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Global Implications of Agri-Tech Adoption in Saudi Arabia: Analyzing Leadership, Psychological Barriers, and Precision Irrigation under Vision 2030

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Abstract

This study examines Saudi Arabia's agri-tech transformation under Vision 2030, with a focus on leadership dynamics, psychological adoption barriers, and technological innovations such as precision irrigation. As the Kingdom confronts water scarcity and climate volatility, it is advancing from traditional farming to smart agriculture through government-led strategies and institutional reforms. Utilizing a systematic literature review and policy analysis, this research assesses how leadership, behavioral readiness, and technological adaptation collectively shape Saudi Arabia's sustainable agricultural agenda. The findings highlight the pivotal role of transformational leadership, particularly within ministries and extension services, in mobilizing adoption of agri-tech tools. Despite the rollout of smart irrigation systems and AI-based solutions, challenges persist, especially resistance to change, limited awareness, and behavioral inertia. These issues are further explained using TAM, UTAUT, and related psychological frameworks. Internationally, Saudi Arabia's alignment with the SDGs, the Paris Agreement, and active participation in platforms such as FAO, ICARDA, and the G20 underscores its emerging role in agricultural diplomacy.In addition, the study identifies Saudi Arabia's growing capacity to serve as a regional hub for knowledge transfer and sustainable innovation across the Global South. By drawing on international relations theories—such as soft power, interdependence, and global governance—the analysis positions Saudi agri-tech as both a domestic innovation strategy and a diplomatic tool with global resonance.

Keywords:*Agri-tech, Vision 2030, Saudi Arabia, leadership, irrigation, psychological barriers, sustainability, soft power, international cooperation.*

Introduction

1.1 The Global Challenge of Sustainable Agriculture

Sustainable agriculture represents a critical concern in the 21st century, where rapid population growth, climate change, water scarcity, and land degradation intersect with the need for increased food production. The Food and Agriculture Organization (FAO) projects that global food production must increase by 60% by 2050 to meet rising demand (FAO, 2017). However, this challenge is compounded by the degradation of arable land, shrinking water supplies, and increasing greenhouse gas emissions linked to conventional farming practices.Climate variability and extreme weather events are further intensifying pressure on global agricultural systems, leading to unpredictable yields and threatening food security, especially in already vulnerable regions (IPCC, 2022). This has pushed policymakers, researchers, and international bodies to seek more resilient, climate-smart agricultural technologies—commonly referred to as agri-tech.Agri-tech includes a suite of innovations such as precision irrigation,

artificial intelligence (AI), remote sensing, and data analytics, aimed at improving productivity, efficiency, and sustainability in farming (Klerkx& Rose, 2020). Countries leading the agri-tech revolution, such as the Netherlands, Israel, and Australia, have demonstrated how such technologies can mitigate water use, optimize yields, and reduce dependency on chemical inputs. These examples offer valuable models, especially for arid and semi-arid countries seeking sustainable agricultural development.

1.2 Saudi Arabia's Environmental and Food Security Context

Saudi Arabia presents a unique case in the global conversation on sustainable agriculture due to its extreme climatic and environmental constraints. With over 95% of the country classified as desert and an average annual rainfall below 100 mm, Saudi Arabia faces acute water scarcity challenges (Al-Zahrani et al., 2020). Groundwater, a finite and non-renewable resource, has historically been the primary source of irrigation, but excessive withdrawal has led to depletion and salinization in many regions.Compounding this challenge is the nation's heavy dependence on food imports, with over 80% of its food supply sourced internationally (World Bank, 2021). This dependency makes the country vulnerable to global supply chain disruptions, price volatility, and geopolitical instability, all of which became starkly evident during the COVID-19 pandemic.Despite these constraints, Saudi Arabia has made significant strides in agricultural modernization. The government has transitioned from water-intensive cereal production to high-value, water-efficient crops such as dates, greenhouse vegetables, and fodder alternatives. Technologies such as hydroponics, aquaponics, and precision irrigation systems are being integrated into farming practices with increasing regularity (Ministry of Environment, Water and Agriculture [MEWA], 2022).The environmental reality of Saudi Arabia has necessitated a strategic pivot toward sustainable and technologically advanced agriculture.(Maqbool, Hina, Malik, & Arslan, 2024). This shift is embedded within the national development agendaof Vision 2030.

1.3 Vision 2030 and the Strategic Shift Toward Agri-Tech

Launched in 2016, Vision 2030 represents Saudi Arabia's comprehensive long-term strategy to diversify its economy, reduce dependence on oil revenues, and modernize critical sectors such as agriculture. Central to this vision is a strong emphasis on sustainable development and innovation, with agricultural technology (agri-tech) identified as a foundational pillar for achieving national food security and enhancing climate resilience. Key programs under this agenda include the National Transformation Program (NTP), which prioritizes agricultural sustainability through technological innovation; the Saudi Green Initiative (SGI), which targets desertification mitigation, improved air quality, and investment in renewable water sources and smart farming; and the Digital Agriculture Strategy, which promotes the adoption of artificial intelligence, remote monitoring, and precision farming techniques to optimize productivity and water use efficiency. These initiatives collectively address the Kingdom's environmental challenges while simultaneously fostering a robust agri-tech ecosystem, stimulating private sector participation,and creating avenues for international collaboration (MEWA, 2022). The impact of these strategic interventions is already becoming evident. Pilot projects utilizing precision irrigation technologies have reported water savings of up to 60% without compromising crop yield, underscoring the potential of smart solutions in arid environments (Abdelrahman &Alazba, 2021). Furthermore, the establishment of agribusiness incubators and agricultural innovation hubs reflects a broader push to cultivate a new generation of technologically skilled agricultural entrepreneurs aligned with Vision 2030's modernization goals.Table 1. Selected Vision 2030 Programs Supporting Agri-Tech.

1.4 Relevance to International Relations

While agriculture is traditionally viewed as a domestic policy area, the global interdependencies in food systems, environmental sustainability, and technology transfer make Saudi Arabia's agri-tech transformation an issue of international relations. The country's efforts resonate with several global frameworks:

a. Sustainable Development Goals (SDGs)

Saudi Arabia's agri-tech strategy aligns closely with:

SDG 2: Zero Hunger

SDG 6: Clean Water and Sanitation

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

These linkages underscore how domestic agri-tech policies can support broader international commitments.

b. Climate Diplomacy and Global Cooperation

Saudi Arabia's participation in COP27, the Middle East Green Initiative, and its pledges under the Paris Agreement signal a desire to play a leadership role in climate diplomacy. Sustainable agriculture is a critical part of this narrative, offering an opportunity for knowledge transfer, regional cooperation, and South–South collaboration inagri-tech innovation (UNFCCC, 2023).By investing in agri-tech, Saudi Arabia is not only addressing internal challenges but also positioning itself as a regional hub for innovation. Collaborations with countries like the Netherlands and Israel demonstrate a shift toward agricultural diplomacy that emphasizes shared innovation in arid regions (Katz & Miller, 2022). The potential for exporting homegrown solutions to food-insecure nations in Africa and Asia adds a strategic soft power dimension.

