary.

Figure No. (5) shows the positioning of technology families and their deployment based on impact potential and ease of implementation criteria. The focus will be on the adoption of the technology families included in the first wave, and then on the second wave of adoption.

Figure 5: Evaluation of technology families



Priority Technologies

The technology waves were defined based on the methodology mentioned in the previous section, with the first wave comprising four technologies targeted for adoption in 2024 and 2025. The second wave also consisted of five technologies targeted for adoption starting 2025. The broader third wave between 2026 and 2030 will be considered based on readiness for adoption.

This report provides details on the first wave of technologies planned for adoption in 2024 and 2025, discussing the demand side (the challenges these technologies help address), the supply side (the capabilities the Kingdom has in these technologies, major obstacles they may face during adoption, and finally the means to adopting them. The first wave included the following technology groups:

1. Ecosystem monitoring
2. Grazing land management
3. Waste management
4. Innovative irrigation techniques for trees and wild plants

Ecosystem monitoring

Overview

Ecosystem monitoring techniques focus on understanding, assessing and managing wildlife ecosystems. It allows for greater levels of effectiveness in tracking, understanding, and monitoring biodiversity in marine and terrestrial environments. Ecosystem monitoring includes:

Ground/terrestrial monitoring: The tools, equipment, and methodologies used to collect data and assess terrestrial biodiversity, such as surveillance cameras, acoustic monitoring, environmental DNA sampling, terrestrial laser scanning, radio telemetry, hyperspectral imaging, and web-based geographic information systems.

Marine surveillance: The tools, equipment, and methodologies used to collect data and assess aquatic biodiversity, such as monitoring buoys, underwater cameras, underwater vehicles, automatic identification systems and pattern recognition software.

Demand drivers

Saudi Arabia aims to achieve a coverage of 17% in terrestrial reserves and 10% in marine reserves. In addition, the Kingdom aims to reach 75%[4] protected biodiversity areas. Technologies will be essential to achieving these goals, which will accelerate the adoption of ecosystem monitoring techniques.

The global ecosystem monitoring technology market is experiencing significant growth, particularly in terrestrial and marine monitoring sectors. In ground monitoring, the market value of ecosystem monitoring technologies is expected to grow from $2.1 billion in 2022 to $4.9 billion by 2030 (at a CAGR of 12%).[5] Similarly, in marine monitoring, the market value is expected to grow from $0.8 billion in 2022 to $1.2 billion by 2030 (at a CAGR of 5%).[6]

Supply drivers

The National Center for Wildlife Development focuses on developing ecosystem monitoring techniques, particularly through the use of hyperspectral imaging cameras, radio telemetry, and web-based geographic information systems. The core R&D efforts are led by three main entities: King Abdulaziz City for Science and Technology (KASCT), King Abdullah University of Science and Technology (KAUST), and King Fahd University of Petroleum and Minerals (KFUPM). KASCT launched the scientific research ship Najel to assess fish stocks and study climate change in marine ecosystems in the Arabian Gulf and the Red Sea, while KAUST concluded cooperation agreements with Ocean Aero for autonomous underwater vehicles, with the aim of assessing unusual currents and biodiverse species in the Red Sea. KAUST also launched a CubeSat satellite in partnership with Spire Global to collect high-resolution data covering terrestrial and oceanic ecosystems. KFUPM, through its Center for Environment and Marine Studies, collaborated with the Red Sea International Company to monitor the marine and terrestrial environments associated with the Red Sea Project. A number of international companies excel in this field, including John Deere, Semex, and Trans Ova Genetics.

