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新農業革命：智慧農業科技，關於產業投資機會的研究

The Next Agricultural Revolution: Smart AgTech, A Study on Sector Investment Opportunities

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The Next Agricultural Revolution: Smart AgTech

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摘要

隨著全球對氣候變化影響的認識增強，人們逐漸開始認識到冰帽和冰川融化等問題的重要性。然而，更迫切的問題是全球糧食安全。農業領域深受氣候變化和污染的影響。而極端天氣、氣候模式的變化以及淡水源的減少都對農業帶來了重大的挑戰。與此同時，授粉昆蟲的減少使這些問題更為嚴重。同時，全球城市化的趨勢使農村地區被遺棄，導致經濟和社會的不平等。本論文強調了這些互相連接的全球挑戰，並為農業領域提出一個新的投資機會。這項研究設想透過專注於電信業以及農村社區持續的投資不足，來促進未來的增長。本論文採用了混合方法，結合了來自行業報告的定量數據和來自定性期刊和研究的見解，以行業內可用的數據得出全面的結論。儘管存在固有的挑戰，但本論文確定了農業領域內的一個可行的投資機會。此外，它強調了解決這些社區歷史性問題所需的多方合作方法的重要性。公共、私人和政府必須團結起來，才能解決圍繞全球糧食安全和農業可持續性的複雜問題。這項研究強調了確保糧食安全和保護農業未來的協調努力的迫切需要。電信行業準備好推動變革，作為全球挑戰和可持續增長機會之間的橋梁。這些變革將會為人類帶來歷史上第四次農業技術變革的頂峰。

關鍵詞：智慧農業、農業科技、ESG、農業、糧食安全、電信

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Abstract

As global awareness of the impacts of climate change grows, issues such as polar ice caps and glacier melts are increasingly recognized. However, a pressing concern closer to home is global food security. The agricultural sector is profoundly affected by climate change and pollution, with extreme weather events, shifting patterns, and dwindling freshwater sources posing significant challenges. Meanwhile, the decline of pollinating insects compounds these issues. Concurrently, global urbanization trends are causing rural areas to be forsaken, leading to economic and social disparities. This dissertation highlights these interconnected global challenges and presents a novel investment opportunity within the agricultural sector. This research envisions a pivotal role in fostering future growth by focusing on the telecommunications industry and the persistent underinvestment in rural communities. A mixed methodology was employed, combining quantitative data from industry reports with insights from qualitative journals and studies to draw a well-rounded conclusion with the available data in the industry. Despite its inherent challenges, the thesis identifies a viable investment opportunity within the agricultural sector. Furthermore, it underscores the importance of a collaborative multi-stakeholder approach to solving the issues that historically plague these communities. Public, private, and governmental entities must unite to address the complex issues surrounding global food security and agricultural sustainability. This research emphasizes the urgent need for coordinated efforts to ensure food security and safeguard the future of agriculture. The telecommunications industry stands poised to drive transformative change, serving as a bridge between global challenges and sustainable growth opportunities. These ultimately will result in the culmination of the fourth wave of transformative agricultural technology shifts in human history.

Keywords: Smart Agriculture, Ag-Tech, ESG, Agriculture, Food Security, Telecom

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List of Abbreviations

AI	Artificial Intelligence
ARS	Agricultural Research Service
BCG	Boston Consulting Group
CAGR	Compound Annual Growth Rate
CRS	Congressional Research Service
EPA	Environmental Protection Agency
ERS	Economic Research Service
ESG	Environment, Social, Governance
FAA	Federal Aviation Agency
FBN	Farmers Business Network
FCC	Federal Communications Commission
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSMA	Groupe Speciale Mobile Association
IoT	Internet of Things
IRS	Internal Revenue Service
Kbps	Kilobytes per second
Mbps	Megabytes per second
ML	Machine Learning
NASS	National Agricultural Statistics Service
NIFA	National Institute of Food and Agriculture
NRECA	National Rural Electric Cooperative Association
NRTC	National Rural Telecommunications Cooperative
NTIA	National Telecommunications & Information Administration
NYSE	New York Stock Exchange
PA	Precision Agriculture
R&D	Research and Development
REA	Rural Electrification Administration
Smart AgTech	Smart Agriculture Technology
UAV	Unmanned Aerial Vehicles
UN	United Nations
UN FAO	United Nations Food & Agriculture Organization
UN SDG	United Nations Sustainable Development Goals
US	United States of America
USD	United States Dollar
USDA	United States Department of Agriculture

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Chapter 1: Introduction

1.1 Research Background

The global political landscape currently focuses on completing UN SDG goals and rethinking corporate valuations based on metrics created to be an all-encompassing measure of corporate ESG impacts. These ESG scores are designed to analyze the organizations' internal business activities and considerations for their entire supply chains, combined with their impacts on the direct communities they operate within. As this trend continues to grow and more industries feel the pressure to boost their ESG scores from both their shareholders and regulators, there is a growing sense that investing activities could buoy scores and show positive intentions to the market. This practice makes the agricultural industry look like an increasingly attractive opportunity to invest in positive impacts while finding ways to generate more value from both technological and investing standpoints. Since the Agricultural industry very closely interacts with the local environment in both positive and negative manners (Reffell, 2022), impacts made here can be easily attributed to increasing ESG investment scores and give a variety of industries potentially huge untapped markets to invest in and create new value for shareholders. The space is ridden with possibilities to improve upon aging technologies. At the same time, it still grapples with how to bring it up to speed with its increasingly interconnected neighbors in the world's growing cities. The IoT revolution has yet to find a strong footing in rural communities due to the multitude of challenges to operate in these regions. Still, as technologies improve and investors with cash are looking for ways to make a positive impact, society could be on the cusp of another agricultural revolution. Whether focusing on finding new treatments that may reduce the need for water usage, utilizing better seed technologies that are more resilient to pests and drought, building networks of sensors to generate more useful data for farmers to analyze like never before, or investing in robotics and self-driving technologies, all are part of the grander

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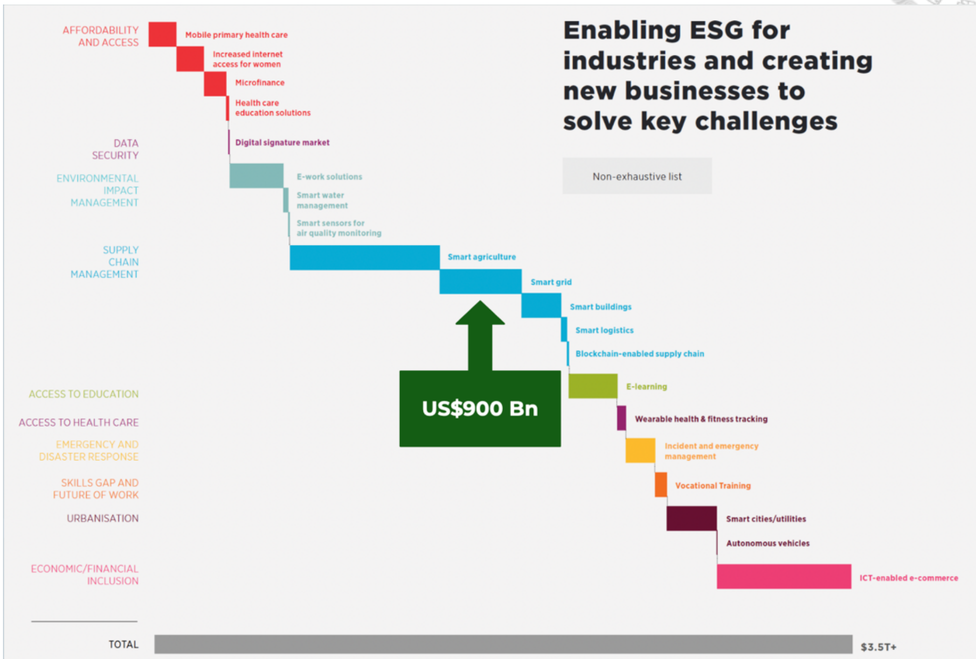
puzzle to reduce human impacts on the environment while also sustaining necessary food supply for our growing populous.

Figure 1: BCG Report on Telecom Industry ESG Investment Opportunities



Source: (2020, March). *Future of Mobile | How Telcos can Unlock New Value Through Total Societal Impact*. GSMA. Retrieved November 30, 2022, from https://www.gsma.com/betterfuture/the-future-of-mobile

These technologies can also all be attributed as potential positive ESG investment opportunities for savvy investors and organizations or as regulations continue to shift needed investments and reporting regarding corporate ESG impacts worldwide. There is a growing industry budding around ESG reporting, scoring, and analysis, and shareholders, governments, and other stakeholders are paying attention to the findings. In a recent BCG report (GSMA: Future of Mobile, 2020), the consulting firm noted a potential market opportunity of roughly 3.5 trillion USD for Telecommunications providers alone by investing in new sectors attributed to positive ESG investing, with smart agriculture investments earmarked as an approximately 900 billion USD market opportunity as its slice of the noted opportunities. This makes sense since telecommunications infrastructure, connectivity, and network operations are all critical nodes to advancing high-tech agriculture solutions

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worldwide. Still, traditionally rural communities are overlooked due to their lower populations and, thus, higher per-user costs to operate (USDA, 2013). While rural communities, due to their higher costs per user, are not as attractive as investing in large projects in metro areas, climate changes and challenges in the agriculture industry are necessitating a rethink of what is needed to make farms, and thus conversely, rural communities, more efficient. These industry rethinks will allow for new technologies to enter the space, infuse cash into underserved or overlooked communities and potentially encourage more established companies and start-ups to focus on the fledgling Smart AgTech industry, ideally finding new ways to minimize impacts on the environment and maintain healthier local ecosystems and food supplies for our communities.