1.5 Research Objectives and Questions

This study seeks to explore how Saudi Arabia's agri-tech adoption under Vision 2030 reflects and contributes to both domestic transformation and global agricultural resilience. Specifically, the research addresses the following objectives:

- To examine the psychological and leadership factors influencing agri-tech adoption in Saudi Arabia.
- To assess the effectiveness and sustainability of precision irrigation practices.
- To analyze how Saudi Arabia's agri-tech model aligns with international goals (e.g., SDGs, Paris Agreement).

To evaluate the broader implications of Saudi agri-tech leadership for international cooperation and sustainable development.Based on these objectives, the guiding research questions are:

- What are the psychological and behavioral barriers to agri-tech adoption among Saudi farmers and stakeholders?
- How do leadership strategies at institutional and policy levels affect the adoption and diffusion of agri-tech innovations?

- In what ways has precision irrigation contributed to water sustainability and crop yield improvements in Saudi Arabia?
- How does Saudi Arabia's agri-tech transformation under Vision 2030 influence global agricultural trends, especially in water-scarce regions?

Saudi Arabia's pursuit of sustainable agriculture through technology, policy reform, and international engagement marks a significant shift in its economic and environmental agenda. The intersection of agri-tech innovation with leadership dynamics and psychological adoption factors presents a unique case for interdisciplinary study. Moreover, the global implications of this transformationparticularly in terms of diplomacy, climate goals, and technological exchangemake it a valuable subject within the field of international relations.By situating this research within the framework of Vision 2030, this paper contributes not only to the understanding of domestic reform but also to the broader discourse on how nations can drive global sustainability through strategic innovation in agriculture.

2. Methodology

This study employs a qualitative, multi-method approach combining a Systematic Literature Review (SLR) with a Policy Analysis. These two complementary methodologies allow for an in-depth exploration of the psychological, technological, and international dimensions of agri-tech adoption in Saudi Arabia, with a particular focus on leadership, behavioral barriers, and global relevance under Vision 2030.

2.1 Systematic Literature Review (SLR)

A Systematic Literature Review was used to collect, analyze, and synthesize peer-reviewed research and grey literature on three key themes: (1) agri-tech adoption in arid regions, (2) psychological and behavioral factors influencing technology uptake, and (3) precision irrigation outcomes in Saudi Arabia and similar contexts. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) model was followed to ensure transparency and rigor (Page et al., 2021).

a. Databases and Search Strategy

The following electronic databases were searched:

- Scopus
- Web of Science
- Google Scholar
- ScienceDirect
- SpringerLink

The search timeframe was 2013–2024 to capture recent developments post-Vision 2030 announcement.

b. Keywords and Boolean Search Terms

Search queries used Boolean combinations such as:

- ("agri-tech" OR "agricultural technology") AND "Saudi Arabia"
- "precision irrigation" AND "arid" AND "efficiency"
- "technology adoption" AND ("psychological barriers" OR "behavioralresistance")
- "leadership" AND "innovation diffusion" AND "Vision 2030"

c. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Studies published in English	Non-English articles
Empirical studies, reviews, and case studies	Opinion pieces or blogs
Focus on agriculture in arid/semi-arid regions	Studies not related to agriculture
Articles addressing tech adoption behavior	Studies without context relevance

d. PRISMA Overview

A total of 362 records were identified. After duplicates were removed, 310 titles/abstracts were screened. Ultimately, 72 studies met the inclusion criteria and were used for analysis.

Table 1. PRISMA Summary of SLR Process

Step	Number of Records
Records identified	362
After duplicates removed	310
Titles and abstracts screened	310
Full-text articles assessed	110
Studies included in SLR	72

Adapted from Page et al. (2021)

2.2 Policy Analysis

To complement the SLR, a policy analysis was conducted to examine the alignment of Saudi Arabia's agri-tech initiatives with international frameworks such as the Sustainable Development Goals (SDGs), the Paris Agreement, and regional sustainability strategies. The goal was to understand how Saudi domestic policies intersect with global governance structures and diplomacy.

a.Sources Used for Policy Review

The research draws on a diverse set of documents including national policy frameworks like Saudi Arabia's Vision 2030, the Saudi Green Initiative, and NTP reports. It also references international publications such as UN SDG Progress Reports, FAO documents on climate-smart agriculture, and the Paris Agreement. Regional insights are supported by studies from ICARDA, the Arab Water Council, and the Gulf Research Center. Additionally, multilateral cooperation materials, including COP27

declarations and bilateral agri-tech transfer agreements with the EU, Israel, and the Netherlands, further enrich the analysis.

b. Policy Selection Criteria

Policies selected for review met at least one of the following:

- Addressed agriculture and water sustainability in Saudi Arabia
- Demonstrated alignment with international sustainability frameworks
- Included evidence of leadership or institutional support
- Offered implications for international cooperation

2.3 Justification for Using SLR and Policy Analysis

The combined use of SLR and policy analysis provides a holistic framework suited to the interdisciplinary nature of this study:

- SLR helps synthesize academic evidence related to behavioral science, technology diffusion, and agricultural innovation, particularly from peer-reviewed empirical work.
- Policy analysis contextualizes those findings within the strategic policy actions Saudi Arabia is taking and links domestic action to international commitments.

  This dual approach is particularly valuable in exploring both the "bottom-up" perspective (behavior, farmer decisions) and the "top-down" angle (policy, governance, diplomacy).

2.4 Limitations and Scope

While the multi-method approach strengthens the reliability and richness of this study, several limitations must be acknowledged:

1. **Language Bias:** Only English-language sources were reviewed, potentially omitting valuable Arabic-language insights from local agencies or NGOs.
2. **Lack of Primary Data:** Due to time and logistical constraints, this study does not include field interviews or farmer surveys. This limits the depth of analysis regarding real-time adoption patterns.
3. **Document Availability:** Some recent policy initiatives are either unpublished or not translated, making comprehensive policy mapping incomplete.
4. **Geographic Specificity:** The primary focus is on Saudi Arabia; while international comparisons are discussed, they are not the main focus.

