Exploring Agricultural Entrepreneurship in Tunisia and its Potential for Growth with AI

Policy Implications & Recommendations

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EXPLORING AGRICULTURAL ENTREPRENEURSHIP IN TUNISIA AND ITS POTENTIAL FOR GROWTH WITH AI: POLICY IMPLICATIONS & RECOMMENDATIONS
Case Study

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ABSTRACT

The paper explores how artificial intelligence (AI) can positively transform and develop Tunisia's agricultural sector, by highlighting existing agri-tech start-ups that leverage AI applications.

In Tunisia, the agricultural sector is considered a critical pillar of not only the country's economy but also its society. Yet, it faces significant challenges that put it at risk, especially due to the rising impacts of climate change. Therefore, this paper aims to provide an in-depth, holistic understanding of AI applications in agriculture startups in Tunisia through qualitative analysis, using semi-structured interviews with stakeholders related to the study's thematic focus.

The agriculture system in Tunisia focuses mainly on the production of water-intensive products such as wheat and barley. The sector consumes around 75 percent of total freshwater resources,[1] highlighting multifaceted challenges such as diminishing water resources, the increasing unpredictability of weather patterns, limited rainfall, and more frequent droughts. In addition, there are traditional farming methods,[2] particularly in rural areas, that are water-consuming, compounding the sector's vulnerability. The impact of global changes from the Russia-Ukraine war and regional and national economic and political constraints add to existing challenges for the sector. Regardless of numerous technological solutions, AI stands out in its capability to tackle the rising threats of climate change in Tunisia's agricultural sector. Through its capability to store and analyze millions of data points such as weather and soil conditions, AI can help in resource optimization, improve crop yield and disease detection, monitor soil, as well as provide many other benefits. By using accurate predictions derived from drone-assisted crop monitoring, farmers can be more strategic about their farming practices. They can choose the optimal planting and harvesting schedule, allowing crops to be planted and harvested at the most appropriate times. AI enables farmers to allocate resources much more efficiently so they can better manage water, fertilizers and labour, allowing for the reduction of expenses and waste.

As mentioned, the research applies qualitative analysis through semi-structured interviews with 3 stakeholders which are AI startups, including Firma Solutions and RoboCare, and an expert in agri-entrepreneurship. The results of the conducted interviews provide valuable perspectives and an initial understanding of AI applications for food security. The interviews highlight the importance of technological advancement through AI, the state of the current investment landscape and its existing challenges, as well as feedback from farmers currently engaged in using AI-powered solutions.

Under the scope of challenges posed by climate change, farmers in Tunisia exhibit a positive engagement in adopting technological advancement. The more they are exposed to the variety of solutions provided by AI-powered startups in Tunisia, they get to explore them further. The benefits range from early detection of pesticides and diseases to resource optimization. Therefore, the paper underlines the promising potential of AI in supporting Tunisia's agriculture in both the short and long term. Therefore, to realize this potential, cooperation between all stakeholders is paramount, from policymakers to agri-tech entrepreneurs and the agricultural community.

I.   INTRODUCTION

The agricultural sector in Tunisia has been undergoing a shift that is weakening the sector and diminishing its role, even though it has been a vital pillar of the country's economy. The sector's importance cannot be overstated — it accounts for 16 per cent of the workforce and 12 per cent of the country's GDP,[3] according to the International Trade Administration. Despite its importance, however, the sector is currently facing various challenges made worse by the increasing impacts of climate change. Among the challenges are the depletion of groundwater resources and the growing unpredictability of weather patterns.[4] Under this reality, the sector heavily depends on rainfed agricultural production,[5] and farmers use water-consuming techniques which are additionally limiting the ability of the sector to cope. As the negative effects of climate change increase, it is becoming more apparent that smart solutions are needed to adapt to these impacts.

In the past few years, entrepreneurship has become increasingly important in Tunisian policy.

1   Mahmoud, M., Figueroa, J., & El-Enbaby, H. 2018. The role of agriculture and agro-processing for development in Tunisia. *IFPRI Middle East and North Africa*. Retrieved from https://www.researchgate.net/publication/324983916_The_Role_of_Agriculture_and_Agro-processing_for_Development_in_Tunisia

2   Holm, H. M., & Santmyer, C. 1964. *Agriculture in Tunisia: Organization, production, and trade*. Agricultural Economists, Regional Analysis Division, Economic Research Service.

3   International Trade Administration. 2022. 'Tunisia–Country Commercial Guide', https://www.trade.gov/country-commercial-guides/tunisia-agricultural-sectors.

4   World Bank. 2022. *Climate variability, drought, and drought management in Tunisia's agricultural sector.* Retrieved from https://documents1.worldbank.org/curated/en/318211538415630621/pdf/130406-WP-P159856-Tunisia-WEB2.pdf

5   Food and Agriculture Organization of the United Nations. *Background and sites | Water efficiency, productivity and sustainability in the NENA regions (WEPS-NENA)*. Retrieved from https://www.fao.org/in-action/water-efficiency-nena/countries/tunisia/background-and-sites/ar/

The country ranked second in North Africa but lost 8 spots since 2023, reaching rank 91 globally,[6] according to the Global Entrepreneurial Index. Agri-entrepreneurship especially emerged as a source of innovation for Tunisia's agricultural sector. A study conducted by the European Union on the green economy in Egypt, Lebanon and Tunisia highlighted the lack of transparency at the administrative level in creating green businesses.[7] The findings highlight unnecessary hurdles for entrepreneurs and investors in green businesses.