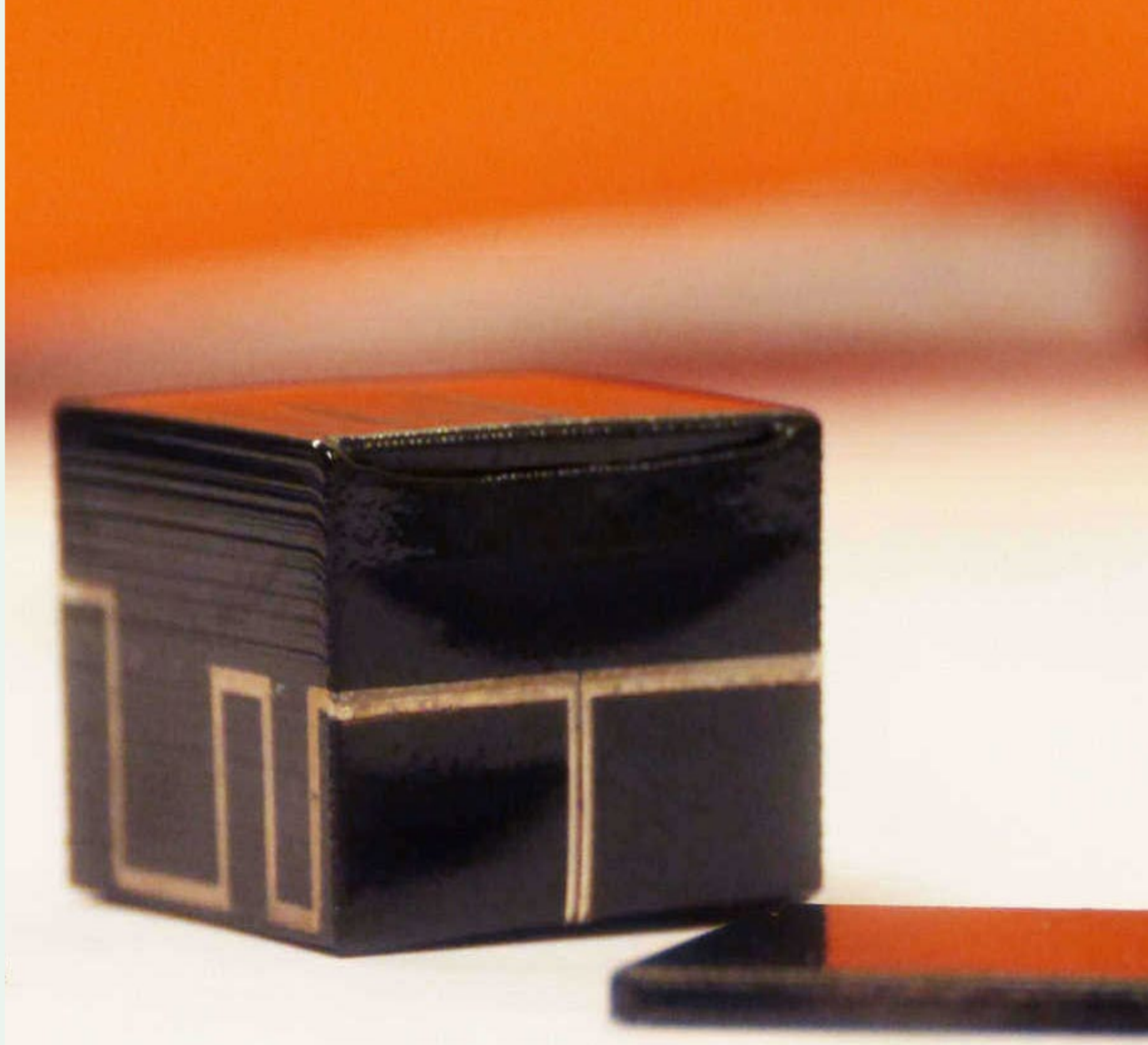
Barriers to adoption

Innovation plays a crucial role in addressing environmental monitoring challenges, particularly in remote areas with limited access to electricity and communication services despite their rich biodiversity. The Ministry has implemented various programs to fulfil the demand for such technologies. These initiatives include fostering partnerships between demand agencies and the private sector and offering technology piloting and demonstration programs. Digital technologies also serve the wildlife sector by fulfilling monitoring needs without requiring physical presence in remote locations.

4 Ministry of Environment, Water and Agriculture, "National Environment Strategy", 2018

5 Global News Wire, 2022

6 Persistence Market Research, 2022



Three-dimensional wireless sensor for real-time environmental monitoring, KAUST

Grazing land management

Overview

Rangeland management techniques aim to sustainably manage pastures and open grazing lands to protect them from overgrazing and desertification. These technologies include:

Grazing monitoring techniques: These methods enhance grazing practices and subsequently improves the health of livestock by monitoring soil health and livestock and pasture conditions. Examples include remote sensing technologies, precision technologies, electronic identification technologies, drones, and grazing programs.

Feeding techniques: These technologies focus on improving the efficiency of livestock feeding and fodder, incorporating methods like insect farming, single-cell protein production, microfeeding, automated feeding, and mixing devices.