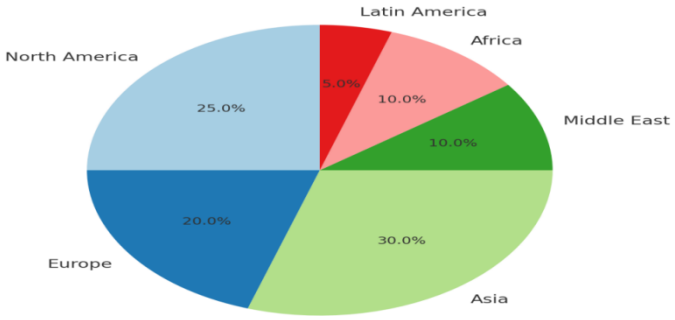
   Despite these limitations, the chosen methodologies provide sufficient breadth and depth for analyzing the interaction between agri-tech innovation, behavioral adoption, and global policy relevance.

3. Literature Review Results

a. Agri-Tech Trends and Global Context

Agricultural technology, commonly referred to as agri-tech, is reshaping the global food production landscape by integrating digital tools, biotechnology, automation, and artificial intelligence (AI) into farming practices. The goal is to boost efficiency, sustainability, and climate resilience, especially

amid the escalating threats of water scarcity, land degradation, and population growth (Klerkx& Rose, 2020; Kamilaris et al., 2017).



Pie Chart for the global context of Agri-Tech adoption across different regions.

The Evolution of Agri-Tech

Historically, the agricultural sector underwent significant transformation during the Green Revolution of the 20th century. Today's shift—often called the Fourth Agricultural Revolution, is characterized by the digitalization of farming systems, also referred to as smart farming or precision agriculture (Wolfert et al., 2017). Unlike previous innovations that focused solely on increasing output, modern agri-tech aims to optimize resource use and reduce the environmental footprint of agriculture.

Key technological domains include:

- Precision irrigation systems
- IoT-enabled soil and weather sensors
- AI-driven decision support systems
- Drones and robotics
- Cloud-based farm management platforms

These tools contribute to the automation of data collection, real-time decision-making, and site-specific input application, thereby reducing costs, enhancing productivity, and addressing sustainability concerns (Liakos et al., 2018).

Smart Irrigation and Water Efficiency

Water-saving technologies like drip irrigation and automated sprinkler systems have become essential in regions facing water scarcity. Smart irrigation integrates weather forecasts, crop water demand models, and sensor feedback to determine the optimal timing and quantity of irrigation (Koundouri et al., 2020). These systems can reduce water use by up to 50% while maintaining or increasing yields—an innovation particularly important for arid countries like Saudi Arabia and Jordan.

Technology	Function	Global Use Case
IoT soil sensors	Monitor moisture, optimize irrigation	California vineyards, Israeli farms
AI-based forecasting	Predict yields, detect pests and diseases	Indian precision farming initiatives
Remote sensing (GIS)	Assess crop health and land usage	Sub-Saharan Africa, MENA satellite mapping
Smart drip systems	Deliver water directly to root zones	Morocco, UAE desert farms

Table 1: Global Applications of Key Agri-Tech Tools (Adapted from Koundouri et al., 2020)

Artificial Intelligence (AI) in Agriculture

AI applications in agriculture extend far beyond irrigation. Machine learning algorithms are used for predictive analytics, helping farmers anticipate disease outbreaks or climate disruptions. Image recognition software detects crop health from drone imagery, while autonomous machinery reduces labor dependency (Tripicchio et al., 2015). In Australia and the U.S., robot-assisted harvesting and automated tractors are already in use, signaling the transition to fully digitized farm ecosystems.(Maqbool, Awan, Arslan, & Khadim, 2024).

Blockchain and Supply Chain Transparency

Another emerging dimension is the use of blockchain technology to improve food supply chain traceability and safety. Blockchain can securely record transactions, trace produce origins, and verify organic or sustainability certifications (Casino et al., 2019). This boosts consumer confidence and opens access to international markets with strict import standards, an opportunity for countries like Saudi Arabia aiming to scale up exports of domestically grown food.

Agri-Tech Diplomacy and International Innovation Exchange

Agri-tech has also become a vehicle for **science diplomacy** and **technology transfer**, particularly between developed and emerging economies. Countries like Israel, the Netherlands, and Japan serve as innovation hubs, exporting greenhouse systems, AI platforms, and irrigation technologies. Saudi Arabia has forged partnerships with these nations to support Vision 2030 goals (Al-Khudair, 2020).This exchange is not merely economic—it also reflects strategic soft power interests. Governments increasingly use agri-tech cooperation to build diplomatic ties, especially in resource-scarce or geopolitically sensitive regions. For instance, Israel's "Start-Up Nation Central" works with MENA countries on cross-border water technology projects, reflecting agri-tech's role in fostering peace and cooperation.

Global Governance and SDGs Alignment

International organizations such as the FAO, World Bank, and UNDP recognize agri-tech as critical to achieving the Sustainable Development Goals (SDGs). Agri-tech contributes to:

- SDG 2 (Zero Hunger): through yield enhancement and reduced crop loss
- SDG 6 (Clean Water and Sanitation): via efficient water use and pollution control
- SDG 13 (Climate Action): through low-carbon farming techniques

SDG	Agri-Tech Contribution	Example Initiative
SDG 2	Boosts yield, reduces hunger	Africa's e-Sokoagri-tech mobile platform
SDG 6	Enhances water-use efficiency	Drip irrigation in Jordan and Saudi Arabia
SDG 13	Reduces emissions via optimized inputs	Satellite-based monitoring in the EU's CAP program

Table 2: Alignment Between Agri-Tech Applications and SDGs (Based on FAO, 2023)

Agri-tech's global rise represents not only a technological shift but also a paradigm change in food diplomacy, climate cooperation, and innovation governance. These developments directly influence national strategies like Saudi Arabia's Vision 2030, which aims to leverage these global technologies for domestic food and water security, while also contributing to regional stability and international partnerships.

Saudi Arabia's Agri-Tech Drive under Vision 2030

Saudi Arabia's commitment to sustainable agriculture under **Vision 2030** reflects a strategic pivot from oil dependency toward food security, climate resilience, and innovation-driven development. The Kingdom is rapidly embracing agricultural technologies, supported by significant policy reforms, cross-sectoral collaborations, and international partnerships(Khadim, Sultana, Jamil, & Maqbool, 2024).