In Tunisia, entrepreneurs in agriculture are applying AI as a tool to provide technological solutions in dealing with the impact of climate change on the sector.[8] AI-powered solutions can help in sustainable resource use which can lead to enhanced crop quality and water management techniques, which is essential in dealing with water scarcity and climate-driven resource limitations.[9] AI-powered data analysis can give farmers real-time insights, enabling them to make informed decisions and adapt their practices to address the challenges caused by climate change.[10]

A few smart innovations emerged in the last few years, encouraging the adoption of AI solutions to support agricultural practices. Among those innovations is a startup called Ezzayra. The company implemented sensors within irrigation pipes and the soil to ensure optimal irrigation.[11] This pioneering example emerged as a solution with tangible and effective results in supporting the Tunisian agriculture sector.

Therefore, this research paper aims to map existing applications of AI deployment in the sector and identify the challenges and opportunities (including the regulatory and policy issues) of AI in Tunisia. Following the FAO framework for food security, the aim is to highlight the challenges AI-powered startups in agriculture are facing under Tunisia's economic and political unrest. As a result, this paper will provide policy recommendations for the responsible use of AI in the agri-food sector in Tunisia, as well as recommendations to enhance the economic situation and policy support for existing agri-tech startups. This is achieved by conducting semi-structured interviews with agri-tech startup owners and an entrepreneurship expert.

1.1. Tunisia's Agriculture Overview

In addition to being a strategic and vital sector in achieving food security, the agricultural sector is considered a key pillar of the national economy in Tunisia[12] due to its contribution to achieving economic development. More than 75 per cent of small and subsistence farmers in Tunisia rely on agriculture as their primary source of livelihood.[13] Tunisia's fertile soil and its Mediterranean climate make it suitable for agriculture, even if there is little arable land given the country's small territory. The Sahara occupies 40 per cent of the country's surface area, and the remaining 60 per cent is considered fertile soil.[14] These characteristics have contributed to shaping the country's identity and glueing its social fabric. However, underneath this reality lies a sector in stress, caught in a changing climate and economic demands.[15] It is a sector marked by farming techniques passed down through generations, but climate change threatens the sector's future, making traditional farming practices no longer sufficient to ensure sustainability.

The agricultural landscape in Tunisia is significantly impacted by the increasing challenges of climate change, causing tangible losses and setbacks. With increasingly unpredictable weather patterns, including reaching the fourth consecutive year of drought, farmers are dealing with overlapping challenges affecting their crop yield and productivity. A World Bank report published in the Tunisia Economic Monitor in 2023 sheds light on how climate-related challenges are slowing down the country's economic recovery due to limited rainfall.[16] Farmers are increasingly growing uncertain as groundwater aquifers are depleting and rainfall patterns

6   Startup Blink. 2023. *Startup ecosystem of Tunisia | Startupblink.* Retrieved from https://www.startupblink.com

7   Ayadi, R., & Forouheshfar, Y. 2023. *Green economy in Egypt, Tunisia and Lebanon: Building an enabling environment for green entrepreneurs.* Retrieved from https://euromed-economists.org

8   Farouk, M. A. 2023. *With AI-powered drones and data, start-ups battle water crisis in Tunisia.* The Arab Weekly. Retrieved from https://thearabweekly.com/ai-powered-drones-and-data-start-ups-battle-water-crisis-tunisia

9   Javaid, M., et al. 2023. Understanding the potential applications of artificial intelligence in the agriculture sector. *Advanced Agrochem, 2*(1), 15–30. https://doi.org/10.1016/j.aac.2022.10.001

10   Utilities One. *Implementing artificial intelligence in agricultural decision-making.* Retrieved from https://utilitiesone.com/implementing-artificial-intelligence-in-agricultural-decision-making

11   AICTO. 2021. *Agriculture of the future* (Issue 3). Retrieved November 10, 2023, from http://www.aicto.org/wp-content/uploads/2021/04/Mag3_Smart_Ag_AICTO.pdf

12   World Food Program. 2021. *Tunisia's annual country report.* Retrieved from https://docs.wfp.org/api/documents/WFP-0000137881/download/

13   Dhehibi, B., et al. 2023. A contextual ICT model to explain adoption of mobile applications in developing countries: A case study of Tunisia. *PloS One, 18*(10), e0287219. https://doi.org/10.1371/journal.pone.0287219

14   UNCCD. 2008. *Social, economic & financing challenges of desertification: Barriers and constraints–Regional challenges in Africa: The case of Tunisia.* [PowerPoint presentation]. Retrieved from https://www.un.org/esa/sustdev/sdissues/desertification/beijing2008/presentations/aloui.pdf

15   Clima-MED. *Policy fiche: Managing the impact of climate change on agriculture.* Retrieved from https://www.climamed.eu/wp-content/uploads/files/Agriculture-CC-Tunisia-.pdf

16   World Bank. 2023. *Tunisia economic monitor: Migration amid a challenging economic context.* Retrieved from https://documents1.worldbank.org/curated/en/099838011032326761/pdf/IDU0b66401ea0d71b04eb00adb20a93d03ca730e.pdf

drastically decrease.[17] The reduced water availability is not merely a matter concerning crop yield, but the survival of communities who view farming as their main source of livelihood.

The Climate Risk Profile published by USAID in 2018 observes how climate stressors, such as rising temperatures, impact this sector's land use and viability.[18] Moreover, water scarcity is becoming a growing concern in Tunisia. According to the World Water Institute, Tunisia's ranking in extreme water stress is greater than 80 per cent, placing it in the extremely high water-stressed countries category.[19] A study in 2022 revealed that given the water stress situation in Tunisia, many areas are facing farming abandonment.[20] The Tunisian government is aware of the sector's role in the economy and has historically implemented a range of policies to support the sector. However, the focus has been on the subsidy model for fertilizers and irrigation equipment to boost productivity.[21] In recent years, policy shifts included introducing measures to encourage water conservation to combat the prolonged drought.[22] Despite this, there is still a lack of policy measures focusing on sustainable solutions and technological advancement for the sector.