Demand drivers

The grazing sustainability index in the Kingdom is expected to decline significantly over the next decade, from 3.2 in 2023 to 1 by 2030.[7] Consequently, technologies for pasture land management are expected to be developed and adopted to mitigate desertification and soil erosion. Globally demand for such technologies is anticipated to increase from $1.6 billion in 2022 toS$3.7 billion by 2032.[8]

Supply drivers

Considerable efforts are currently underway in researching and developing grazing land management technologies, led by KAUST and many private sector participants. For instance, Al Maha Systems, a startup company at KAUST, is developing animal health monitoring systems. The university also conducts research programs for grazing land management, particularly in sensor technology for monitoring. In addition, several companies, including Additives, Unibio, Calisio, and Food Caravan are currently piloting multiple initiatives to develop suitable alternatives to animal feed.

Barriers to adoption

The adoption of grazing control techniques hinges on regulated demand channels and sustainable revenue streams, especially given the need for adaptation to the Kingdom's climate and geography. To address this, the Ministry has initiated various programs, such as experimenting with ready-made technologies and demonstrating their effectiveness within the Kingdom. Furthermore, regulatory updates are required for feeding technologies, necessitating coordination with multiple government agencies. To facilitate this process, the Ministry has launched the Experimental Legislative Environment Program, aiming to identify regulatory obstacles and streamline coordination with regulatory agencies.

7 Ministry of Environment, Water and Agriculture, National Environment Strategy, 2018

8 Markets and Markets, "Livestock Monitoring Marketsize by Livestock Type», 2022

Arabian Oryx Monitoring System, KAUST

Waste treatment

Overview

Waste treatment technologies include material recycling, energy recovery, and recycling of organic waste into all types of waste, including construction and demolition waste, municipal solid waste, and agricultural waste. These technologies include:

Material recycling: This involves sorting waste materials into new products or raw materials that can be reused and reprocessed through processes like cutting, sorting, and assembling.

Energy recovery: This recycling process converts non-recyclable waste materials into usable energy forms such as electricity, heat, and fuel. Methods include incineration, gasification, pyrolysis, and anaerobic digestion.

Organic waste recycling: This process involves converting organic waste into useful products and resources through methods like composting, anaerobic digestion, and fermentation.

Demand drivers

Saudi Arabia aims to achieve a diversion rate of 50% from landfills and landfills by 2030, and 94% from municipal solid waste landfills by 2035. This will accelerate the adoption of waste treatment technologies, as studies highlight that the journey to transforming landfills takes 20 to 25 years[9] in some G20 countries and other developed countries. The global waste generation market is expected to grow from 2.3 billion tons in 2022 to 2.9 billion tons by 2032 (at a CAGR of 2.3%).[10] The main drivers of this increase are increasing waste generation in Sub-Saharan Africa, South Asia, the Middle East, and North Africa. It is expected to triple in the case of Sub-Saharan Africa, and twice in the case of South Asia, the Middle East, and North Africa.

Supply drivers

Saudi Arabia established the Saudi Recycling Investment Company (SRIC), owned by the Public Investment Fund, to advance recycling efforts in the Kingdom under the National Waste Management Center. SRIC plays a vital role in developing pilot projects in various waste treatment pathways, including composting and waste-to-energy conversion. Additionally, King Abdullah University of Science and Technology (KAUST) has launched several research programs in waste treatment, resulting in startups like Edama Organic Solutions. Private sector entities like Sadara, Waco, and Unitco are also developing pilot and commercial solutions. Furthermore, international companies such as AMP Robotics, Enevo Inc., WasteIQ, BinMaster, and Wasteology excel in waste management.

Barriers to adoption

The field of waste management is subject to numerous regulations, presenting regulatory obstacles to the application of technologies. To address this, the Ministry launched the Regulatory Legislative Environments Program to support technology adoption in waste management. Many technologies require suitable environments for experimentation, leading to the Ministry's initiative to demonstrate and experiment with technologies to ensure their adaptability to the local environment and potential for large-scale application.

9 International Trade Administration, "waste management", 2024

10 The World Bank, "Trends in Solid Waste Management", 2020

Waste Recycling Technology, Edamah Organic Solutions

Innovative irrigation techniques for trees and wild plants

Overview

Innovative irrigation techniques for trees and wild plants encompass a range of systems designed to facilitate the growth of natural vegetation while optimizing water usage and increasing efficiency in managing water resources. These techniques allow for the efficient allocation of irrigation water tailored to specific plant needs and land characteristics, without compromising plant growth. These technologies include:

Micro/drip irrigation: Delivers water directly to the roots of plants in small quantities that can be controlled using a network of pipes, releasing water in the form of drops or a slow, steady flow.