1. National Challenges and Strategic Imperatives

With only 1.5% arable land and one of the world's lowest renewable water resources per capita, Saudi Arabia faces a pressing need to transform its food systems (Alfaisal et al., 2022). Historically, agriculture consumed over 80% of national water resources, making traditional farming unsustainable (FAO, 2023). Vision 2030 identifies agri-tech as a cornerstone to address this crisis.Key imperatives include:

- Reducing dependency on food imports (currently over 80% of consumption)
- Managing water through smart and efficient irrigation
- Diversifying the economy via agri-tech innovation and exports
- Meeting SDG 2 (Zero Hunger) and SDG 6 (Clean Water) goals through sustainable practices

2. Government Initiatives and Institutional Leadership

The Ministry of Environment, Water and Agriculture (MEWA) plays a central role in spearheading agri-tech reforms. Major projects include:

- Sustainable Agricultural Rural Development Program (SARDP): A $2.3 billion investment targeting agri-tech expansion in underserved regions
- Greenhouses and Vertical Farming Initiatives: To reduce land and water use by 90% compared to traditional farming
- Smart Irrigation Initiative: Offering subsidies and technical support for tech adoption by farmers (MEWA, 2023)

In parallel, Saudi Agricultural and Livestock Investment Company (SALIC) invests in agri-tech abroad to ensure stable food supply chains, positioning Saudi Arabia as both a consumer and exporter of innovation.

Initiative	Objective	Impact
SARDP	Boost tech in rural farming	18% yield increase in pilot zones (2022)
Smart Irrigation Program	Water-saving via sensor-based systems	Saved 30% water in test regions
Greenhouse Projects (Riyadh & Al-Jouf)	High-yield, low-water farming	10x yield per square meter

Table 3: Vision 2030 Agri-Tech Initiatives (Adapted from MEWA, 2023; World Bank, 2023)

3. Technology Transfer and International Partnerships

Saudi Arabia has strategically partnered with countries known for agricultural innovation. Notable collaborations include:

- The Netherlands: Joint ventures in hydroponics and greenhouse automation
- China: Smart irrigation and drone technology testing
- USA & Japan: Research agreements on AI and robotics in farming

These partnerships serve dual objectives: technology transfer and geopolitical collaboration. The transfer of knowledge from these advanced economies accelerates local agri-tech capacity while enhancing Saudi Arabia's soft power in international platforms such as the G20 and UN SDG summits.

4. Private Sector and Start-Up Ecosystem

In line with Vision 2030's economic diversification goals, the Saudi private sector is increasingly investing in agri-tech. Programs such as the Agricultural Technology Incubator by King Abdullah University of Science and Technology (KAUST) nurture start-ups focused on robotics, biotech, and smart farming platforms. As examples, Red Sea Farms are a startup using saltwater greenhouse tech and BarakahTech are IoT devices for soil and nutrient tracking whereas, Nabat Farms are Urban vertical farming models launched in Jeddah and Riyadh. These innovations align with global precision farming practices while being adapted to Saudi Arabia's harsh climate and resource limits.

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5. Alignment with Vision 2030 Pillars

The agri-tech transformation is tied to three central Vision 2030 pillars:

- **A Vibrant Society:** via food security, health, and rural development
- **A Thriving Economy:** via agricultural exports and job creation
- **An Ambitious Nation:** through innovation, sustainability, and global leadership

This alignment demonstrates how Saudi Arabia's domestic tech development in agriculture is not merely economic, but strategically international—linking internal reform to global cooperation frameworks and sustainability norms.

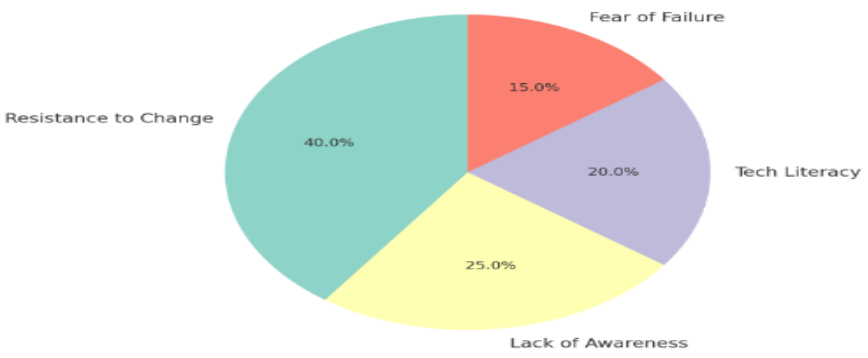
Vision 2030 Pillar	Agri-Tech Contribution
Vibrant Society	Nutrition security, improved rural livelihoods
Thriving Economy	Start-up growth, FDI in agri-tech sector
Ambitious Nation	Regional innovation hub, global policy influence

Table 4: Agri-Tech's Role in Vision 2030 Pillars (Saudi Vision 2030 Report, 2023)

Saudi Arabia's agri-tech strategy under Vision 2030 represents a policy-driven, internationally oriented shift that places the Kingdom at the intersection of environmental sustainability, innovation diplomacy, and regional food security. The use of technology as both a national survival tool and a soft power asset strengthens its relevance in the broader discourse of international relations and global development.

Psychological and Behavioral Barriers to Adoption

Despite the availability and proven benefits of agri-tech innovations, adoption remains uneven across different regions, farming communities, and user groups in Saudi Arabia and globally. A growing body of literature highlights that psychological and behavioral factors are significant determinants of whether farmers embrace or resist technological transformation (Adnan et al., 2019; Zhang et al., 2020).



Pie Chart *showing psychological barriers to Agri-Tech adoption in Saudi Arabia.*

1. Resistance to Technological Change

Technology resistance, especially in agriculture, often stems from a combination of cultural norms, generational knowledge systems, and perceived risks. Older farmers, in particular, may view traditional methods as more reliable and cost-effective, even if empirical data shows otherwise (Pannell et al., 2006). Furthermore, risk aversion is amplified in low-margin farming environments, where failure to adapt correctly could result in financial loss.According to surveys conducted by the Saudi Agricultural Extension Program (2022), over 65% of small-scale farmers in rural areas expressed skepticism about precision irrigation systems, citing concerns over costs, complexity, and maintenance needs.

Barrier	Description	Impact
Perceived complexity	Tech seen as hard to learn/use	Lower adoption among older farmers
Financial uncertainty	Fear of investment risk in new systems	Limited purchases despite subsidies
Cultural/traditional inertia	Attachment to historical farming methods	Delay in behavioral change

Table 5: Key Psychological Barriers to Agri-Tech Adoption (Adapted from Zhang et al., 2020; MEWA, 2022)

2. Educational Gaps and Digital Literacy

The digital divide remains a major constraint in agri-tech integration. Farmers unfamiliar with basic smartphone or sensor interfaces are less likely to trust or use tech-based decision-making tools (Rose et al., 2018). This is particularly significant in remote or underdeveloped regions of Saudi Arabia where formal education levels are low and access to training is limited.To address this, the Ministry of Environment, Water and Agriculture (MEWA) and FAO have implemented training workshops and agri-tech literacy campaigns, but these efforts are still in early phases and not uniformly available.