With water stress and reduced rainfall, drought is increasing and negatively affecting farming activity. Consequently, the agriculture sector in Tunisia requires adaptation and mitigation efforts to support farmers in coping with the impacts of climate change. The paper aims to emphasize the importance of AI applications in agriculture to provide better support for farmers.

1.2. Technology Advancement and Challenges

Tunisia's changing climate requires major changes to the agriculture sector. However, one of the major challenges that is limiting change is the technological divide in Tunisia. With financial capacity, some large-scale farms began adopt-

17   Fanack Water. 2023. *Tunisia's vulnerable groups bear the brunt of climate change.* Fanack Water. Retrieved from https://fanack.com/climate/features-insights/tunisias-vulnerable-groups-bear-the-brunt-of-climate-change/

18   USAID. 2018. *Climate risk profile.* Retrieved from https://www.climatelinks.org/sites/default/files/asset/document/Tunisia_CRP.pdf

19   Kuzma, S., Saccoccia, L., & Chertock, M. 2023. *25 countries, housing one-quarter of the population, face extremely high water stress.* World Resources Institute. Retrieved from https://www.wri.org/insights/highest-water-stressed-countries

20   Soltani, L., & Mellah, T. (2023). Exploring farmers' adaptation strategies to water shortage under climate change in the Tunisian semi-arid region. *Environmental Management, 71*(1), 74–86. https://doi.org/10.1007/s00267-022-01604-z

21   World Bank. *The unfinished revolution: Chapter 9.* Retrieved November 9, 2023, from https://www.banquemondiale.org/content/dam/Worldbank/document/MNA/tunisia_report/the_unfinished_revolution_eng_chap9.pdf

22   Speakman Cordall, I. 2023. Water ban in drought-stricken Tunisia adds to growing crisis. The Guardian, Global Development. Retrieved from https://www.theguardian.com/global-development/2023/apr/05/water-ban-in-drought-stricken-tunisia-adds-to-growing-crisis

ing modern agricultural technologies. Whereas small farms, which make up a substantial portion[23] of Tunisia's agricultural sector, are still behind. There are economic pressures within the sector in terms of the need to maintain crop yields and ensure quality to compete in international markets as olive oil, citrus and vegetable products are exported to Europe.[24] But there is also the pressure on how to achieve the former in a manner that is economically viable for farmers. In this context, development infrastructure has been uneven as large-scale farms often benefit from better access to modern systems and technologies, while small-scale farms use traditional farming practices.

In 2018, Tunisia launched the Development of the National AI Strategy,[25] which established an artificial intelligence system to promote fair and sustainable development. While steps are still in the early stages, Tunisian startups are helping farmers cope with the climate crisis by using AI

23   Jouili, M. 2009. Tunisian agriculture: Are small farms doomed to disappear? Paper presented at the 111th EAAE-IAAE Seminar 'Small Farms: Decline or Persistence,' European Association of Agricultural Economists & International Association of Agricultural Economists, Canterbury, United Kingdom. Retrieved from https://hal.science/hal-01180353/document

24   Apia. 2023. *Fruit Logistica 2023.* Retrieved from https://www.apia.com.tn/medias/files/supports-promotionnels/fruit-logistica2023.pdf