1.2 Research Motivation

This paper is motivated by a perceived opportunity to positively impact multiple industries through investments focusing on improving one critical industry, Agriculture. There has been an increase in investments in the space by large players and entrepreneurs; however, much more can be done. Focusing on implementing Smart AgTech IoT solutions requires a multi-stakeholder approach across multiple industries, making the market more difficult for many. The lynchpin in the sector is historical under-investment by telecommunications providers in rural agricultural centers worldwide. As the world thinks more about the impacts we have across supply chains, it can be said that by not investing in rural communities, we have backed ourselves into a corner. As we focus on reducing emissions and other ESG initiatives, supply chain disruptions and issues come into play. While the Agricultural industry is a major contributor to various global pollution indexes, it is also essential to maintain or improve production rates to feed our growing masses. Current estimates place the global population at over 10 billion by the early 2050s, up from 8 billion (as of November 2022), based on potentially underestimated birth rates (De Clercq et al.,

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2018). This massive population increase will put immense pressure on the global agricultural and food production markets and will be further complicated by the effects of climate change. It is expected that global food production needs to increase by 70% to feed the populous in 2050 while "using less energy, fertilizer, and pesticide, … lowering levels of GHGs and coping with climate change" (De Clercq et al., 2018).

The Agricultural industry and, for this dissertation, Smart Agricultural Technology is poised to bring major changes to the world if we can work around the hurdles faced along the way. As a society, we may be on the precipice, or some might argue, in the middle of a fourth agricultural revolution. These changes will have massive implications for everyone globally, so this discussion will position Smart AgTech as "The Next Agricultural Revolution."

1.3 Research Goal

The world faces several congruent challenges in the coming years surrounding Global issues such as Climate Change and Food Security. We are increasingly turning towards ESG initiatives to meet them head-on. Agricultural production is often linked to its negative impacts on the environment. However, there are ways to improve this image or utilize the industry as a launchpad for changes.

As governments and organizations worldwide seek to make positive impacts on climate change and look for areas to increase investments, agriculture looks like a winner. It certainly isn't as flashy or visible as pushing the electrification of vehicles; however, agriculture is necessary to ensure our markets stay stocked, and this paper will discuss why this overlooked area of the economy could very easily house a looming disaster if we fail to act. This research will examine this transition and ways to incentivize increased investments to secure a better tomorrow. It will consider existing studies and data in a mixed methodology and conclude with reasonable recommendations on areas to focus on to make the largest impact.

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1.4 Research Objectives

This thesis comprises six main chapters; Chapter 1: Introduction, Chapter 2: Literature Review, Chapter 3: Research Methodology, Chapter 4: Research Findings, Chapter 5: Discussion, and Chapter 6: Recommendations. An Appendix and Bibliography, including source information and additional resources relevant to the findings herein, will follow all of these.

The Literature Review, which is the focus of Chapter 2, will provide additional background to the Smart Agriculture market and the discussions started in Chapter 1. This chapter will set the stage for further discussion throughout the remainder of this thesis. In Chapter 3, an introduction to the mixed research methodology is utilized to build on the discussions in the first chapters. Chapter 4 will add further context to this dissertation by adding secondary research and datasets into the Smart Agriculture industry discussion. The aim of Chapter 4 is to hone the ideas which prompted the investigation therein; ideally, the findings will ultimately support the discussions started here.

Further discussion of the data introduced in Chapter 4 will continue in Chapter 5, focusing on introducing the data uncovered in research and formulating a summary of the findings. A discussion of unexpected results will be included in more detail. All these discussions will lead to a conclusion and any recommendations derived from findings throughout the process within Chapter 6. Additionally, relevant information or data will be added to the Appendix section following Chapter 6, and all source materials from the research completed as a part of this thesis will be listed in the Bibliography section.

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Chapter 2: Literature Review

In this chapter, several components of the Smart Agricultural industry will be discussed, alongside initiatives at the organizational and investor levels up to governmental policy implications and global initiatives. These will be summarized in a manner that will facilitate further discussion within this dissertation and will aim to foster a broader understanding of the Smart Agriculture industry as it stands today.

2.1 Smart Agriculture

Understanding what encompasses a sector is an important step in industry research. Smart Agriculture, or Agriculture 4.0, is an overarching term that essentially calls out the IoT revolution on farms. However, many would categorize it as “precision agriculture” or “precision farming” first (This New Approach to Farming Is Transforming Agriculture While Protecting the Environment, n.d.). While this is fitting, the industry stands to make a massive impact on our world. Much in the same way that human discovery of how to farm in the first place started thousands of years ago, how humans discovered how to reorganize farmland in the 17th century or discovered chemical fertilizers and pesticides that could significantly increase crop yields alongside heavy machinery in the mid-1900s, Smart AgTech will revolutionize how we produce and distribute our food in every way. The industry is partly born out of natural progression and necessity. The pollution-driven effects of climate change are causing larger, more intense storms and shifting seasonal patterns, which majorly affect the agricultural industry (US EPA, 2022).

Meanwhile, increases in urbanization have caused the children of agricultural families to leave for the economic opportunities that metropolises bring along with their growth (Lloyd, 2019). Urbanization in the United States accounted for an increase of 6.4% of the population between the 2010 and 2020 National Censuses, even with changing the definitions of urban and rural communities, which resulted in the number of rural areas increasing

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congruently, by definition (US Census Bureau, 2023). An aging population of owner-operators, who are generally less prepared to adopt newer technologies, is now forced to deal with new environmental regulations, less help, and rampant underinvestment in infrastructure and education in these rural communities. At the same time, the expected benefits of Smart Agriculture implementations are an anticipated 7.5% lower risk of food security issues, better traceability and accountability surrounding food production and safety, 40% less fuel usage, 20-50%+ lower water usage, and up to an 80% reduction in chemical use (USDA, 2019). Unlike many other industries, these factors lead to a market opportunity: an industry with growing and needed investments for improvement while existing as a necessity for human survival.

2.2 ESG and UN SDG Initiatives

There is plenty of talk worldwide about ESG and UN SDG initiatives, but what are they, and what do they aim to accomplish? Discussion on IoT revolutions in any market can only happen with first understanding these two critical frameworks.

ESG, or "Environment, Social, Governance," typically aims to grade a specific organization's impact on society more holistically than its predecessor, SROI. Where SROI was centered around driving investment returns based on societal impacts, ESG focuses on other ways organizations impact the broader market, from environmental impacts to implications on society and their employees up to the executive suite and practices therein (Brock, 2022). These standards are levied based on company performances and attributed to scores, which investors utilize to determine whether companies align with their values. More organizations are considering ways to improve ESG scores and, as a result, their perceptions as more responsible actors within the broader economy (ESG Evaluation | S&P Global Rankings, n.d.). A unique aspect of how organizations factor in their ESG practices is factoring in their investments. So, for instance, if the organization invests in a green initiative,

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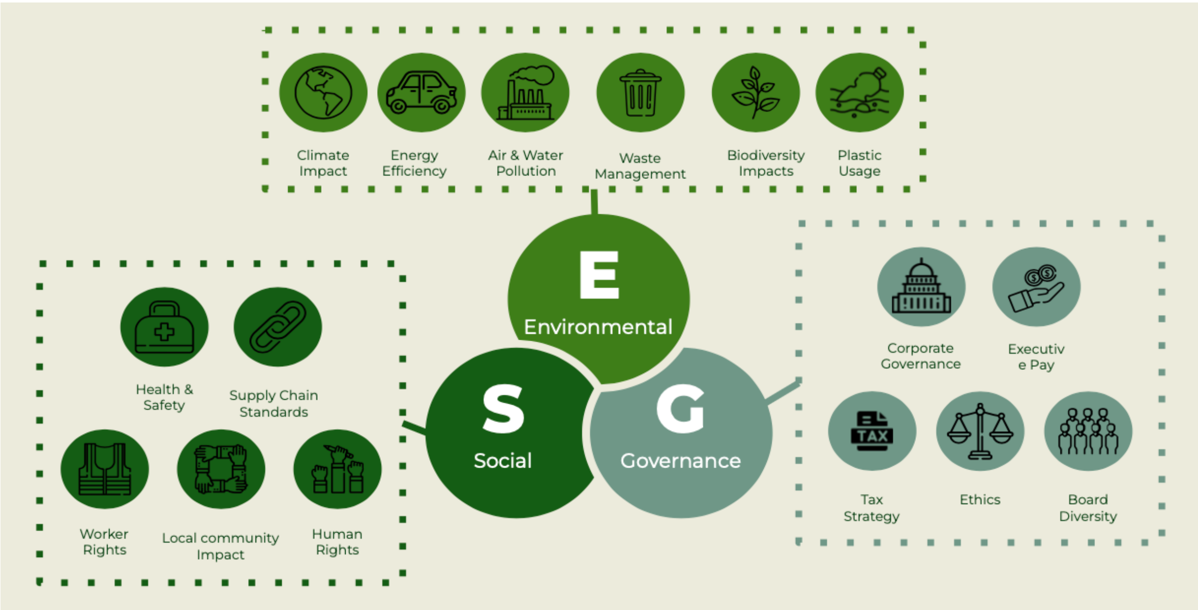
it can attribute this activity as a positive ESG consideration on its reports to shareholders. These reports inform shareholders of the company's efforts as a more positive actor worldwide. Furthermore, recent McKinsey US consumer studies have shown that even individual products making positive "ESG claims averaged 28 percent cumulative growth over the past five years, compared to 20 percent for products that do not make such claims" (Bland et al., 2023).