Flood irrigation in ponds: A mobile irrigation system for watering large areas by retaining water above the root part of plants using medium-depth basins. It is particularly suitable for flat terrain.

Subsurface irrigation with leaky hoses: Pipes are buried and irrigation water is delivered directly to the root area with slow drainage.

Smart irrigation: Systems that include sensors, weather data, and internet connectivity to monitor and adjust irrigation schedules based on prevailing conditions at the time of actual irrigation.

Demand drivers

The Kingdom aspires to achieve many environmental goals by planting 10 billion trees, which will contribute to the rehabilitation of 40 million hectares of degraded lands. These afforestation operations require regular irrigation until the trees reach the stage of self-reliance. Moreover, as the Kingdom faces significant water stress, with 80% of agricultural water sourced from non-renewable groundwater, adopting modern irrigation techniques becomes imperative to achieve long-term sustainability. Innovative irrigation methods lead to increased vegetation growth with a significant reduction in water use, compared to a traditional open irrigation system. For example, partial irrigation techniques can reduce water consumption by 10% to 15%.[11] Globally, the demand for micro-irrigation/drip irrigation systems is surging, with market projections indicating a fourfold increase from $15 billion in 2022 to $64 billion by 2032.[12]

Supply drivers

Institutions such as KAUST, specifically the Center for Desert Agriculture, along with the National Center for Vegetation Development and Combating Desertification, are involved in significant research and development activities in the field of innovative irrigation technologies. The Kingdom also benefits from advanced technologies, with increased adoption of systems like partial irrigation/drip irrigation. International companies such as Netafim, Jain Irrigation Systems, and The Toro Company excel in this field.

Barriers to adoption

Significant barriers hinder the widespread adoption of innovative irrigation technologies. These systems entail substantial investments, with partial irrigation systems costing over $1,000 per hectare. To address this challenge, the Ministry of Environment, Water, and Agriculture has initiated programs aimed at fostering cooperation among entities involved in technology adoption and innovation. Additionally, development programs offer financial support to facilitate technology adoption activities.

11 EPA Water Sense, "Saving Water with Micro irrigation", 2023

12 Morgan Stanley, "Sustainability Report", 2022

Using drip irrigation technology to grow lettuce

Wider technologies

In addition to the four priority technology families in the first implementation wave, there are 18 other technology families that have the potential to address sector challenges in Saudi Arabia. These technologies are supported by a combination of targeted initiatives designed specifically for their adoption and more comprehensive systemic approaches.

The next section provides an overview of the implementation plan, covering all technologies suitable for the environment sector, in addition to the specific initiatives described above for the four technology families in the first wave.

Ministry's Executive Plan for Adopting and Disseminating Technologies

The Ministry of Environment, Water, and Agriculture conducted a review and analysis of existing efforts in the environment sector to achieve the sector's ambitious future aspirations under Saudi Vision 2030. The analysis covered: Priorities, aspirations, and the National Environment Strategy, in addition to the National Research, Development, and Innovation Agenda, the current state of technology adoption and innovation activities in the environment sector, and the state of technology adoption and innovation enablers such as available infrastructure, human capabilities working in the environmental innovation ecosystem, and policies and regulations supporting technology adoption and innovation in the sector.

Based on this, current challenges and gaps were identified. Drawing on best practices in sectoral and national innovation policymaking, the scope of priority institutional measures to promote technology adoption and innovation in the sector was defined to achieve four main goals:

Directing and coordinating plans, efforts and resources allocated to adopting technology and innovation in the environment sector. The focus is on addressing pressing sectoral challenges, in line with national research, development, and innovation priorities and relevant national strategies.

Improving connection and cooperation between stakeholders active in adopting technology and innovation in the environment sector to enhance partnerships and synergies within the sector and share knowledge. The goal is also to raise awareness of the environmental ecosystem's efforts and successes in embedding technology and innovation in their plans and operations to create positive momentum and ensure the sustainability of these efforts.

Stimulating demand for technology products and innovative solutions adoption in the environment sector and improving demand responsiveness to available technology supply through deliberate measures and targeted incentives.

Building research, development, and innovation capacities in the environment sector to ensure sufficient and continuous local supply of technology products and innovative solutions.