25   Agence Nationale de la Promotion de la Recherche Scientifique. *National AI strategy: Unlocking Tunisia's capabilities potential.* Retrieved from http://www.anpr.tn/national-ai-strategy-unlocking-tunisias-capabilities-potential/
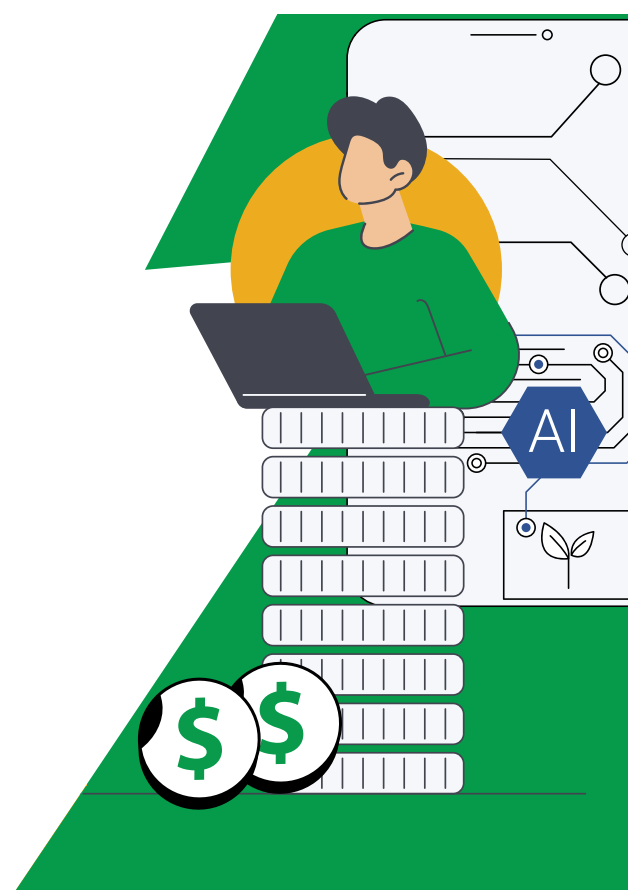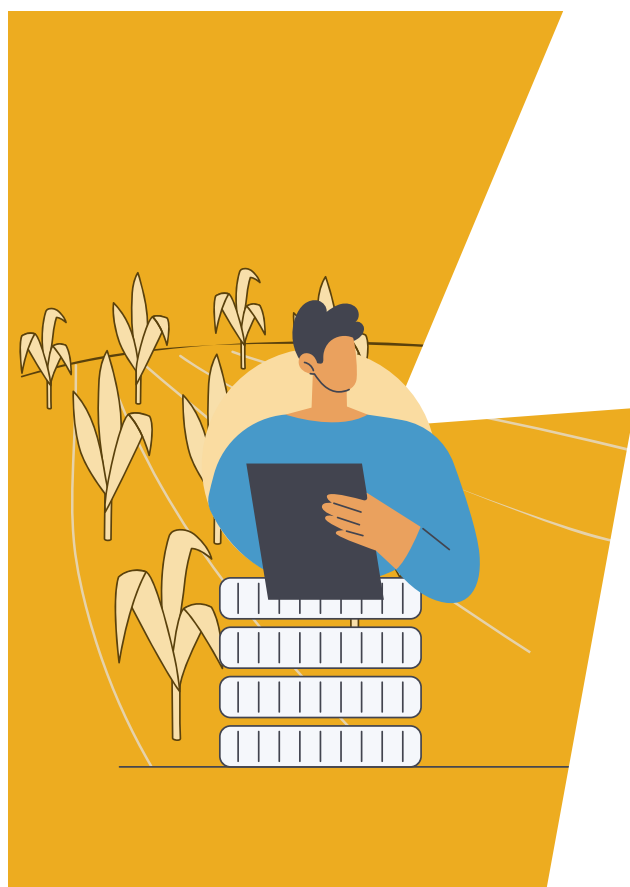
applications to modernize their farming practices and provide innovative tools and techniques. However, the launch of further steps under the National AI Strategy raises many questions as Tunisian President Kais Saied described AI as a threat.[26] Such a statement has the potential to hinder any progress related to AI, returning restrictive laws and measures instead of development. The statement of the president accuses AI of conspiring against humans, saying it threatens human existence. It portrays AI from a narrow lens and a one-sided reflection without taking into account that it is a tool in the hands of human intelligence which can be employed for achieving progress and well-being of humanity, as well as for the destruction of humanity. In this context, it is important to take into account how AI applications can be used negatively. This also applies to applications of AI in agriculture. For example, the limited ability to keep digital agriculture aligned with the farmers' thought processes, in terms of the traditional "philosophy" of farming that is based on historical methods that have been applied for decades. Moreover, there are security implications such as cyber-attacks, hackers' adoption of destructive strategies for digital programs and the sabotage of

26   *Restrictive AI Laws and "false Hope" Hinder Technological Innovation in Tunisia. Majalla.* Retrieved from https://en.majalla.com/node/300116

algorithms for agricultural artificial intelligence which result in crop losses.

There is a lack of regulations and standards tailored to AI applications in agriculture. Also, there is an absence of robust data privacy regulations which poses significant challenges.[27] In the context of the agriculture sector and activities, the challenges of the absence of clear data privacy regulations are related to the management of sensitive data collected from farmers. For example, information about land productivity and crop yield could be exploited if mishandled, or the ethical concerns around AI use in agriculture such as bias in algorithms,[28] which needs to be assessed through well-designed and defined policies. Biases in algorithms refer to favouring certain crops, methods and techniques in farming due to the processing of biased or incomplete datasets. In other words, if datasets used to train AI models predominantly focus on big farms in terms of production and high-scale technology, this does not take into account data related to small-scale farms. Favoring also applies in terms of providing datasets that focus on specific geographical locations that do not take into account developing countries such as Tunisia, resulting in biases which can have negative impacts on the production and viability of land as well as crop yields.

The political and economic ecosystem in Tunisia influences the adoption of AI-powered solutions in agriculture. Involving all stakeholders, including farmers, the private sector, technological solutions developers such as engineers, educational institutions, in addition to government institutions and policymakers, is key to facilitating the adoption of such solutions. End users here are farmers who have the potential to share their direct needs, challenges and opportunities with the aforementioned stakeholders. It is a loop that requires all stakeholders to engage and communicate to ensure that potential challenges are addressed from different levels, meaning investment, development, training and policy-making.

II. METHODOLOGY

2.1. Outline of Research Methodology

This research paper focuses on the agricultural sector in Tunisia and aims to understand AI applications in the sector through semi-structured interviews with key stakeholders. The re-

sults explore the impact of AI on agriculture, challenges of existing AI applications, identify policy gaps and measure the effectiveness of existing policy measures. The research process also includes reviewing secondary data sources through literature reviews of studies, policy papers and reports to complement the qualitative data from interviews.

In addition, the selection of interviewees was based on their expertise, professional relevance and involvement in the agricultural sector. As a result, the interviews included two agri-tech startups and one expert on agri-entrepreneurship. The interviews were semi-structured and varied in length, between 45 minutes to one hour, and were conducted in Arabic as well as English, all factors which provided flexibility and opportunities to address as many aspects as possible based on each interviewee's scope and experience. The selected agritech startups for this study were RoboCare and Firma Solutions. The two startups provided contrast as the former is an esteemed company with intensive experience while the other is relatively new to the market.

Moreover, in terms of logistics, the interviews were conducted fully online via Zoom calls and recorded upon the participants' consent. Once conducted, the interviews were transcribed verbatim and translated, if conducted in Arabic, to ensure accurate data interpretation. It is important to highlight that in this research, ethical considerations were given the utmost importance to ensure confidentiality and informed consent for recording. This research uses a rigorous and ethical methodology to provide concrete policy recommendations that would reflect the complex reality of AI integration in agriculture in Tunisia.