Figure 2: ESG Diagram



Source: Harnden, R., Hoang, N., & Lafond-Wise, L. (2022, May 27). Smart Agriculture as a Social Impact Investment Opportunity [Unpublished presentation]. College of Management, GMBA, National Taiwan University. Retrieved November 30, 2022

Smart Agriculture and ESG investing are in lockstep as each requires the other. Advanced technologies and IoT solutions utilized to bring Smart Agriculture as an industry to life promote better use of our limited resources. Precision farming is a wonderful example of this idea; in this style of agriculture, smarter interconnected irrigation systems reduce water waste by only watering when and where plants need water rather than broadcasting water across an entire area. Smart Agriculture and ESG tie together in less thought-of ways as well. Improving monitoring and care of livestock and improving their lives on-farm can tap into

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the social portion of ESG investment considerations. Likewise, Smart Agriculture can also be attributed to positive Governance scores by improving decision-making through data usage while ensuring accountability in operations. Overall, there are many avenues in which focusing on ESG and Smart Agriculture together can lead to a much stronger, more sustainable food supply chain, which is a positive outcome for everyone involved.

Figure 3: 2019 UN SDG Poster

Source: United Nations. (2015). *The 17 Sustainable Development Goals*. United Nations. Retrieved December 15, 2022, from https://sdgs.un.org/goals

Conversely, UN SDG initiatives surround 17 "Sustainable Development Goals," described by the UN as "a call to action for by all countries – developed and developing – in a global partnership … recogniz[ing] that ending poverty and other deprivations must go hand-in-hand with [other initiatives] … all while tackling climate change…" (United Nations, 2015). These initiatives take a broader look at society at a global scale and are typically discussed at a national scale in individual nations. While ESG is considered at the scale of an organizational level and designed to inform individual investors, UN SDGs are intended to bring the world together by considering factors that drive people to less sustainable practices.

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When considering UN SDGs versus the goals of Smart Agriculture solutions, it is obvious that many of the areas of consideration in Figure 3, above, could be affected by improvements made in the Agricultural industry. Some of the most notable examples would be SDG 2, SDG 12, SDG 13, and SDG 15. Both SDG 2 and SDG 12 are affected by improving data usage and precision farming to stabilize food supply and reduce wasted resources through irrigation or fertilizer usage. SDG 13 focuses on combatting climate change, and Smart Agriculture could lower emissions and improve resource management that could affect this goal. SDG 15 will also see an effect of more efficient usage of resources and technology and the chance to reduce the impacts farming can have on biodiversity and the overall ecosystem.

While these two initiatives certainly overlap in areas, they are not always utilized side-by-side or by the same people, and each deserves its distinction. ESG scores and reports are designed to guide investment decision-making while factoring in wider impacts on the world. It is a principle-based approach to a market-driven concept at the individual level and has shown much success in mitigating risks and driving value. The ESG investing market has grown by over 18% in recent years (GSMA: Future of Mobile, 2020). UN SDGs are significantly broader in scope and encompass a wider set of the world, from civil society to business and governments. These are designed to be a global framework to partner UN member nations in a common cause to improve the world we all live in. Even with their differences in focus or scale, the two are interwoven and complementary in nature. Organizations or entire markets focusing on improving operations through their ESG scores will likely also assist in the global push to achieve the 17 UN SDGs.

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2.3 Government Research & Policy

In the same way that the UN has been encouraging member nations to think about their impacts on people and the environment through their SDG initiatives, individual governments also play critical roles within their borders in setting the tone for developing and implementing new technologies such as Smart AgTech solutions. This is accomplished through funding academic and private research, direct research, and policy generation. This role falls to the USDA and its ERS and ARS divisions in the United States. The ERS focuses on the impacts of new agriculture technologies, while the ARS researches the development of new technologies and data models. Both divisions of the USDA, alongside the NIFA, assist with funding these programs and encouraging farmers to implement these new technologies. Congress and the President in the US can set up Agricultural policies and programs through the US Farm Bill. This legislation is a "multiyear law that governs an array of agricultural and food programs" (Johnson & Monke, 2023), the last of which was signed into law by the Trump administration in 2018. The Farm Bill is updated every five years and has received updates since its introduction in the 1930s. For this discussion, a copy of the most recent budget table and pie chart for the 2018 Farm Bill can be reviewed in Figure 4 below. This budget breakdown shows that Rural Development is showing a negative 2.326 billion USD in spending between 2019 and 2028, which according to the CRS, results from having "no current programs with baseline" data (Johnson & Monke, 2023). Public investments in the 2018 Farm Bill in research and development of new technologies in AgTech are shown to be north of 1.2 billion USD over the same period.

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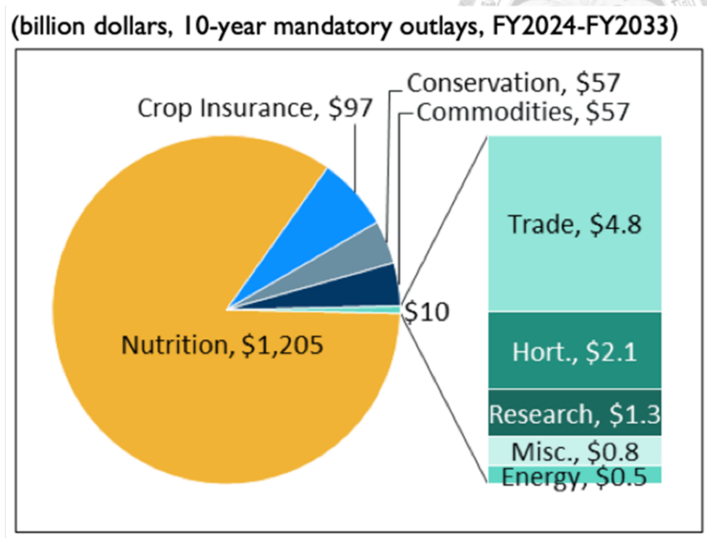
Figure 4: CRS Reported US Farm Bill Budget Breakdown

(million dollars, 10-year mandatory outlays)

Titles	2018 Farm Bill at Enactment FY2019-FY2028 ($ millions)	Baseline as of February 2023 FY2024-FY2033 ($ millions)
Commodities	61,414	56,996
Conservation	59,748	57,479
Trade	4,094	4,810
Nutrition	663,828	1,205,440
Credit	-4,558	a/
Rural Development	-2,362	a/
Research	1,219	1,300
Forestry	10	a/
Energy	737	500
Horticulture	2,047	2,100
Crop Insurance	77,933	96,974
Miscellaneous	3,091	800
Total	**867,200**	**1,426,399**



Note: Negative Credit title indicates payments to Farm Credit System Insurance, Negative Rural Development is due to a lack of current programs; The total value of the estimated baseline is $1.463 billion (USD)

Source: Renée Johnson & Jim Monke, Farm Bill Primer: What Is the Farm Bill? (2023, February 22). In *Congressional Research Service*. Retrieved April 20, 2023, from https://crsreports.congress.gov/product/pdf/IF/IF12047

Government policies can be derived to drive changes through investments such as those discussed briefly above, but they can also influence change through regulations imposed on the market. These can be regulations on the usage of certain chemicals deemed unsafe or on technologies for one reason or another. As discussed previously, regulations that affect Smart Agriculture solutions may come from somewhere other than Agricultural focused government bodies such as the USDA. For example, drones utilized in a commercial (including agricultural) manner or over a certain weight and size are required to register with the FAA, have specific training, and adhere to other regulations imposed by the FAA (Getting Started, n.d.). The usage, storage, privacy, and security implications surrounding the data collected through Smart AgTech solutions are also subject to a variety of government regulations as well. All these regulations must be considered in any Smart AgTech installation or investment opportunity.