Therefore, the Ministry will implement four institutional initiatives encompassing several carefully designed of sub-programs:

Initiative to Technology Adoption and Innovation Steering and Coordination in the Environment Sector, which aims to

- Establish a transparent and effective governance framework defining the roles and mechanisms required to identify priority innovative solutions aligned with national and sectoral priorities, and engage stakeholders in the ecosystem through aligning objectives and enabling effective information exchange and collaboration to sustain technology adoption and innovation activities in the sectors.
- Develop a mechanism to direct funding from various entities towards technology adoption and innovation activities in the environment, water and agriculture sectors undertaken by public and private entities in the ecosystem, in a performance-based manner considering alignment with priority innovative solutions for the environment, water, and agriculture sectors, and balancing institutional and project financing.
- Develop and activate tools to measure and monitor the performance of the environment ecosystem in technology adoption and innovation, and provide evidence-based visions and recommendations on the current state of technology adoption and innovation activities in the sector to support decision-making processes.
- Develop an institutional technology foresight program to provide regular insights on potential technologies and innovative solutions that might be suitable to address challenges and leverage opportunities in the environment sector, and support planning processes and institutional policy proposals.

Initiative to Improve Collaboration and Raise Awareness on Technology, Innovation, and Entrepreneurship in the Environment sector, which aims to

- Develop a framework for initiating and managing technology adoption and innovation partnerships in the environment sector with various potential partners including government, private, research and innovation entities locally and internationally, enhancing the efficiency of such partnerships and achieving their intended goals.
- Develop a digital platform containing information on available support programs, ongoing research projects, advisory services, Research, Development and Innovation (RDI) outputs and technology adoption, learning opportunities, news, events, and success stories, to support communication and connection in the ecosystem.
- Plan and launch competitions and awards for technology adoption and innovation, in collaboration with relevant entities, to promote a culture of research, development, innovation, and technology adoption, and disseminate success stories in the sector for inspiration.
- Raise awareness on the efforts of the environment, water, and agriculture ecosystem in technology adoption and innovation by publishing periodic reports on prominent platforms about the environment innovation ecosystem's key achievements and aspirations.
- Organize events and exhibitions to provide a platform for local and international R&D entities and technology providers to showcase their products to potential investors and buyers, facilitating partnerships and encouraging innovation and uptake of the latest technologies in the environment sector.

Initiative to Stimulate Demand for Innovative Products and Solutions in the Environment Sector, which aims to

- Review and develop legislative environments to address existing barriers constraining demand for environment Research, Development and Innovation (RDI) technologies and solutions, through coordination with regulators.
- Validate priority environment technologies and innovations by testing them in real environments for adaptation and deployment suitable for widescale local rollout.
- Propose mechanisms and policies to incentivize demand for priority environment Research, Development, and Innovation (RDI) technologies and solutions.
- Increase technology absorptive capacity of end-users in the environment sector to improve adoption of innovative products and solutions and boost market demand.

Initiative to Build Environment Research, Development, and Innovation Capabilities to Ensure Sufficient Local Supply of Innovative Solutions, which aims to

- Strengthen the entrepreneurship ecosystem in the environment sector, including developing mechanisms to attract financing and investment towards emerging sector companies, establishing entrepreneur communities, addressing information barriers and regulatory challenges faced by entrepreneurs, and tracking emerging company and market performance in the sector.
- Facilitate the establishment of dedicated environment entrepreneurship spaces and entrepreneurship support programs encompassing incubators, accelerators, startup studios, co-working spaces and technical support offices, in collaboration with relevant stakeholders at national and sector levels.
- Establish intermediary innovation organizations to bridge the gap between the environment sector and research/academia, such as technology development centers, technology valleys, technology transfer offices, etc.
- Develop institutional policies and frameworks for technology management and intellectual property protection in the environment sector, and collaborate with the Saudi Authority for Intellectual Property to develop relevant national IP policies pertaining to the sector.

Conclusion

Technologies play a critical role in addressing challenges faced by the environmental sector, including the pressing need to preserve biodiversity, conserve natural resources, adapt to harsh environmental conditions and water scarcity, deal with land degradation and desertification, and waste management. Innovative technologies enable finding sustainable solutions to these problems, as well as create numerous opportunities to increase the environmental sector's contribution to economic output, achieve environmental sustainability, and reach national goals.

This report sought to demonstrate the role of technology adoption and innovation in solving challenges in the Kingdom's environment sector, citing international and local examples of environmental innovation where technologies play a key role in providing solutions. Its key objective was to map the challenges faced by the Kingdom in the environment, water and agriculture sectors to readily available technology solutions, and outline the Ministry's implementation plan to adopt and deploy these technologies in the short and medium term.