2.2. Research Limitations

Although the research period was conducted in a strict 5-month timeline, limitations have been identified. For instance, the initial selection process intended to include not only startups using AI solutions but also financial experts, policy experts, engineers, farmers and academics. However, the interviews resulted in a limited number of interviewees due to logistical constraints, given that they were conducted solely online. Although the 3 semi-structured interviews provided informative results, the number is low, and more interviews would have provided a better understanding of the topic under study.

27 Oleksy, K. 2023. *How Tunisia is embracing artificial intelligence for a brighter future.* Isp.Page. Retrieved from https://isp.page/news/how-tunisia-is-embracing-artificial-intelligence-for-a-brighter-future/

28 Dara, R., Hazrati Fard, S. M., & Kaur, J. 2022. Recommendations for ethical and responsible use of artificial intelligence in digital agriculture. *Frontiers in Artificial Intelligence.* https://doi.org/10.3389/frai.2022.884192

III. FINDINGS ANALYSIS

The following section provides a summary of the conducted interviews with the two start-ups and the agri-entrepreneurship expert. In this section, the data collected from interviews is processed and analyzed to identify and understand the obstacles AI-powered startups face, and also to identify the farmers' impressions and reactions to AI applications in the field. It is important to underline how AI, and in general technological advancement, is having a growing influence on Tunisia's agriculture sector. The interviewees all consider AI a crucial tool in addressing the threats imposed by climate change, which directly affect Tunisia's vital sector. The first startup interviewed for this research was RoboCare. It is considered an experienced startup in the field of AI applications in agriculture as it was founded by experienced researchers. The second interview was with Firma Solution, a relatively new startup that exemplifies the adaptivity of new businesses to include AI-based solutions in its work.

Overview of Agri-tech Startups in Tunisia

Founded in 2020, RoboCare works directly with farmers through their AI-powered solutions. Covering different regions in Tunisia, they surveyed farmers to better understand and identify common issues based on the diverse agricultural zones of the country. For example, the north is known for large-scale products, including citrus fruits, whereas the south is known for growing dates, and the center is known for olives. The services it provides include a variety of options such as disease detection alerts, irrigation plans and fertilization optimization recommendations. AI applications used by RoboCare are for image analysis from satellites and drones. The company relies on inputs from farmers they work with to improve the basic model and enhance its accuracy. In the interview, RoboCare highlighted that the data is validated through research and development units and research entities before commercialization.

The second startup is relatively new in the market and is called Firma Solutions. It is a startup specialized in the development of innovative solutions for arid regions with high salinity. The company began its journey in the field in 2022 and was officially labelled in May 2023. In its early stages, the startup didn't necessarily focus on AI but on the unavailability of electronic components as well as the associated high export taxes. This led them to develop their AI component in early 2023. Replacing some sensors with AI models and algorithms resulted in the optimization of manufacturing costs. Firma Solutions primarily covers the southern regions, including Djerba, Medinine, Gabes and Tataouine, as they urgently need the optimization of irrigation practices. The company's team is currently working on enhancing the accuracy of their framework by developing an advanced AI model to calibrate.

Although Tunisia has made notable efforts to promote technologically innovative solutions and entrepreneurship, there remains a need for a dedicated policy framework specifically targeting AI applications in agriculture. Tunisia can draw inspiration from countries with well-established AI policies, such as Canada's Pan-Canadian AI Strategy[29] or the European Union's AI Act.[30] Even if AI-powered solutions are emerging in the sector with advanced solutions, the absence of clear standards and regulations for AI in agriculture can widen gaps and heighten uncertainty for entrepreneurs and investors wishing to get into this domain. The EU AI Act, for example, is considered a comprehensive regulation that mitigates risks associated with safety and ethics. It has fundamental pillars that focus primarily on ensuring human agency and oversight, in addition to fairness, accountability and transparency. An example of an EU-funded project is AgrifoodTEF,[31] which was launched in January 2023 for a 5-year implementation period. The project's purpose is to combine AI and robotics solutions to help the agri-food sector. In the case of Tunisia, the absence of guidelines creates an environment of uncertainty and lack of clarity among entrepreneurs and investors, on whether to develop AI-powered solutions in agriculture or use existing solutions. The absence of clear and well-identified regulations creates space for uneven growth, as risk is higher along with the uncertainty. However, designing a tailored comprehensive AI framework for Tunisia is essential to ensure that it takes into account all specificities of Tunisia's social, economic and political structures.

29   Innovation, Science and Economic Development Canada. 2022. *Pan-Canadian artificial intelligence strategy–Home.* Retrieved from https://ised-isde.canada.ca/site/ai-strategy/en/pan-canadian-artificial-intelligence-strategy

30   European Parliament. 2023. *EU AI Act: First regulation on artificial intelligence.* Retrieved from https://www.europarl.europa.eu/news/en/headlines/society/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence