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Governments also seek to create socially beneficial policies that help citizens in areas lacking ample opportunity or investments. New technologies bring new advantages to those who can access them, and these technologies often require internet access. Unfortunately, internet access is not universal in a country as large and geographically diverse as the United States. The idea of a divide between the rural and urban communities in the US is a problem the government has been trying to solve since the days of wired phone connections. This idea had to be reconsidered entirely in the 1990s with the rise of computers and the internet. A US Department of Commerce report in 1995 stated that "while a standard telephone line can be an individual's pathway to the riches of the Information Age, a personal computer and modem are rapidly becoming the keys to the vault" (Brown et al., 1995). This was one of the earliest times a government agency in the US admitted that internet connectivity would be paramount to the country's citizens and that non-urban areas of the nation were at a severe disadvantage (Bonivel, 2022). One would expect that this would have resulted in a rapid deployment of resources to spread internet access throughout the country; however, what is now coined as the "digital divide" still exists today. The idea of the digital divide is certainly ever-present in discussions of Smart AgTech implementations and is one of the greatest challenges the industry must overcome to achieve widespread market adoption.

2.4 Smart AgTech Components

Smart AgTech, as discussed in Section 2.1, at the base level is the idea of utilizing modern technological advances to improve productivity and efficiencies more sustainably. Several potential technological components can be adapted to the industry and are important considerations for this dissertation. The first of which is IoT as a whole. IoT, or the "Internet of Things," in relation to agriculture, encompasses the holistic integration and communication of several sensors and devices with each other to create a digital picture of agricultural operations and lead to smarter or more informed decision-making. Sensor data

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can include everything from moisture and nutrient levels, weather conditions, plant and crop health, livestock monitoring, and other on-farm activities (Javaid et al., 2022). By harnessing the data from various sources, farmers can make decisions based on real-time data and real-world conditions on the fly. Combining sensors with other systems, such as irrigation systems, can allow a more precise approach to water usage and thus reduce wasted resources.

Furthering the IoT discussion, though, potentially deserving of their category are AI (Artificial Intelligence) and ML (Machine Learning). These technologies put forth the potential to process and digest the vast amounts of data available in Smart Agriculture systems by employing the arrays of sensors available and then presenting the data in a more manageable way for farmers to utilize in an actionable manner. AI and ML technologies can also be integrated into newer technologies such as Robotics and Autonomous vehicles, which allow for a severe reduction in direct manual labor needed on farmland. Finally, another major potential component of Smart AgTech implementations is aerial monitoring tools such as Satellites, Drones, and UAVs. All these devices, when used as tools, can sense field conditions, accurately determine the needs of crops, and detect diseases or insect infestations, all in a very accurate manner. Drones and UAVs can also be used separately in seeding and pesticide spraying or irrigation applications (IOT Solutions World Congress, 2019), furthering their usefulness in implementation strategies. The collection of all these potential components builds a system or network of data generation and usage devices throughout the agricultural process. By implementing a variety of them, farms can optimize their operations in a way that caters to the exact needs of their fields and gives crops the best chance at success, all while serving to reduce wasted resources. This will be necessary to push the bounds of agriculture as it stands today and feed the growing population more sustainably.

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2.5 Big Data

Figure 5: Smart AgTech Infographic

Source: Reffell, C. (2022). Climate-smart Agriculture on a BOLD Path to a Bright Future. *BOLD Awards*. Retrieved March 24, 2023, from https://bold-awards.com/climate-smart-agriculture-bold-path-bright-future/

Regardless of the industry, a critical part of all IoT installations is the large troves of data generated using the new technologies. As described in Section 2.4, farms can generate data at a scale never seen at any other point in history by utilizing many more diverse subsets of connected devices. According to industry research, "the average farm will generate 4.1 million data points daily in 2050" (De Clercq et al., 2018). An integral part of this data availability is figuring out how to digest it and make it useful to average farmers and agribusinesses in their decision-making processes. A key hurdle to this data may be the general preparedness or education of average agribusiness owner-operators and their willingness to dive into the "tech-forward" world of Big Data. To process the enormous datasets, platforms are beginning to turn to AI and ML applications to build models to better track potential yields, needs, or diseases and make this information easier to understand for users. Another way that an increase in the availability and usage of data can be utilized is the increase in transparency throughout the entire agricultural supply chain, which allows

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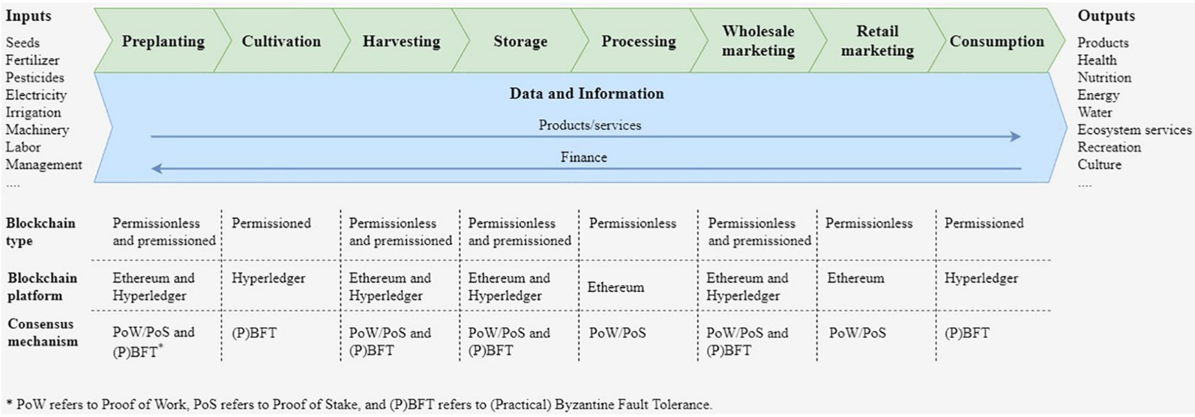
consumers or customers to better understand and verify the inputs up until the moment they eat their meal (Columbus, 2021). This could prove a positive should any industry verification tools be introduced, such as a proposed "USDA-backed climate-smart certification" (Thurman, 2022) or other newer technologies, such as blockchain infrastructure, which "ensures … data and information are transparent … and all recorded data are immutable" (Xiong et al., 2020). Figure 6, below, shows how data would flow through blockchain architecture utilization in a Smart Agriculture setting.

Figure 6: Blockchain Data & Information Flows



Source: Xiong, H., Dalhaus, T., Wang, P., & Huang, J. (2020). Blockchain Technology for Agriculture: Applications and Rationale. *Frontiers in Blockchain, Blockchain for Good, Volume 3 (2020)*. Retrieved June 16, 2023, from https://www.frontiersin.org/articles/10.3389/fbloc.2020.00007/full

While the large amounts of data from newly connected Smart Farms are significant for the industry, it also comes with potential issues. Several key concerns stem from data in any industry, and Agriculture is not unique. Farmers may take issue with how organizations collect, utilize and share information generated on their farms. They may also not like the level to which they have access to that information, if at all, in some cases. Many organizations in the space are advocating for open data infrastructures in the Smart AgTech sphere to assist with the data privacy, ownership, and security issues that have come up. There is a belief that it is the best way to ensure the market sees the potential benefits of these new technologies (Wolfert et al., 2017). Table 1, below, lays out some potential data-driven

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technologies throughout the agriculture supply chain that can be implemented in Smart Agriculture transitions. These data-generating connected systems exemplify what Industry 4.0 looks like in the agricultural marketplace. Ensuring proper and equitable data access, privacy, and security is thus a significant opportunity.

Table 1: Examples of Big Data Applications in Smart Farming

Cycle of Smart Farming	Arable	Livestock	Horticulture	Fishery
Smart sensing and monitoring	Robotics and sensors (*Faulkner and Cebul, 2014*)	Biometric sensing, GPS tracking (*Sonka, 2014*)	Robotics and sensors (temperature, humidity, CO2, etc.), greenhouse computers (*Sun et al., 2013a)*	Automated Identification Systems (AIS) (*Natale et al., 2015*)
Smart analysis and planning	Seeding, Planting, Soil typing, Crop health, yield modelling (*Noyes, 2014*)	Breeding, monitoring (*Cole et al., 2012*)	Lighting, energy management (*Li and Wang, 2014*)	Surveillance, monitoring (*Yan et al., 2013*)
Smart control	Precision farming (*Sun et al., 2013b*)	Milk robots (*Grobart, 2012*)	Climate control, Precision control (*Luo et al., 2012*)	Surveillance, monitoring (*Yan et al., 2013*)
Big Data in the cloud	Weather/climate data, Yield data, Soil types, Market information, agricultural census data (*Chen et al., 2014*)	Livestock movements (*Faulkner and Cebul, 2014; Wamba and Wicks, 2010*)	Weather/climate, market information, social media (*Verdouw et al., 2013*)	Market data (*Yan et al., 2013)* Satellite data, (*European Space Agency, 2016*)

Source: Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. (2017). Big Data in Smart Farming – A review. *Agricultural Systems*, *153*, 69–80. Retrieved May 27, 2023, from https://doi.org/10.1016/j.agsy.2017.01.023

2.6 Legacy Agriculture Companies

As with many industries, "legacy" or "traditional" agricultural companies are also beginning to recognize and understand the enormous market opportunities in implementing Smart Agriculture solutions. Many have started investing in research and development to generate more comprehensive solutions in the space or have made acquisitions to jumpstart their technology implementations. Some of the major players making headlines for their involvements in the space are John Deere, Monsanto (which has been acquired by Bayer), Corteva Agriscience, and CNH Industrial.