The report followed an objective methodology to identify a list of ready-to-deploy technologies that provide solutions for the environment sector, starting by identifying the challenges faced by this sector in the Kingdom, dividing the sector into five segments: biodiversity, land vegetation and desertification, waste management, pollution control and compliance and meteorology. It then looked at available technologies and categorized them into technology groups according to these sector groups before prioritizing them based on the impact of these technologies and the ease of their adoption and deployment. This resulted in three technology waves that the Ministry intends to adopt in the coming years.

Given the complexity of the environment, water, and agriculture ecosystem, and the multitude of stakeholders in the environment sector, the report considered the national and sectoral strategies of the environment and national innovation ecosystems. It also incorporated the perspectives of the Ministry's sector representatives, through a series of meetings and workshops with more than 30 entities, taking into account the views of over 120 experts and specialists at all preparation waves.

In publishing this report, the Ministry of Environment, Water, and Agriculture has several objectives. Firstly, it aims to demonstrate its strategic direction towards adopting technologies that address sectoral challenges. It also seeks to explain its implementation plan to deploy these technologies. The report defines its four key objectives in this regard: Steering and coordinating plans, efforts, and resources allocated to technology adoption and innovation in the environment sector within a focused strategic scope. This scope targets the resolution of sectoral challenges. The next objective is improving connectivity and cooperation between players in the environment research, development, and innovation ecosystem. This cooperation aims to build positive momentum in the sector, ensuring the sustainability of efforts. The third objective is stimulating demand for adopting innovative products and solutions in the environment sector. This includes improving the sector's responsiveness to available supply through targeted interventions and incentives. The final objective is building environment research and innovation capabilities to ensure sufficient and continuous supply of innovative products and solutions.

Arabian Oryx, Ministry of Environment, Water and Agriculture

The Ministry firmly believes in the importance of collaborative work and its necessity to achieve national targets and invites all its partners across environment sector stakeholders to contribute to the implementation of this plan. The Ministry aspires for this report to be an enabler in adopting innovative solutions that help overcome challenges faced by ecosystem players and make possible the realization of ambitions and national targets for the environment, water, and agriculture sectors.

Finally, the Ministry of Environment, Water, and Agriculture expresses its sincere gratitude to all who contributed to this report, including its ecosystem partners, the team of experts who offered their invaluable expertise, and the dedicated efforts of the Research and Innovation Deputyship team in developing and editing this report.

Appendix

Localization and definition of technologies

	English Technology Group	English Description	English Technology Examples
1	Conservation techniques	Conservation and preservation techniques employed to protect and sustainably manage ecosystems, species, and genetic diversity	Assisted Reproduction Farming Conservation Technology DNA Storage Gene Banks DNA Banks Genetic Identification Genetic Sequencing Microbiology Testing
2	Protected areas management	Technologies to prevent and mitigate detrimental events in terrestrial, marine and coastal ecosystems	Fire Prevention and Fighting Technology Modified Clay Technology Spatial Planning Technology Smart Fences
3	Ecosystem monitoring	Technologies employed to understand, assess and manage ecosystems	Terrestrial Monitoring Marine Monitoring
4	Plant improvement technology	Various techniques and approaches used to enhance the characteristics, traits, and performance of plants, including nurseries	Nursery Technologies Cryopreservation Germination/Microbiology Testing DNA and Pollen Storage Field Gene Bank
5	Horticulture technology	Technologies around advancing seeding and planting techniques	Greenhouse Automation Rooting Technology Mechanized and Advanced Seed Harvesting and Processing Machine Planting Sensor-Aided Analysis Advanced Reseeding and Transplanting Technologies
6	Support for natural regeneration of vegetation cover	Techniques to support the regeneration of vegetation and facilitating ecosystem restoration	Natural Regeneration Technology Regeneration-Aiding Technology Ecological Modelling
7	Protection from desertification	Technologies to protect land from desertification, including erosion control and soil optimization	Erosion Control Technologies Soil Optimization
8	Innovative irrigation for wild trees and shrubs	Technologies to optimize efficiency and effectiveness of water irrigation systems for wild trees and shrubs	Micro/drip irrigation Smart Irrigation