31   European Commission. *Digital success stories.* Retrieved from https://digital-strategy.ec.europa.eu/en/factpages/digital-success-stories-ai-testing-and-experimentation-facilities-agrifoodtef#:~:text=One%20example%20is%20the%20AgrifoodTEF,model%20to%20optimise%20sprinkler%20irrigation
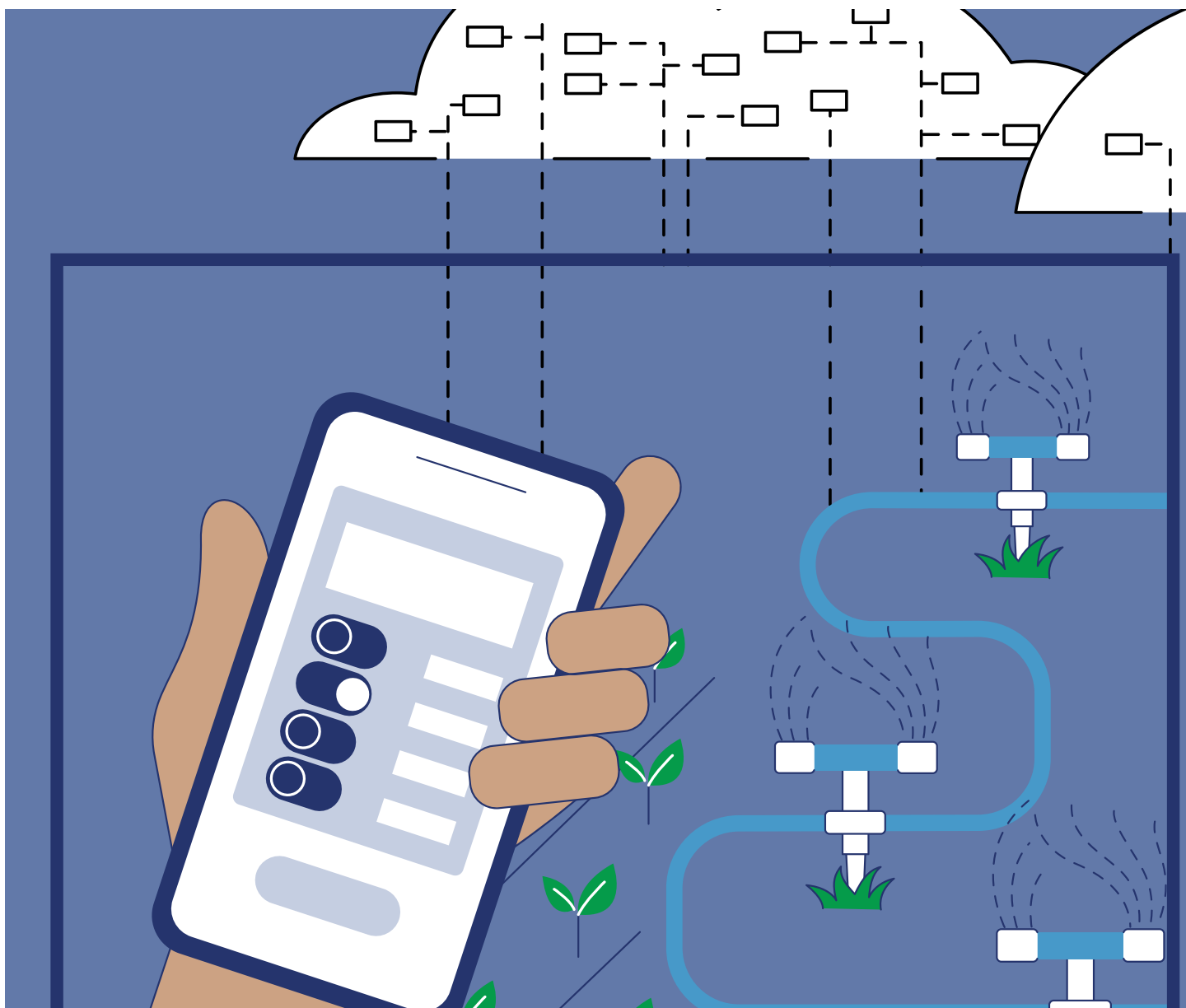
CHALLENGES AND OPPORTUNITIES

Based on interview results with startups, the following subsections will outline the challenges faced by the startups in their work and will showcase the impression of farmers who Robo-Care and Firma Solutions worked with:

Both interviewees highlighted the importance of data in implementing AI solutions. Through their work, they face challenges related to data accuracy and accessibility. There is an apparent lack of awareness and trust between service providers, startups and farmers. RoboCare mentioned that there is an awareness gap in addition to trust issues available when it comes to data sharing. Many farmers may not be familiar with the potential benefits of AI-powered solutions in agriculture, or they might have information and

understanding of what AI generally means as it relates to technology, and the use of big data in agriculture could be viewed as complex.

Trust concerns how data could be treated and used, for example, an issue of trust would be collected data being sold. It is critical to ensure clear and active communication between service providers and beneficiaries of the service. This will ensure that farmers understand clearly how their data will be utilised, stored and managed, and the data they will provide will be directly used for the benefit of their farms and sustainability.