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As with IoT transformations in any industry, the legacy players must be involved in the transition. While there are risks that they could lose their market positions if they held out on implementing new technologies, it is also critical for the agricultural industry to see that the names they know and trust are some of the organizations leading the charge. John Deere has made several investments and acquisitions in the space, in the billions of dollars, that has positioned them as one of the leaders in Smart AgTech integration as it stands now. John Deere's CEO, John May, recently said in an interview that he "projects that 10% of Deere's annual revenue will come from fees for using software" by the end of the 2020s after they announced new technologies such as autonomous tractors and smart sprayers (Tita, & Bunge, 2022*)*. Even trusted major brands such as John Deere do not receive a blank cheque from the market, however, as many individual farmers and farming unions are taking issue with new technologies "giving the equipment company greater influence over … operations, while collecting data to benefit [their] own technology development" (Tita, & Bunge, 2022). Despite natural pushback to the influx of new technologies into the space, the consensus is more positive surrounding new tech, so long as it doesn't have failures.

Other legacy companies are making investments that may be overlooked in typical discussions about impacting sustainability and improving ESG. A great example of this comes from Monsanto, which was acquired by Bayer, who, along with creating a platform for data optimization based on field yields, has invested heavily in better seed technologies to assist farmers with existing climate change concerns. They are utilizing technologies such as gene editing in combination with existing genetic modification techniques to tailor plants to be more resilient in the new normal as the effects of climate change take hold around the world (Polansek, 2018).

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2.7 Smart AgTech Start-ups

A wide array of new AgTech startups have begun to enter the fray over the last few years. With the overarching Smart Agriculture market changing at a break-neck pace, new players are vying for their chance to cement their roles within it. The new entrants to the Smart agriculture market have a wide range of services they are providing, ranging from supply chain optimization to precision agriculture and overall operations management software. Companies such as FBN thought that by banding Farmers together and maintaining transparency, they could collectively utilize the data they collect and increase their buying power by operating as a group. As more members join their network, their dataset strengthens, and they can better optimize their operations (Proudly Farmers First®, n.d.). Indigo Agriculture utilizes microbiology and monitoring software to improve crop yields while maintaining a transparent process, granting customers and consumers better access to traceable food sources (Ag, n.d.).

While FBN, Indigo Agriculture, and others operate based on current agricultural norms, other startups are trying to pursue a new path. Vertical farming, or a farm that utilizes a space other than a field to produce high-quality crops, typically in upright positions, is becoming an interesting space. This is especially true within the confines of large global metropolises, as any unused space could become a self-contained and controlled source of fresh food. Companies such as Plenty and AeroFarms are two startups operating in this total rethink of farming as we know it. Plenty describes the process as a “growing platform [that] can be used for a wide range of crops and deployed anywhere in the world [where] there is space and an electrical current” (Plenty, 2022). These innovative and completely new ways of looking at farming could be an essential addition to the global food supply chain, and the startup industry is proving that it is a viable business option in the space.

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2.8 Telecommunications Companies

In the introduction section of this dissertation, Telecommunications companies were positioned as a lynchpin to the Smart Agriculture industry as reliable connectivity is a major concern within rural communities and necessary for developing IoT solutions within them. This central placement places Telecom companies at the center of any changes in this critical industry, but it is not all for naught, as major publications such as the BCG and GSMA report *Future of Mobile* indicate that there is an enormous opportunity in the space, upwards of $3.5 trillion total with increased ESG investing, with a sizable consideration of roughly $900 million in new profitability specifically earmarked for investments in Smart Agriculture alone (GSMA: Future of Mobile, 2020). There are numerous avenues for telecom organizations to make a difference in this space that can each be attributed back to their ESG scores and, thus, improve their shareholders' perceptions of their operations, despite the perception that their organizations will not benefit from such endeavors. Some areas Telecoms can focus on to make an impact on both the issue at hand and boost their ESG reputation to shareholders are:

- General infrastructure development.
- Direct investments in IoT solutions and technologies.
- Creation of entirely new business units within the space.
- Partnerships with startups and existing stakeholders such as governments and legacy farming companies.
- Outreach efforts to train and educate agricultural owners and their staff on new technologies that can benefit from their services.
- Data security and storage for IoT projects in rural communities.
- Contribute in general to positive resource usage and waste reduction in agriculture.

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Each of these could be utilized as marketing or investment opportunities for telecom companies, would benefit the communities they serve, increase global food security, and serve as a potential avenue for immense untapped profitability. The GSMA report describes these organizations needing to generate their "license to lead" in the ESG space by addressing these key issues and bettering society, all while unlocking a potential $3.5 trillion market opportunity (GSMA: Future of Mobile, 2020). While there appears to be a significant market opportunity, as suggested in the GSMA and BCG report, the cost of deployment remains a major hurdle in rural communities due to the lack of population. A report on Federal Funding and Electrical Co-operatives in the US suggests "the average cost of fiber deployment … [is] between $16,500 and $26,520 per areal mile … [with an additional] $1,400 and $3,750 to prepare an existing pole for each fiber line attachment … [however, also notes that] laying fiber cable underground costs between $36,000 and $59,000 per mile" (Greig & Nelson, 2022), creating a significant cost hurdle.

2.9 Future Trends

The Smart AgTech market is poised for exponential growth in the coming years at the crossroads of better technologies and the climate-driven need for more sustainable production. The increased introduction of AI and ML technologies in other industries will filter into the market and drive aggressive changes in farmers' businesses. Combining these new technologies with a greater emphasis on sensor technologies and data acquisition and usage has set the industry up for explosive growth. Needed IoT infrastructure investments in rural communities will bring increased investments in under-developed rural communities, which may help stem the tide of movement into urban metropolises. These trends will only speed up with increased investments in the space, driving costs down and making technology adoption more accessible to a wider market subset. According to a report by Grand View Research, "The global smart agriculture market … was valued at USD 20.30 billion in 2022

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and is expected to expand at a … CAGR of 13.4% from 2023 to 2030" (Grand View Research, n.d.). The report shows that a growing share of farming revenues will be captured using and implementing smart agriculture systems. The North American marketplace leads the global charge in adoption rates of new technologies in this space, and that trend is expected to continue while the tech begins to proliferate to the remainder of the world.

If population trends do not slow down or reverse, the necessity to integrate autonomous technologies on a greater scale will also increase significantly. While concerns surround increased reliance on data and storage, new solutions will be built to safeguard the industry. New industries will also be built in our metropolises to better utilize otherwise wasted spaces with indoor agriculture techniques such as vertical farming. Finally, as the consumers in the marketplace are looking for supplier transparency, a new supply chain infrastructure will need to be built to facilitate this information transfer. While these are not "end all be all" solutions and will come with challenges, these market opportunities point to a significantly positive future trend for Smart AgTech and paints a picture of a potential "diamond in the rough" investment opportunity.

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Chapter 3: Research Methodology

In this chapter, qualitative and quantitative collection methodology will be discussed to strengthen the discussion started throughout the Introduction of the research inquiries and then the Literature Review in Chapter 2. The Chapter will lay out the structure of the completed research and how data will be further discussed.

3.1 Methodology Background

This thesis will use qualitative and quantitative datasets to take a mixed approach to the industry, current investments, and future opportunities. These will primarily be discussed through comprehensive reviews of scholarly journals, industry, and government reports and surveys. All the data utilized will be secondary in nature. Overall, this paper will aim to prove that there is a market opportunity for new entrants at either the telecommunications organizational or individual investor level in Smart AgTech solutions. On top of that primary objective, the surrounding business needs of the industry will be discussed to position the budding smart agriculture industry as the next wave in historical human-driven agricultural revolutions. To complete this objective, a cohesive conversation including multiple data styles will serve as the basis of a stronger argument. The research conducted as a part of the Literature Review and subsequent data analyses resulted in the review and analysis of 120 various data sources for the completion of this dissertation and countless other sources deemed irrelevant to the topic.

On top of the literature-based discussion in Chapter 2, insights from qualitative-based industry reports closer to the industry professionals and farm operators were deemed valuable to gain insights surrounding the real-world usage of these technologies and their effectiveness. These will be accessed in a secondary data collection method and will be based upon larger surveys from major players and market research organizations interested in the space. Organizations like McKinsey & Co., BCG, and Global Research Universities will all

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have useful information for our discussion. This data is expected to provide critical feedback on the perspectives from around the industry on the trends and shortcomings in the market as it stands today. Given a general understanding of the industry, one can anticipate some of the expected concerns or challenges to implementing these technologies; however, a broader understanding is necessary for completing this thesis.