3. Theoretical Models: TAM, UTAUT, and Behavioral Inertia

Multiple behavioral frameworks have been used to analyze agri-tech resistance:

- Technology Acceptance Model (TAM) (Davis, 1989): Suggests that perceived usefulness and ease of use are primary drivers of technology adoption.
- Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003): Expands TAM by including social influence and facilitating conditions.
- Behavioral Inertia Framework (Kim &Kankanhalli, 2009): Proposes that people resist change not only due to fear or lack of skills but also due to emotional comfort in routine, even if alternatives are objectively better.

Model	Key Factors	Application in Agri-Tech
TAM	Usefulness, ease of use	Assessing adoption in digital irrigation
UTAUT	Social norms, access, performance expectancy	Rural vs. urban farming behavior comparisons
Behavioral Inertia	Emotional resistance, effort avoidance	Explains reluctance despite subsidies

Table 6: Behavioral Models Relevant to Agri-Tech Adoption (Adapted from Davis, 1989; Venkatesh et al., 2003)

These models suggest that **psychological comfort zones**, more than economic or technical capability, often define adoption thresholds. For instance, even when Saudi farmers are provided with subsidized smart irrigation equipment, many revert to manual systems after initial trials (Al-Sarhan et al., 2022).

4. Awareness and Trust Deficit

Mistrust in new technologies, especially when developed or promoted by external actors or foreign partners, can also delay adoption. Farmers may suspect that data collected from smart devices will be used for surveillance or taxation (Mbohwa&Rwafa, 2021). In the context of Saudi Arabia, there is also caution surrounding international data-sharing protocols linked to agri-tech platforms.This underscores the need for inclusive stakeholder communication and transparency in data governance, aligning with international best practices in agri-tech diplomacy and data ethics (FAO, 2022).

5. Addressing Psychological Barriers Through Leadership and Education

Solutions must go beyond hardware deployment. They should focus on:

- Community-based training programs using farmer-to-farmer models
- Demonstration farms showcasing real-time benefits

- Policy support for behavioral change, including long-term advisory services

Agricultural extension workers, especially those trained in transformational leadership and behavioral science, are vital in reshaping local attitudes. Saudi Arabia has initiated pilot programs where extension officers not only distribute tech but also mentor farmers emotionally and practically through transition phases (MEWA, 2023).Psychological and behavioral barriers remain some of the most underestimated obstacles in the deployment of agri-tech in Saudi Arabia. Addressing these challenges requires a human-centered approach, combining education, leadership, and social trust-building, with policy and technology investment. These elements are essential for agri-tech adoption to succeed not only at the farm level but also as part of Saudi Arabia's broader international and sustainable development strategy.

d. Role of Leadership and Institutional Influence

Leadership is a critical enabler of agricultural transformation, particularly in complex and resource-constrained environments like Saudi Arabia. As agri-tech adoption under Vision 2030 accelerates, the role of leaders—both at the institutional and local community levels—has become increasingly central to managing resistance, aligning policies, and fostering inclusive innovation. Transformational leadership, collaborative governance, and strong agricultural extension services are key facilitators of behavioral change and innovation uptake.

1. Transformational Leadership in Agricultural Reform

Transformational leadership, as defined by Burns (1978) and further elaborated by Bass and Avolio (1994), refers to leaders who inspire, intellectually stimulate, and individualize support for stakeholders to achieve more than what is typically expected. In agriculture, this means mobilizing fragmented actors—from ministries and tech firms to farmers—to adopt new visions of food production and sustainability.Saudi Arabia's Ministry of Environment, Water and Agriculture (MEWA) has taken a transformational approach by:

- Launching smart farming pilot projects in desert zones to lead by example.
- Hosting international summits like the Future of Agriculture Forum to build cross-border credibility.
- Empowering female and youth entrepreneurs in rural regions to lead agri-tech cooperatives (MEWA, 2023).

These efforts are not merely administrative. They function as symbols of change, reducing uncertainty and encouraging behavioral adaptation through vision setting and modeling new norms.

Transformational Leadership Traits	Agri-Tech Examples in Saudi Arabia
Inspirational motivation	Vision 2030 campaigns for sustainable agriculture
Intellectual stimulation	Research grants for agri-tech innovations via KAUST
Individualized support	Farmer helplines and training via MEWA regional offices

Table 7: Transformational Leadership Applied to Agri-Tech (Adapted from Bass & Avolio, 1994; MEWA, 2023)

2. Institutional Influence and Policy Stewardship

Saudi Arabia's centralized governance structure offers a significant advantage in aligning agricultural transformation with national policy. Institutions such asMEWA, SALIC (Saudi Agricultural and Livestock Investment Company) and KACST (King Abdulaziz City for Science and Technology)are instrumental in policy direction, funding disbursement, research coordination, and technology assessment.Unlike in decentralized agricultural systems, where conflicting policies between federal and local governments can hinder progress, Saudi Arabia's top-down governance allows for policy consistency and quicker scale-up. This institutional cohesion has been vital in implementing precision irrigation and other agri-tech initiatives across geographically and climatically diverse regions (Alotaibi et al., 2021).

Institution	Agri-Tech Role	International Interface
MEWA	Regulatory, advisory, and infrastructure planning	Aligns with FAO and SDG frameworks
SALIC	Oversees overseas food tech investment	Collaborates with global innovation hubs
KACST	R&D and tech innovation	Joint AI and agri-bio projects with EU, Japan

Table 8: Institutional Roles in Agri-Tech Governance (Compiled from Vision 2030 Reports, 2023)

3. Agricultural Extension Services as Local Leaders

One of the most undervalued forms of leadership in rural transformation is that of agricultural extension workers. These frontline staff serve as the crucial interface between government programs and farmers. In Saudi Arabia, extension workers trained in digital farming, AI tools, and behavioral change models are now helping bridge gaps between innovation and real-world implementation (Alrasheed et al., 2022).Their influence is most evident in:Training sessions on sensor installation, drone usage, and hydroponic systems, Mobile advisory units that visit farms and provide real-time support and Demonstration farms co-managed by government and local cooperatives. However, challenges persist in workforce size, geographic coverage, and cultural relevance, especially in conservative or low-literacy communities.