	Arabic Technology Group	Arabic Description	Arabic Technology Examples
1	تقنيات الحفاظ على التوع البيئي	تقنيات الصون والحفظ المستخدمة لحماية وإدارة النظم البيئية والأنواع الحية والتنوع الجيني بشكل مستدام	التقنيات المساعدة في التكاثر تقنية الحفاظ على الزراعة تخزين الحمض النووي [DNA] بنوك الجينات بنوك الحمض النووي [DNA] التعرف الوراثي تسلسل الجينات الوراثية اختبارات علم الأحياء الدقيقة
2	إدارة المناطق المحمية	تقنيات لمنع الأحداث الضارة في البيئات البرية والبحرية والساحلية والحد منها	تقنيات الوقاية من الحرائق ومكافحتها تقنيات الطين المعدل تقنيات التخطيط المكاني السياج الذكي
3	تقنيات متابعة الأنظمة البيئية	التقنيات المستخدمة لفهم النظم البيئية وتقييمها وإدارتها	الرصد الأرضي المراقبة البحرية
4	تقنية تحسين النبات [التقنية الحيوية]	تقنيات وأساليب مختلفة تستخدم لتعزيز خصائص وسمات وأداء النباتات	تقنيات الحضانة الحفظ بالتبريد اختبار الإنبات/علم الأحياء الدقيقة تخزين الحمض النووي وحبوب اللقاح بنك الجينات الميدانية
5	تقنية البستنة	تقنيات تطوير أساليب البذر والزراعة	الأتمتة في البيوت الزراعية تقنيات نمو الجذور تقنيات حصاد ومعالجة البذور المتقدمة زراعة بالآلات التحليل بمساعدة الأجهزة الاستشعارية تقنيات إعادة الزرع ونقل الشتلات المتقدمة
6	دعم التجدد الطبيعي للغطاء النباتي	تقنيات لدعم تجديد الغطاء النباتي وتعزيز ترميم الأنظمة البيئية	تقنية التجدد الطبيعي تقنية المساعدة في التجدد النمذجة البيئية
7	الحماية من التصحر	تقنيات حماية الأراضي من التصحر، بما في ذلك مكافحة التآكل وتحسين التربة	تقنيات التحكم في التآكل تحسين التربة
8	الري المبتكر للأشجار والنباتات البرية	تقنيات لتحسين كفاءة وفعالية أنظمة الري للأشجار والنباتات البرية	الري الجزئي / بالتنقيط. الري الذكي [بما في ذلك الأتمتة، وتحليلات البيانات، والذكاء الاصطناعي، والصمامات، وما إلى ذلك].

	English Technology Group	English Description	English Technology Examples
9	Grazing land management	Technologies aim to sustainably manage and protect pastures and rangeland from over-grazing and desertification	Grazing monitoring Technology Feeding Technology
10	Land monitoring	Data and information gathering for effective land management, including technologies to monitor and mitigate harm on the environment	Remote Data Analysis Motion Monitoring Technology Environmental Digital Modelling Precision Forestry
11	Collection devices, systems and vehicles	Technologies involved in the collection and transportation of waste materials from point of generation to designated waste management facilities	Collection Devices and Systems Collection Vehicles
12	Automated sorting	Automated separation of types of waste after collection	Robotic Sorting Advanced Sorting Radiological Sorting of Contaminated Solids
13	Waste Treatment (including recycling, composting and energy recovery)	Technologies in which waste materials undergo processes to reduce environmental impact and recover materials from them	Material Recycling Energy Recovery Organic Waste Recycling Biochar
14	Disposal technology	Final stage of waste management, involving the removal of waste materials from the human environment	Landfilling Technologies Biodegradation of Organics or Non-Metallic Inorganics
15	Waste monitoring	Collection, analysis and interpretation of data related to waste management	Smart Waste Management Waste Visualization and Analytics
16	Air pollution prevention and mitigation	Technologies to stop air pollution from occurring and reduce air pollution once emitted	Industrial Emissions Reduction Technology Methane reduction Technology Gas to Liquid Technology Pollution Reduction Infrastructure Solutions
17	Water pollution prevention and mitigation	Technologies to stop water pollution from occurring and reduce water pollution once discharged	Organic Matter Removal Filtration Technology Renewable Energy Purification UV and Ozone Disinfection Aeration and Air Stripping Technologies