One of the significant challenges which slow down any progress made is related to funding and investment. The interviewed agri-tech startups expressed challenges in securing adequate funding, specifically from local banks, as highlighted by the interview with the agri-tech entrepreneurship expert.
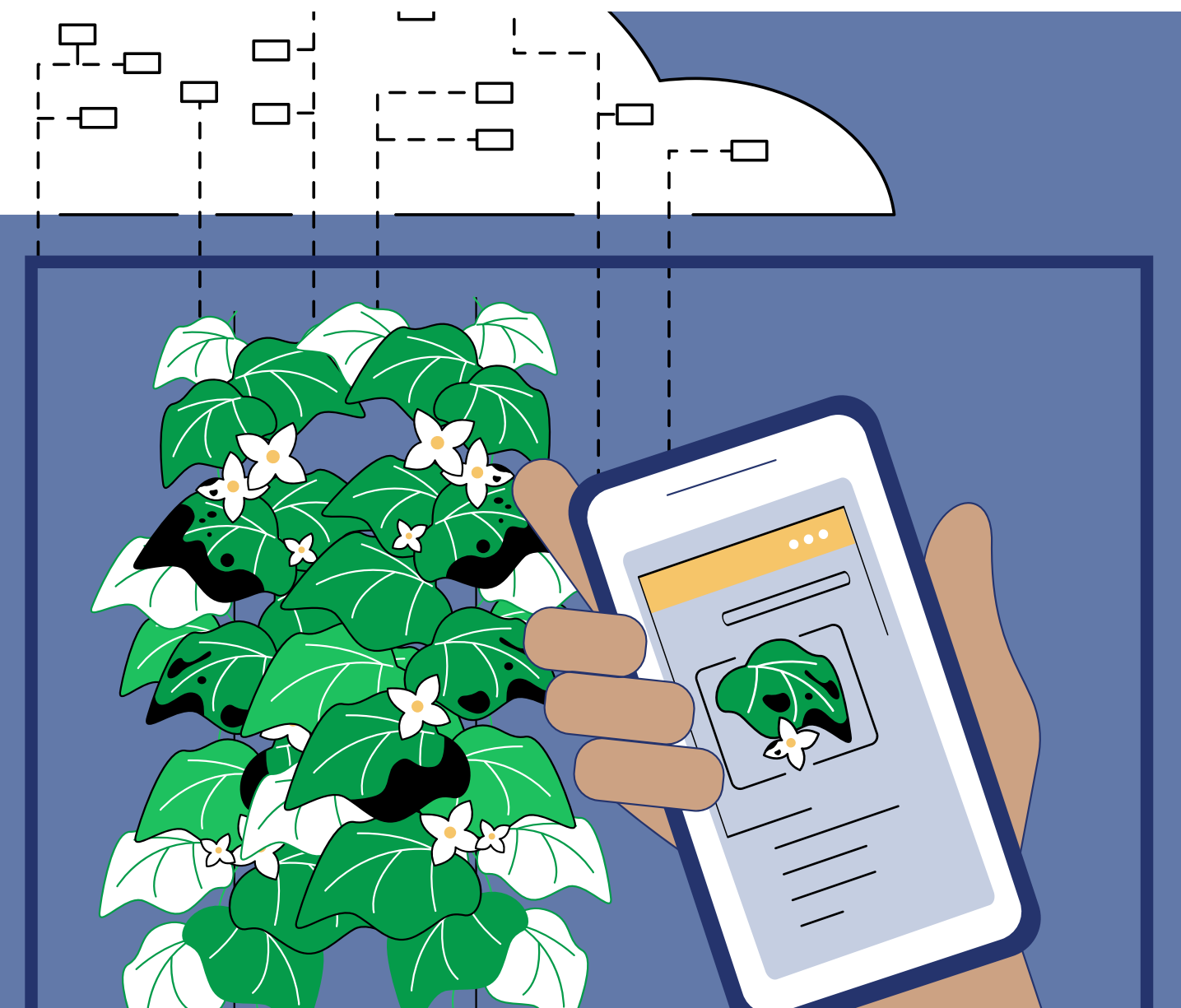
Firma Solutions stressed the limited technical exposure for farmers, as many are considered above the age of 50. Regulatory and policy challenges are highlighted in the interviews, specifically in terms of outdated administrative procedures. For example, the results highlighted how the registration process of AI-powered agri-tech startups is lengthy and can be complicated as the defined category for AI-powered agri-techs is not yet implemented, making the registration process lengthy and daunting.

The interviewees stated that even though farmers have limited technological knowledge when it relates to AI applications in agriculture, they have shown eagerness for the solutions provided in terms of reduced water consumption, early disease detection and decreasing pesticide issues. The interviews reveal the willingness of farmers to embrace the solutions. However,

RoboCare outlined how some farmers are still unwilling to adopt AI-powered solutions. There are numerous factors for farmers' unwillingness to adopt such solutions, such as the aforementioned financial constraints. Accessibility to AI-powered solutions often requires large-scale and commercial farms with the financial capacity to invest in these solutions, but Tunisia has a high share of small-scale farms that do not necessarily have the financial capacity to invest. Also, another interpretation could be connected to the social factor and cultural importance of farming, as it is considered a part of the cultural heritage of Tunisian society and is passed down from one generation to another. This can create an attitude of resistance to change and a lack of acceptance of external or unfamiliar solutions, which could be perceived as aiming to change the landscape of traditional agriculture in the country.

Enhancing Policy Role

Activating the role of policies is essential to motivate farmers to adopt such solutions. The interview with RoboCare underlined the lack of awareness around the impacts of climate change by some farmers, which also burdens existing technological advancement, awareness, understanding and capabilities. A lack of awareness of the effects of climate change is dangerous in light of the challenging reality of the agriculture sector. This makes it more challenging to persuade farmers to adopt solutions as they don't see any abnormality, and therefore the urgency, of the situation. Another point is the challenges farmers face regarding smartphone accessibility.

Results show that due to limited job prospects, advanced degrees such as PhDs are highly sought after by Tunisian graduates. This can be further observed as an opportunity to use the skills developed in tackling local challenges. This is the case with RoboCare, as the founders are PhD holders and have used their skills for the benefit of Tunisia's agriculture. Nonetheless, interviews revealed how international entities such as GIZ and Expertise France provide substantial support and assistance to promote knowledge sharing through training programs and workshops. RoboCare also highlighted that their initial funding source was out of pocket, but with time and proven results, they have gained trust and received grants, mainly from international entities. Although existing accelerators and incubators in Tunisia assist AI-solution-oriented start-ups, there is no dedicated entity that could provide comprehensive and AI-oriented support.

Interview results highlight the active promotion of technological advancement in Tunisia, including research and development (R&D) university laboratories and the active support provided by international bodies. However, from a local perspective, public organizations such as Agence de Promotion des Investissements Agricoles (APIA) -show the importance of the government in promoting agri-entrepreneurship. This involvement in terms of support could still be enhanced to involve public entities, in terms of providing financial support, consultations and monitoring programs.

In addition, the research identifies critical challenges that negatively affect the green economy and the development of agri-tech startups. Challenges remain at the public administrative level in terms of the categorization of newly created green startups, as there is a lack of the correct categorization options which can delay and prolong registration, often rendering it an arduous process.