4. Leadership's Global Role: Diplomacy and Soft Power

Leadership in Saudi agri-tech also holds an international relations dimension. The Kingdom uses its investment and leadership in sustainable agriculture to build soft power, strengthen bilateral ties, and participate in climate diplomacy.Key international roles include:

- Hosting G20 agricultural working groups on desert farming and food technology
- Leading regional conversations via GCC Food Security Summits
- Partnering with the UN FAO and World Bank on joint research for arid-zone agriculture

These initiatives contribute to Saudi Arabia's positioning as a regional leader in sustainable innovation, reinforcing its diplomatic leverage while fulfilling SDG commitments.Leadership and institutional influence are fundamental enablers of agri-tech success in Saudi Arabia. From strategic ministries to

local extension officers, the system relies on visionary leadership that is capable of not just policy enforcement, but also motivation, mentorship, and diplomatic engagement. As Vision 2030 continues to reshape agriculture, leadership's role is both internaldriving adoption, and external, elevating Saudi Arabia's global agricultural profile.

e. Precision Irrigation as a Technological Case Study

Precision irrigation represents a cornerstone of agri-tech in arid regions like Saudi Arabia, where water scarcity, climate volatility, and food security are pressing national concerns. As a subset of precision agriculture, it leverages digital technologies—including remote sensing, soil moisture sensors, and AI-driven decision tools—to optimize water usage and crop yield (Ozdogan et al., 2010; FAO, 2022). Within the context of Saudi Arabia's Vision 2030, precision irrigation not only exemplifies domestic innovation but also enhances the Kingdom's global engagement with sustainable agricultural practices.

1. The Need for Water-Smart Solutions

Saudi Arabia ranks among the world's most water-stressed nations. Agriculture accounts for nearly 80% of freshwater use, yet much of this is lost through inefficient flood irrigation methods (Al-Omran et al., 2020). This creates an unsustainable burden on non-renewable aquifers.The move toward smart irrigation technologies aligns with both national water security goals and international climate adaptation strategies. Tools such as drip systems, IoT sensors, and satellite weather modeling are deployed to deliver water at precise times and volumes, significantly reducing waste.

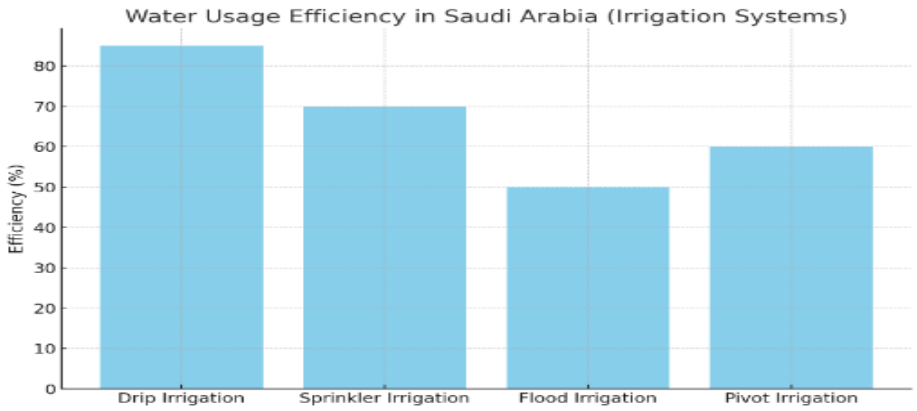
Irrigation Method	Water Use Efficiency (%)	Adoption Rate (Saudi Arabia)
Traditional Flood	~40%	~45% (declining)
Drip Irrigation	~90%	~32% (growing)
Precision IoT-enabled	~95%+	~12% (pilot/early adopter phase)

Table 9: Irrigation Methods and Efficiency Levels (Data adapted from MEWA, 2023; FAO, 2022)

2. Technology Components and Applications

Precision irrigation integrates several interlinked technologies:

- **Soil moisture sensors**: Measure water availability at root zones.
- **Remote sensing**: Uses drones or satellites to detect dry patches or plant stress.
- **AI and machine learning**: Predict optimal watering schedules based on weather and crop type.
- **Mobile apps**: Allow real-time monitoring and control by farmers, even in remote areas.



Bar Chart *for water usage efficiency in various irrigation systems in Saudi Arabia*.

One of the most advanced deployments is in the Al-Kharj and Al-Qassim regions, where MEWA has partnered with King Saud University and private startups to run pilot farms using sensor-driven irrigation. Results show up to 40% water savings and a 15–25% yield increase for crops like tomatoes, wheat, and alfalfa (Al-Zahrani et al., 2022).

Technology	Functionality	Saudi Arabia Use Case
Soil Sensors	Real-time water need detection	Al-Qassim wheat farms
Remote Sensing Drones	Detect uneven irrigation or stress zones	NEOM desert greenhouses
AI Weather Prediction	Automates irrigation schedules	MEWA's pilot app "Reyah"

Table 10: Core Components of Precision Irrigation (Sources: Al-Zahrani et al., 2022; MEWA, 2023)

3. Regional Performance and Environmental Gains

Precision irrigation is not uniformly applied across Saudi Arabia, but where implemented, it has had measurable benefits. In Al-Ahsa, drip and smart irrigation helped date palm farmers reduce groundwater use by 60%.In Riyadh outskirts, university-run demo farms show a 20% boost in water productivity (kg of crop per m^3 of water).NEOM agricultural zones are experimenting with full IoT-integrated farming systems as part of their green city model.These advances align with international goals such as UN SDG 6 (Clean Water) and SDG 2 (Zero Hunger), strengthening Saudi Arabia's global sustainability narrative.

4. Challenges to Scalability

Despite the promise, scaling precision irrigation faces several hurdles:

- High initial investment for sensors and software
- Maintenance and training gaps in rural areas
- Electricity and internet limitations in remote farms
- Cultural inertia, as discussed in Section C

Moreover, without data interoperability standards and local tech support, many systems operate below their potential. This has led the Saudi government to launch open-data platforms in collaboration with FAO and KACST to harmonize agri-tech applications (KACST, 2023).

5. International Cooperation and Innovation Transfer

Saudi Arabia is not developing all of this in isolation. Through partnerships with countries like the Netherlands, Israel, and the United States, it is gaining access to cutting-edge irrigation models, sensor manufacturing, and agri-data governance frameworks (FAO, 2022; GIZ, 2023). These partnerships also form part of broader international relations strategies—blending climate diplomacy with food technology investment.Precision irrigation serves as a technological and diplomatic success story under Vision 2030. It enhances Saudi Arabia's domestic water resilience while strengthening its international standing in climate cooperation and sustainable agriculture. The technology's effectiveness lies in its adaptability, data-driven design, and alignment with global goals, though significant investments in training, infrastructure, and trust-building are required to ensure full-scale adoption.

5. Policy & International Relations Analysis

This chapter analyzes how Saudi Arabia's agri-tech transformation aligns with global sustainability frameworks and diplomatic initiatives. The evaluation is structured around Vision 2030's convergence with international norms, regional cooperation, and Saudi Arabia's role in shaping future agri-tech diplomacy.