Arabic Technology Examples	Arabic Description	Arabic Technology Group	
تقنية مراقبة الرعي تقنية التغذية	تهدف التقنيات إلى الإدارة المستدامة للمراعي وحمايتها من الرعي الجائر والتصحر	إدارة أراضي الرعي	9
تحليل بيانات عن بعد تقنية مراقبة التحركات نمذجة رقمية بيئية زراعة الغابات الدقيقة	جمع البيانات والمعلومات لإدارة فعالة للأراضي، بما في ذلك تقنيات رصد الاعمال المضرة على البيئة والحد منها	مراقبة الأراضي	10
أجهزة وأنظمة التجميع مركبات التجميع	التقنيات المستخدمة في تجميع المخلفات ونقلها من نقطة التوليد إلى مرافق إدارة النفايات المخصصة	أجهزة وأنظمة ومركبات التجميع	11
الفرز الالي الفرز المتقدم الفرز الإشعاعي للمواد الصلبة الملوثة	تقنيات فرز النفايات بشكل آلي بعد جمعها	الفرز الآلي	12
إعادة تدوير المواد استعادة الطاقة إعادة تدوير النفايات العضوية تكرين المواد العضوية	التقنيات التي تخضع فيها مواد النفايات لعمليات لتقليل التأثير البيئي واستعادة المواد الأولية منها	معالجة النفايات (بما في ذلك إعادة التدوير والتسميد واستعادة الطاقة)	13
تقنيات دفن النفايات تحلل الكائنات العضوية أو اللاعضوية غير المعدنية	المرحلة النهائية لإدارة المخلفات، والتي تنطوي على نقلها عن البيئة البشرية	تقنية التخلص من النفايات	14
إدارة النفايات الذكية تصوير وتحليل النفايات	قياس وتتبع وتحليل الملوثات الموجودة في البيئة	مراقبة النفايات	15
تقنية تقليل الانبعاثات الأخرى تقنية تقليل انبعاثات الميثان تقنية الغاز إلى السوائل حلول البنية التحتية لتقليل التلوث	تقنيات تبديد تلوث الهواء والحد منه بمجرد انبعاثه	منع تلوث الهواء والتخفيف من حدته	16
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	English Technology Group	English Description	English Technology Examples
18	Soil pollution prevention and mitigation	Technologies to stop soil pollution from occurring and reduce soil pollution once contaminated	Pedology and Soil Improvement Soil Remediation Techniques
19	Pollution monitoring	Measuring, tracking, and analyzing pollutants present in environment	Mobile Pollution Monitoring Devices and Systems Traffic Data Smart Energy Control
20	Data acquisition methods and monitoring	Collection, gathering and monitoring of various types of data related to weather and atmospheric conditions	Citizen Science Ocean Buoys Autonomous Vehicle Data Collection Surface Stations Compliant with WMO Criteria Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Deep Sea Monitoring System
21	Weather and climate forecasting	Observation, analysis and prediction of atmospheric conditions to provide timely and accurate information about current and future weather patterns	Weather Data Analysis Weather Data Visualization Early Weather Warning Technology Real Time Reporting on Shared Online Platforms Hazard Forecasting
22	Weather augment technology	Weather modification technologies, including cloud seeding and fog harvesting	Cloud Seeding Fog Harvesting

	Arabic Technology Group	Arabic Description	Arabic Technology Examples
18	منع تلوث التربة والتخفيف من آثاره	تقنيات تبديد تلوث التربة والحد منه بمجرد وقوعه	التربة وتحسينها تقنيات تنقية التربة
19	مراقبة التلوث	التقنيات المستخدمة لقياس وتتبع وتحليل الملوثات في البيئة وإدارتها	أجهزة وأنظمة مراقبة التلوث المتنقلة بيانات المرور التحكم الذكي في الطاقة
20	طرق الحصول على البيانات ومراقبتها	جمع وتصنيف ورصد شتى أنواع بيانات الطقس والأحوال الجوية	اشراك الجمهور في جمع البيانات العوامات البحرية جمع البيانات بواسطة مركبات ذاتية القيادة محطات السطح متوافقة مع معايير منظمة الأرصاد العالمية تقرير بيانات الأرصاد الجوية في الطبقة السفلية للغلاف الجوي نظام مراقبة البحر العميق
21	التنبؤ بالطقس والمناخ	مراقبة الظروف الجوية والتنبؤ بها لتوفير معلومات دقيقة عن أنماط الطقس المستقبلية	تحليل بيانات الطقس رسم بيانات الطقس تقنيات الإنذار المبكر إعداد التقارير اللحظية على المنصات المشتركة عبر الإنترنت التنبؤ بالمخاطر
22	تقنية تعزيز الطقس	تقنيات تعديل الطقس، بما في ذلك تلقيح السحب وحصد الضباب	الاستمطار استخلاص الماء من الضباب

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