In conjunction with the qualitative industry research noted above, publicly available agricultural datasets will also be discussed as a key component to analyze the broader industry trends and environmental concerns therein. One of the major sources of existing open agrarian data can be publicly accessed via Data.gov, which houses available datasets for the US Government. Other sources for agricultural data can be found by utilizing usda.gov (a site from the US Department of Agriculture as well as its components such as NASS), Statista.com (a large statistical and data analysis organization), fao.org and data.un.org (both of which house data from the United Nations and its Food and Agriculture Organization). The data will be utilized through secondary data collection methods based on or found within the industry and research community-based reporting on the sites noted prior.

Since the data collection method is secondary to this research's qualitative and quantitative data, all included data will be studied in a “document-study” fashion and further cross-checked against additional sources to ensure accuracy before inclusion. Once reviewed for all qualitative datasets, such as reports and journals, a content analysis method was employed to categorize information for inclusion. The quantitative data, such as industry and government reporting, utilized a data visualization method to better understand and communicate findings.

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Chapter 4: Research Findings

In Chapter 3, the research methodology and data collection methods were outlined to strengthen the discussion of the Smart AgTech sector. This chapter will organize and introduce the individual datasets into the larger dialogue. These reports, datasets, and statistics will be briefly presented in Chapter 4, and a broader discussion of their implication for this discussion will be included in Chapter 5. This section will divide the datasets into three main overarching categories, with sub-categories for each specific inclusion.

4.1 US Government Data

Since this dissertation focuses primarily on the US market, US government data has proven to be an integral part of the data collected throughout the process. This section will introduce various studies completed by US Government agencies such as the USDA, NASS, and FCC as discovered throughout the research process. Each dataset or source will be briefly introduced, as mentioned in the introduction. Further discussions on the implications of the reports included in Section 4.1 will be in later sections of this thesis.

One of the most critical datasets available in the US agriculture market is the Census of Agriculture, completed every five years by the USDA. The Census is the only constant, far-reaching agricultural dataset including each county in the entire US. The document broadly focuses on the industry, including operations and expenses, production values, economic impacts, and general demographics. A wide range of people and organizations utilize the data within the report, including but not limited to local and federal government agencies, agribusinesses, trade associations, and research institutions. These organizations and many more utilize the data for planning and decision-making, research and development, rural development programs, and advocacy. The last Census of Agriculture was put out by the USDA in 2017, with the next iteration due to Congress in 2023, so the 2017 Census was utilized for this research. Due to the sheer size of the USDA Census of Agriculture, it is

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difficult to include an overview of the entire scope of the report here. Data from the report has been included via resources such as the USDA's NASS service to gather more digestible information for inclusion in this study.

4.1.1 Average Age of US Producers by County: 2017 vs. 2012

There is an understanding in the agriculture industry that the average farm operator is aging, and the 2017 Census of Agriculture data supports this claim. According to the reported data, the overall population within farming communities is aging, showing that the average age of producers increased from 56.3 in the 2012 report to 57.5 in the 2017 report. Figure 7, below, depicts a county-level map of average producer ages within the US. This NASS map pulling from broader 2017 Census of Agriculture data, shows that the Midwest Region has the youngest average age of operators, with the Mid-Atlantic, South, and West having much older average operator ages. This overall trend is not specific to the agriculture industry, as longer lifespans and delays in retirement are more common occurrences. Additional roadblocks exist for the younger generations trying to get into the agricultural space, as land and equipment costs are seemingly insurmountable entry barriers.

Additionally, the agriculture industry is often less profitable than other industries or opportunities, so it is even harder to overcome those barriers after entering the market. Social factors also create entry barriers, as the attractiveness (or lack thereof) of the lifestyle that comes with the profession and the tendency of farms to be passed down through generations serve as additional hurdles to overcome. Overall, this data proves that the average age of operators is increasing in the US and highlights the critical need to encourage further engagement in the space from the up-and-coming generations.

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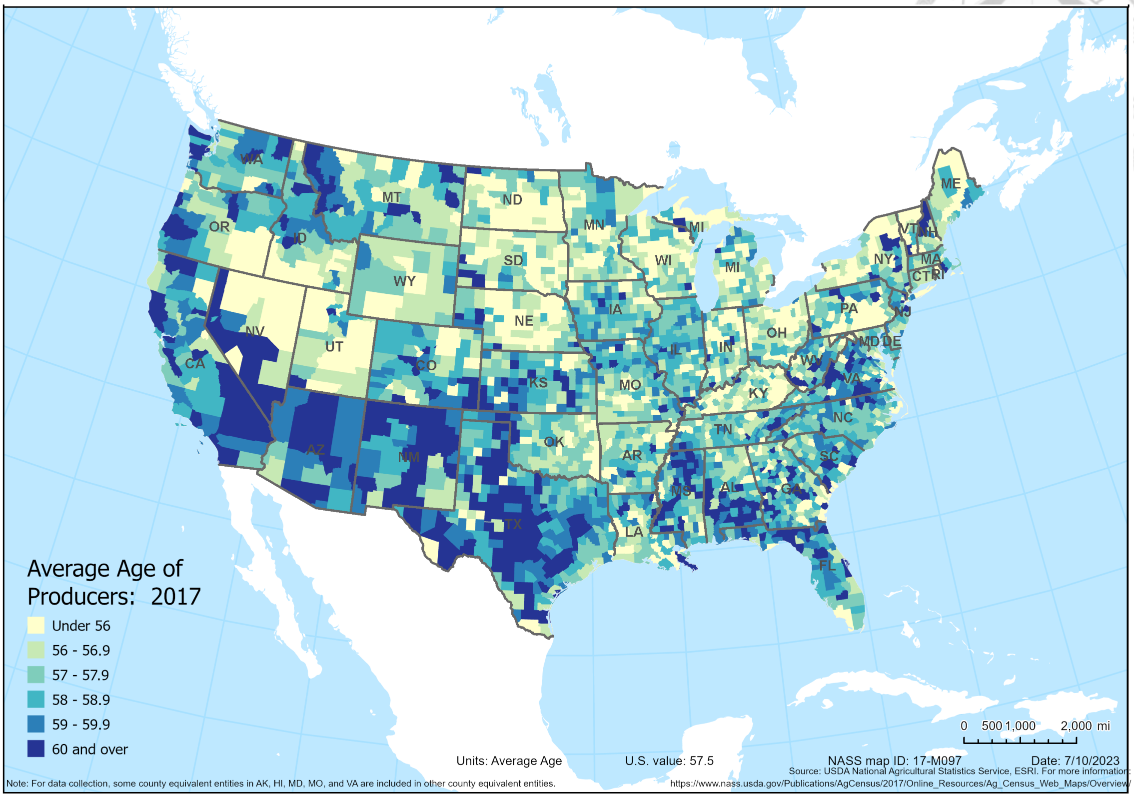
Figure 7: Average Age of Producers, 2017



Note: Units are ages, and an increase in average age correlates with darker colors on the chart.

Source: USDA NASS. (2017a). *Average Age of Producers, 2017*. In 2017 Ag Census Web Maps | USDA/NASS. Retrieved July 10, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Ag_Census_Web_Maps/index.php

4.1.2 Farm Income and Losses of US Sole Proprietors

In the modern age, farming as an occupation has an image issue, and a large portion of that can be shown in the staggering profit and loss data available on the market. The USDA ERS division has compiled a chart analyzing the income and losses reported by US farm operators over the 20 years between 2000 and 2020 (see Figure 8 below). The graph reports the total revenue for farms reporting positive cashflows and losses for those who reported negative cashflows and utilized farming data in conjunction with data from the IRS to compile the information (USDA ERS, n.d.). Figure 8 indicates that farming losses have dramatically increased over the 20 years, from $17.3 billion in 2000 to $34.8 billion in 2020. The trend could be attributed to increased operating costs, such as seed and fertilizer costs,

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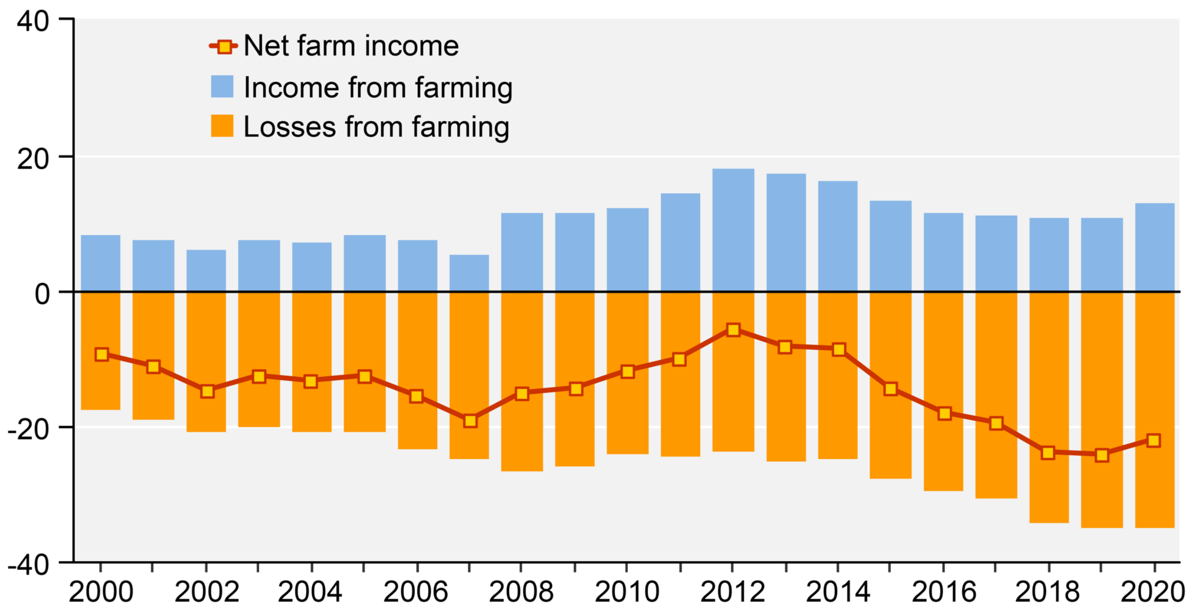
machinery and land costs, or a larger number of farms with operating losses. While losses have accelerated over this time, farms with positive incomes have remained relatively steady, with some fluctuation from year to year and a noticeable uptick between 2011 and 2014. These could be due to the changing supply and demand or weather dynamics from year to year; however, the overall negative trend of farms with positive income should be concerning. At this point, the chart paints a grim image of the agricultural industry. Still, it gets worse when net income is considered, as this data shows that the industry operators appear to be operating with continuous financial losses during the entire period in question.