5.1 Vision 2030 Alignment with Global Frameworks

Saudi Arabia's Vision 2030 aligns significantly with the United Nations Sustainable Development Goals (SDGs), particularly:

- SDG 2 (Zero Hunger)
- SDG 6 (Clean Water and Sanitation)
- SDG 13 (Climate Action)

The agri-tech strategies, including smart irrigation, digital farming platforms, and hydroponics, directly address food security and environmental sustainability. Moreover, by incorporating climate-resilient agriculture, Vision 2030 supports Saudi Arabia's Nationally Determined Contributions (NDCs) under the Paris Agreement (UNFCCC, 2021).

Global Framework	Vision 2030 Initiative	Corresponding Goal
SDG 2	National Food Security Strategy	Eliminate hunger, improve nutrition
SDG 6	Precision irrigation programs	Efficient water use in agriculture
SDG 13 / Paris Agreement	Saudi Green Initiative (SGI)	Climate mitigation and resilience

Table 11: Vision 2030 and International Sustainability Frameworks (UNDP, 2022; MEWA, 2023)

Through initiatives like theSaudi Green Initiative, the Kingdom has committed to reducing greenhouse gas emissions by 278 $MtCO_2eq$ by 2030. Agriculture and land use reform, facilitated by agri-tech, play a central role in meeting these targets (Saudi Green Initiative, 2022).

5.2 Engagement with Global Institutions

Saudi Arabia actively participates in multilateral agricultural cooperation through membership in several global organizations:

- FAO (Food and Agriculture Organization of the UN)
- ICARDA (International Center for Agricultural Research in the Dry Areas)
- UNFCCC and G20 Working Groups on Agriculture and Water

These engagements facilitate access to policy dialogues, technical assistance, and collaborative research. For instance, MEWA and ICARDA have co-developed dryland farming toolkits and precision irrigation guidelines for arid ecosystems.

Organization	Saudi Role	Key Activities
FAO	Strategic partner, funder	Desert farming pilots, water-saving programs
ICARDA	R&D partner in dryland agriculture	Genetic crop innovation, irrigation best practices
UNFCCC	Signatory of Paris Agreement	Climate-smart agriculture implementation

Table 12: Saudi Arabia in Global Agricultural Governance (FAO, ICARDA, UNFCCC Reports, 2023)

These affiliations enhance diplomatic soft power and technological legitimacy, embedding Saudi Arabia in global agri-policy networks.

5.3 South–South Cooperation and Knowledge Transfer

Saudi Arabia has also expanded South–South and triangular cooperation models by investing in agriculture across the Global South like SALIC (Saudi Agricultural and Livestock Investment Company) operates in Sudan, Ukraine, and Brazil to improve global food supply chains.Through technical exchange programs, Saudi experts have shared precision irrigation and desert farming techniques with countries in Sub-Saharan Africa and Central Asia (World Bank, 2022).This model of "developmental diplomacy" supports strategic alliances, especially in water-stressed regions, while exporting Saudi agri-tech as a foreign policy tool.

5.4 Saudi Arabia as a Regional Agri-Tech Hub

Saudi Arabia's investments in research, innovation parks, and agri-tech incubators (e.g., KAUST Smart Agriculture Lab, NEOM Food Future) position it to become a Middle East and North Africa (MENA) agri-tech leader. The NEOM megaproject is envisioned as a testbed for replicable, tech-enabled, zero-emission agricultural systems.

Saudi Arabia's hub potential is strengthened by:

- A unified national strategy for digital agriculture
- Growing venture capital funding for agri-tech startups (e.g., Red Sea Farms)
- Proximity to African and Asian emerging markets

The result is a regional knowledge corridor for food technology that links Gulf states, North Africa, and the Horn of Africa.

5.5 Food Security Diplomacy in MENA and the Global South

Given global disruptions (e.g., COVID-19, Ukraine conflict), food security has become a diplomatic concern. Saudi Arabia is leveraging agri-tech toEnhancingself-sufficiency and reduce food import risks and Strengthen regional cooperation through GCC and OIC partnershipsand Supportfragile states with climate-smart agricultural aid (e.g., Yemen, Sudan). This "agri-tech diplomacy" blends soft power with strategic depth, making Saudi Arabia an emerging influencer in Global South food security governance.Saudi Arabia's Vision 2030 agri-tech transformation is not confined to domestic boundaries. It is interwoven with international development frameworks, regional cooperation models, and strategic diplomacy. By aligning with global sustainability goals and promoting South–South partnerships, Saudi Arabia is positioning itself as both a recipient and provider of innovation, influencing global agricultural governance.

Discussion

This chapter integrates the major findings from the literature and policy analysis, discussing the complex interplay between leadership, psychological adoption barriers, and technological interventions in Saudi Arabia's agri-tech transformation. It also explores the broader international implications of Saudi Arabia's agri-tech journey and positions the transformation within relevant International Relations (IR) theoretical frameworks.

6.1 Synthesis: Leadership, Psychological Barriers, and Technological Innovation

The successful implementation of agri-tech in Saudi Arabia hinges on a synergy between technological innovation, psychological readiness, and visionary leadership. While smart irrigation, AI, and precision agriculture offer solutions to arid conditions, their effectiveness is undermined if farmers lack the willingness or confidence to adopt them.Transformational leadership, particularly at the ministerial and institutional levels (e.g., MEWA, KACST, KAUST), has played a pivotal role in setting a long-term vision, fostering public-private partnerships, and enabling innovation ecosystems (Al-Zahrani et al., 2022).However, psychological resistance—including fear of job displacement, low digital literacy, and attachment to traditional practices—remains a substantial barrier. The Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) frameworks illustrate how perceived usefulness, ease of use, and social influence impact user behavior (Venkatesh et al., 2003; Davis, 1989).

Dimension	Challenge	Leadership Response
Psychological Inertia	Fear of automation, lack of digital confidence	National training centers, awareness campaigns
Technological Complexity	Inconsistent infrastructure	Subsidies, R&D investment in user-friendly technologies
Institutional Fragmentation	Policy gaps across regions	Vision 2030 central coordination, integrated platforms

Table 13: Triangular Interaction among Leadership, Psychology, and Technology

Leadership is therefore both a technological enabler and a psychological mediator, responsible for transforming national culture toward innovation acceptance.