Successful examples of AI-powered startups such as CIBEX, Ezzayra and RoboCare positively reflect a powerful venture in Tunisia. Their success is shown in how they managed to create job opportunities, build trust with customers, generate profit and fill the service gaps in the market. They show a vital role in the industry and illustrate the need to have more AI-powered startups. From an end-user perspective, challenges still exist in terms of age demographics, primarily among farmers above the age of 50, according to Firma Solutions. Raising awareness of technological advancement using tailored approaches is crucial.

Another major aspect in terms of challenges is financial support. There is a lack of financial accessibility and technological follow-ups, specifically for smallholder farmers. These multifaceted challenges faced by the farming community reveal the complexity, but also the opportunities, to enhance the sector by focusing on smallholder farmers. Yet, results reveal insufficient investment in the green economy, reluctance from local banks to provide support to green businesses and investment caution in Tunisia in comparison to other countries in the region. Given the outlined challenges and analysis, the following section will provide holistic policy recommendations.

POLICY RECOMMENDATIONS

1) **The development of AI-specialized incubators:**
   The research results highlight the absence of AI-specialized entities. The development of AI incubators could provide a nurturing environment for innovations, which would provide mentorship, technical support, as well as tailored assistance and resources specific to the sector. Such incubators could serve as a space for innovation, where cross-disciplinary knowledge from universities, industry experts and tech pioneers would be accessible and therefore provide solutions for agricultural challenges through the applications of AI.

2) **Targeted awareness and capacity building initiatives:**
   The interviewed AI-powered startups proved that technical advancement requires addressing the knowledge gaps among the end-users (farmers). Policies should include effective awareness programs, capacity-building workshops and training programs that use tailored language to allow farmers to familiarize themselves with the advantages provided by AI

as well as climate change risks. This will foster a receptive environment for technology adoption and better integration of these solutions.

3) Providing financial incentives for green investment:

Policy intervention could help ease the challenges around securing investment for AI-powered green technologies. For example, risk sharing and dedicated funds could be used to attract domestic and international capital, which could mitigate the investment risk in Tunisia's green sector.

4) Developing a clear framework for green businesses:

Results revealed administrative issues in the lack of categories for green businesses. Therefore, policies could provide support in terms of crafting a clear legal framework that recognizes the role of green businesses categorically. This would enable the government to streamline processes and provide clarity for both investors and entrepreneurs.

5) Public-private partnership:

The successful implementation of AI in agriculture hinges on continuous innovation. Therefore, policies fostering research and development collaborations could accelerate the creation of cutting-edge solutions. By incentivizing partnerships between private enterprises, academic institutions and government bodies, a symbiotic ecosystem can be cultivated where theoretical research is rapidly converted into practical, field-ready technologies.

6) National data governance framework:

Data is the lifeblood of AI applications, yet concerns over privacy and trust can impede its integration. A national data strategy that balances privacy with accessibility could act as regulatory support, ensuring that data collection benefits all stakeholders. By setting clear standards for data usage, the policy could enhance trust among farmers and facilitate a more robust data-sharing culture.

7) Adaptive policies for diverse agroecological zones:

Encouraging innovation specific to each region, such as the development of salinity-resistant crops or the implementation of precision irrigation in arid zones, could significantly enhance the utilization of AI in these complex environments. By em-

phasizing region-specific solutions, agricultural practices can be optimized for greater efficiency and productivity while minimizing potential adverse environmental impacts.

8) Promoting sustainable agricultural practices:
Under the impacts of climate change, policymakers should prioritize and advocate for AI-powered solutions, such as smart water management systems and resource optimization through remote sensing, drones and Internet of Things (IoT) sensors, which could improve crop yield and ensure optimal use of resources, like more efficient water use.

9) Technical infrastructure for all stakeholders:
With the lack of adequate internet access in rural areas, governments must invest in developing technical infrastructure to allow farmers better connectivity to AI-powered tools, ensure equitable access and overcome the existing digital divide. This can help bridge the social gap and reduce inequalities.

10) Regulatory framework:
Policymakers should work toward establishing a regulatory framework that sets standards for data privacy, technology safety and ethical AI use. They must ensure that regulations are flexible enough to accommodate evolving AI technologies.

11) Ensuring technical education is aligned with industry needs:
An analytical look at the technical prowess of companies like RoboCare reveals an opportunity in educational policies to positively impact the sector if curriculums are aligned with industry requirements. By integrating AI, IoT and big data analytics into specialized curriculums, the education system can prepare a future workforce well-equipped to drive the Tunisian agricultural sector's growth through technology.

CONCLUSION

Under the FAO framing for food security, which aims to apply four cross-sectional accelerators including technology, data, innovation and complements (i.e. governance, human capital and institutions), this paper has undertaken a comprehensive exploration of the current role of AI in supporting the Tunisian agricultural sector through interviews with key stakeholders working on applying AI in their innovations. The paper shows to an extent the capabilities of AI to improve the sector's resilience, enabling it to mitigate and adapt to the impacts of climate change effectively while maintaining a key livelihood source for many Tunisians.

Nonetheless, realizing this potential requires concrete efforts and political will from various stakeholders to incentivize implementation and create opportunities for better and safer employment of AI. Addressing legal frameworks and intellectual property rights in AI technologies for agriculture is crucial to promoting innovation, ensuring data privacy and building trust in the AI ecosystem. Developing clear, ethical and balanced legal frameworks can contribute to the sustainable growth of AI-powered agriculture in Tunisia. These frameworks should strike a balance between protecting innovation and safeguarding the interests of farmers and society at large. Implementing the right policies can support the development of this sector, contributing to and reflecting global efforts in achieving resilient agricultural systems.

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