Figure 8: US Farm Sole Proprietor Income and Losses, Based on Tax Reporting



Note: Units in Billions of USD; Compiled by the USDA ERS with IRS data sources.

Source: USDA ERS. (n.d.). Farm income and losses of US farm sole proprietors reported for tax purposes, 2000-20. In *USDA | ERS*. USDA. Retrieved June 18, 2023, from https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=81953

4.1.3 US Farm Internet Access by County: 2007 vs. 2017

In Figure 9, below, the US national internet access percentages are shown in a range from less than 55% to 85% or more with access to the internet. The chart comes from the NASS based on data from the US Census of Agriculture. The US Census of Agriculture is a

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holistic review of the industry that the USDA is tasked with updating every five years. It defines any "farm" as a "place from which $1,000 or more of agricultural products were produced and sold during the year" (Basu & Chakraborty, 2017). The chart is set up with data at the county level across the country. It is also essential to note that this report bases its definition of "internet access" on the FCC benchmark for terrestrial broadband access, which is set as internet access with "at least 25/3 Mbps" download/upload speeds (Commissioner Carr, 2021). This distinction means that the report does include areas that may fall outside the typical distinction of "rural areas," as the focus is on reporting based on the earlier described definition of a farm location. These distinctions are utilized to create the US government policy on the minimum acceptable level of access for most day-to-day applications. However, not all smart agriculture or business-related tasks or applications would work adequately under these conditions. A closer look at the chart shows that internet access appears to be better on average in Northern states and worse by percentage with access in Southern and Central regions. A limitation of this charted data may be the lack of a topographical consideration along with this information, as some areas with lower overall percentages of access appear to be along the Mississippi and Ohio River valley regions, which in some areas do have difficult-to-manage terrain.

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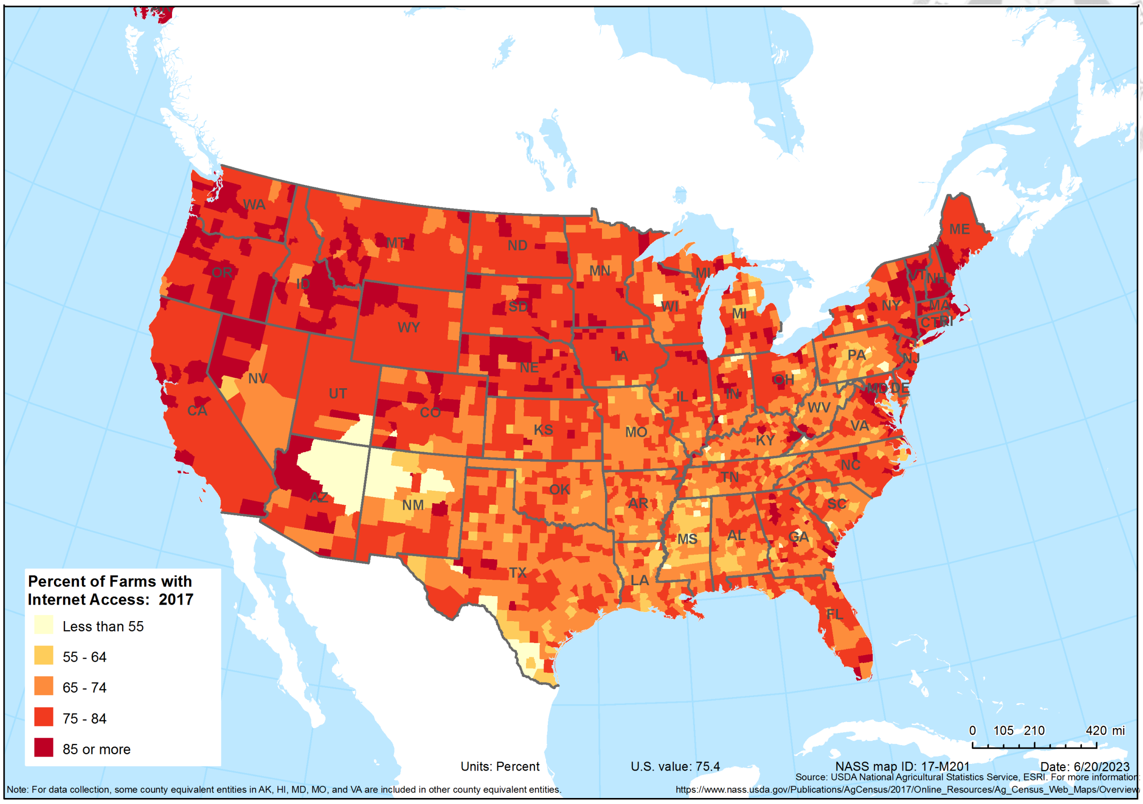
Figure 9: Percent of Farms with Internet Access, 2017



Note: Units are in percentages; The US National value is 75.4%

Source: USDA NASS. (2017b). *Percent of Farms with Internet Access: 2017*. 2017 Ag Census Web Maps | USDA/NASS. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Ag_Census_Web_Maps/index.php

For comparison, archived US Census of Agriculture reports were also analyzed for reporting on internet access in rural communities and farms; the NASS did not seem to have any data on internet access before the 2007 Census year, so the 2007 Census of Agriculture data was utilized to give us a sense of the improvement in the space. Figure 10 below shows the 2007 USDA County-level farm data on high-speed internet access. In 2007, "high-speed services" or "broadband services" were defined by the FCC in a policy-setting report to Congress as internet "services that deliver an information-carrying capacity in excess of 200 kbps in at least one direction" (Chairman Martin & Commissioners Copps, 2007). This benchmark is significantly lower than the current one; nonetheless, it is understandable for a significant technological advancement over ten years. The 2007 report shows a baseline of "less than 20" through a maximum of "50 or more" in terms of percent access to the internet

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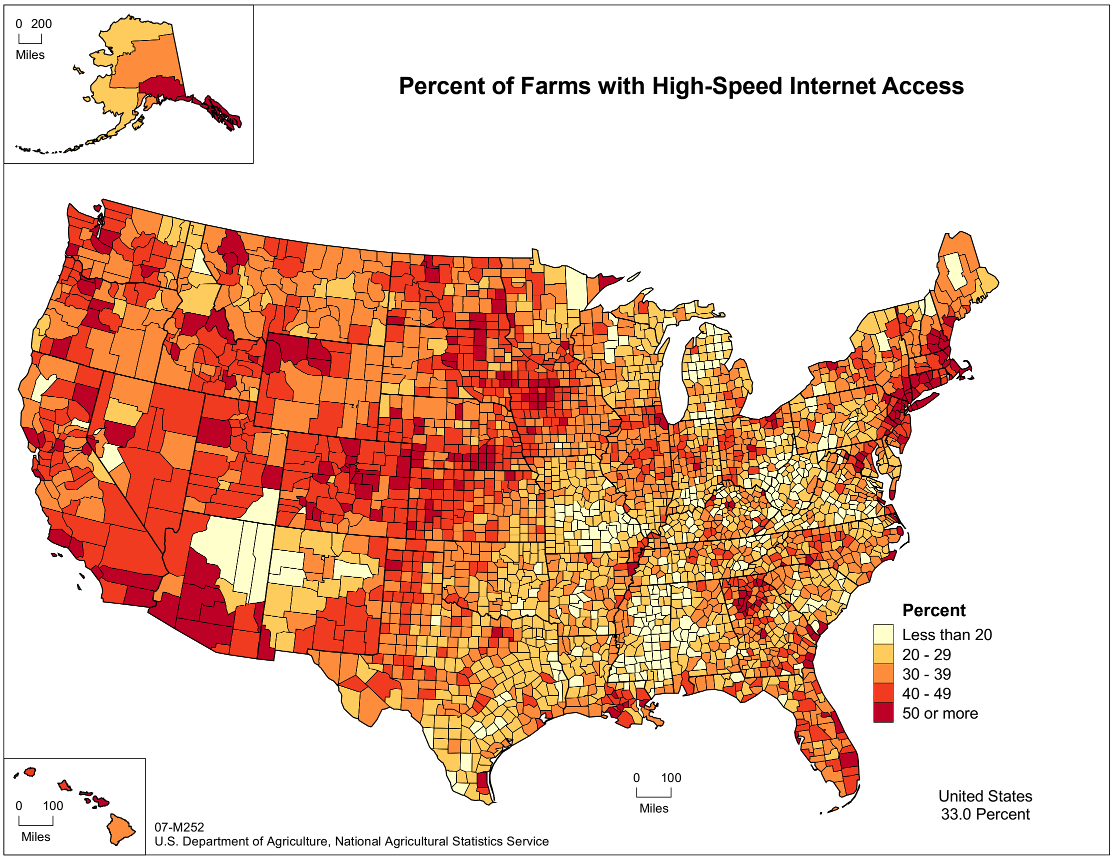
with speeds over the benchmark at that time. This report points to a significant improvement in this timeframe. However, the massive differences in benchmark speeds, advancements in internet technologies, and the respective speeds required to operate them properly remain unaccounted for when looking at these two figures on their own. Analyzing these reports together shows that in 2007 the farms in the Southwest and overall Western region had significantly better internet access than those across the Eastern portion of the US, which seems to contrast with 2017 data directly.