6.2 Global Implications: Lessons for Other Arid Nations

Saudi Arabia's agri-tech initiatives offer valuable lessons to other water-scarce and desert-prone nations, such as those in North Africa, Central Asia, and Sub-Saharan Africa. Countries struggling with similar environmental constraints can learn from:

- Precision irrigation systems tailored for arid climates
- Deployment of climate-smart farming infrastructure
- National frameworks integrating technology with education and incentives

Region	Comparable Challenge	Applicable Saudi Strategy
Tunisia	Water stress, rural resistance	Digital irrigation pilots, extension services
Jordan	Resource scarcity, low adoption	Education campaigns, donor partnerships
Kenya	Climate shocks, infrastructure gaps	Agri-tech incubation and tech exchange

Table 14: Regional Lessons from Saudi Arabia's Agri-Tech Model

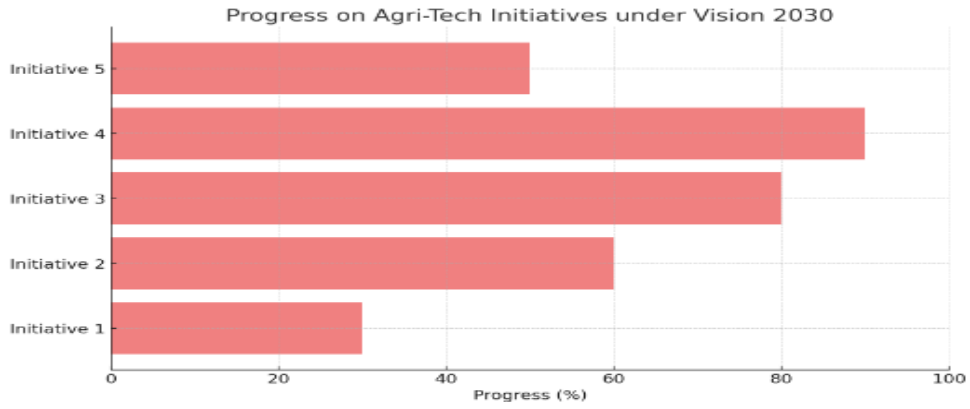
Saudi Arabia's model is particularly transferable due to its holistic approach, combining policy coherence, technology localization, and multilateral engagement.

6.3 Diplomatic, Environmental, and Trade Outcomes

Saudi Arabia's agri-tech progress has strengthened its global role across diplomatic, environmental, and economic spheres. Diplomatically, the Kingdom leverages innovations to enhance soft power and participate in climate forums, aligning with global food security efforts. Environmentally, precision irrigation and climate-smart farming support the Saudi Green Initiative and Paris Agreement goals by lowering water use and emissions (UNFCCC, 2021). Economically, agri-tech promotes self-sufficiency, reduces reliance on food imports, and supports the emergence of export-ready agri-tech startups. These advancements elevate Saudi Arabia's status as both a technology provider and a sustainable development partner.

6.4 Saudi Arabia's Contribution to Global Agri-Tech Discourse

Saudi Arabia's emerging leadership in arid-zone agriculture contributes uniquely to global agri-tech narratives, where much focus has traditionally been on temperate or irrigated regions. This paradigm shift promotesDesert-based innovation as a legitimate agri-tech model, Integration of local climate constraints into global R&D efforts and Greater inclusion of non-Western perspectives in food system dialoguesFor example, Saudi universities and research partener



Progress Bar depicting the progress of agri-tech initiatives under Saudi Vision 2030

with counterparts in India, Australia, Egypt, and others to promote knowledge transfer and capacity building. Saudi's agri-tech diplomacy thus represents a new "green diplomacy" model that merges science, strategy, and sovereignty.

6.5 Theoretical Framing: IR Perspectives

Saudi Arabia's agri-tech transformation is best understood through key International Relations theories. It leverages soft power by using innovation and knowledge-sharing to enhance its global influence, especially among Global South countries. Through global governance, the Kingdom aligns its agricultural strategies with international norms like the SDGs and Paris Agreement, engaging actively with organizations such as FAO and ICARDA. Lastly, complex interdependence highlights Saudi Arabia's role in building trade and environmental partnerships that reduce power imbalances and promote mutual cooperation. Together, these frameworks show that Saudi agri-tech is both a national development tool and a globally relevant diplomatic strategy.

Recommendations

Drawing from the findings on leadership, behavioral barriers, and technological integration in Saudi Arabia's agri-tech shift, several targeted recommendations are proposed. Policymakers should prioritize digital literacy and agri-tech training through local workshops and e-learning platforms, alongside region-specific incentives like subsidies for precision irrigation tools to support small-scale farmers. Behavioral science should be embedded within the Ministry of Environment, Water and Agriculture (MEWA) and extension services to counter psychological resistance and build trust in automation.

International stakeholders, such as FAO, ICARDA, and bilateral donors—should promote South–South cooperation through regional innovation labs, foster joint research with Saudi institutions, and support agri-tech forums for technology transfer. These actions would advance climate-resilient solutions and expand Saudi influence in agricultural diplomacy.

Further empirical research is needed on farmer attitudes across rural demographics and regional agri-tech comparisons with nations like the UAE and Israel. Diplomatically, Saudi Arabia should embed agri-tech narratives in global forums like COP and G20 while launching agri-diplomacy initiatives to shape sustainable development agendas across the Global South.

8. Conclusion

This research explored the global implications of Saudi Arabia's agri-tech adoption under Vision 2030, focusing on leadership, psychological factors, and precision irrigation technologies. The analysis revealed that Saudi Arabia is making significant progress in integrating digital agriculture and sustainable practices to address its food security and water scarcity challenges. Vision 2030, as a strategic national roadmap, has positioned the Kingdom to become a regional leader in agri-tech innovation by leveraging artificial intelligence, smart irrigation, and institutional reforms. These domestic innovations are reinforced by strong leadership from key ministries and emerging public–private partnerships that are accelerating the pace of transformation.The study further emphasized that psychological and behavioral barriers, such as resistance to technology, lack of awareness, and traditional farming mindsets, remain critical obstacles to widespread adoption. However, these can be addressed through targeted policy interventions and inclusive educational campaigns. Importantly, the research highlighted how Saudi Arabia's agri-tech model intersects with international relations. By aligning with the UN Sustainable Development Goals (SDGs), participating in global climate diplomacy, and contributing to South–South cooperation, Saudi Arabia is not only modernizing its agriculture sector but also enhancing its global standing.

In closing, Saudi Arabia's Vision 2030 serves as a powerful example of how domestic innovation can generate international influence. The country's efforts in agri-tech have potential to shape regional agricultural diplomacy, encourage collaborative innovation, and contribute solutions to shared global challenges—particularly in arid and water-scarce regions. The intersection of leadership, technology, and behavioral insights in Saudi Arabia's strategy offers lessons for both developed and developing nations pursuing sustainable agriculture in the face of climate change and geopolitical interdependence.

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