Figure 10: Percent of Farms with High-Speed Internet Access, 2007



Note: Units are percentages; the US National value is 33%

Source: USDA NASS. (2007). *Percent of Farms with High-Speed Internet Access*. 2007 Ag Census Library at Cornell University | USDA/NASS. https://agcensus.library.cornell.edu/wp-content/uploads/2007-Ag_Atlas_Maps-Farms-07-M251-RGBChor-largetext.pdf

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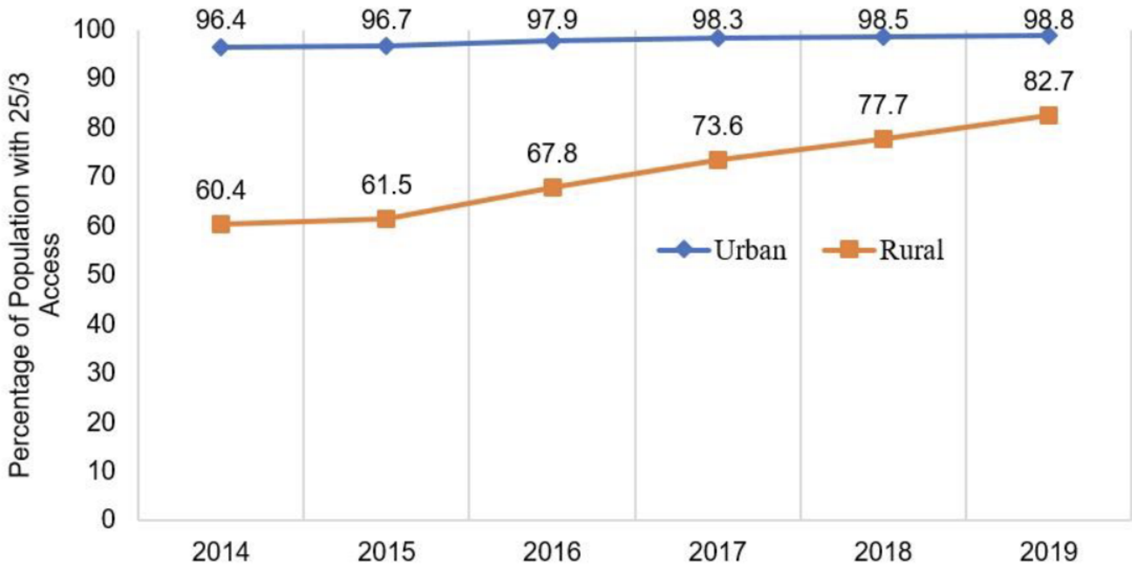
4.1.4 US Rural vs. Urban Internet Access, 2014 – 2019

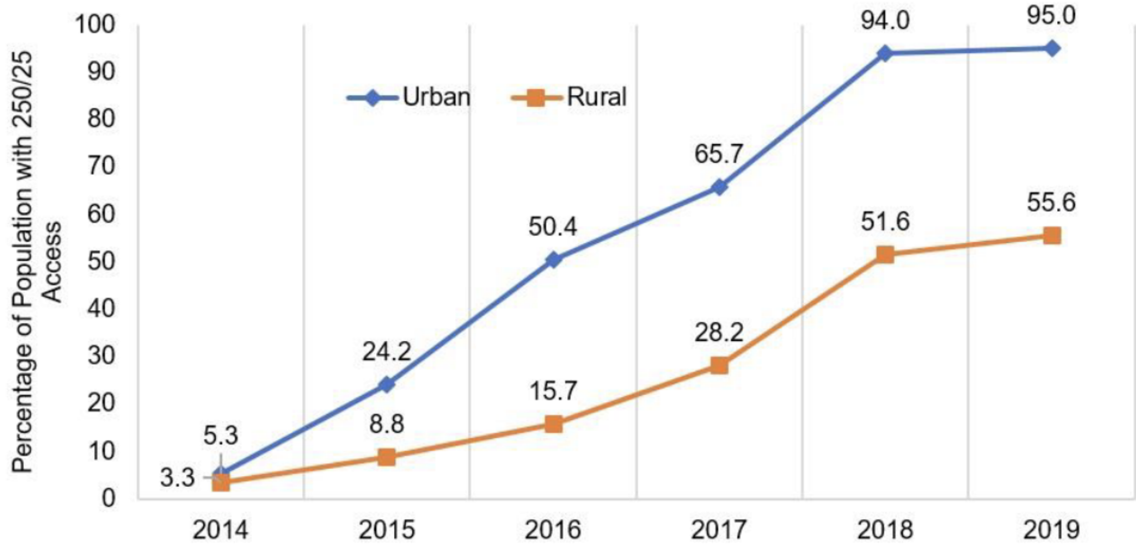
Figure 11: Percentage of US Population with 25/3 Access (Rural vs. Urban)



Note: Data points are percentages; Rural & Urban are based on US Census definitions.

Source: Whitacre, B. E. (2021). COVID-19 and Rural Broadband. *Agricultural & Applied Economics Association*, *Choices, 3rd Quarter 2021, Vol. 36*(No. 3 (3rd Quarter 2021)), 1–10. https://www.jstor.org/stable/10.2307/27098595

Figure 12: Percentage of US Population with 250/3 Access (Rural vs. Urban)



Note: Data points are percentages; Rural & Urban are based on US Census definitions.

Source: Whitacre, B. E. (2021). COVID-19 and Rural Broadband. *Agricultural & Applied Economics Association*, *Choices, 3rd Quarter 2021, Vol. 36*(No. 3 (3rd Quarter 2021)), 1–10. https://www.jstor.org/stable/10.2307/27098595

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In Section 4.1.3 farm specific internet access was discussed at the county level. In this section, 4.1.4, the data specifically focuses on rural vs. urban populations and their access to the Internet. The data paints a similar picture between the two distinctions; however, this report also includes access well above the baseline terrestrial broadband speeds, as mentioned prior (25/3 access). This report shows that in 2019 while 82.7% of rural communities had access to basic 25/3 access, as defined by the FCC, only 55.6% had access at speeds of 250/25. Despite the increased speed options and availability, the FCC has determined that they still do not need to increase their benchmark speed from the 25/3 access speed. They claim this for three reasons:

1. "The definition of advanced telecommunications capability … does not suggest that "advanced" necessarily means the highest quality service possible" (Commissioner Carr, 2021).
2. "The benchmark [should] … be tied to the statutory definition of 'advanced telecommunications capability,' rather than being set as an 'audacious goal' (Commissioner Carr, 2021).
3. "It remains the case that a 25/3 connection generally is sufficient to enable … [work, school, and telehealth] applications" (Commissioner Carr, 2021).

Even in keeping with this distinction, there are still 17.3% of the American rural populace, roughly "14.5 million Americans" (Commissioner Carr, 2021), that still do not have basic access to the internet under the current threshold as defined by the FCC in their guidelines for Congress. The data included in the above Figures (11 and 12) are directly from the FCC 2019 "Broadband Deployment Report" (Commissioner Carr, 2021), which is the most recent iteration of the report, and shows a positive trend of closing the "digital divide" when the baseline 25/3 speeds are considered. As far as increased speeds, the data shows that there is more work to be done.

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4.2 Statista-Generated Reports

While researching the topic of the Smart Agriculture industry, its impacts on the environment, and the challenges to investing in the space, Statista proved to be a valuable resource due not only to their individually available statistics but also large, categorized reports on various topics. Statista is a market and consumer data provider well known for its comprehensive coverage of multiple industries and specialties. Best known for quantitative datasets catering to businesses, academics, and individual users, Statista has a database of over 22,500 sources. The company is a reliable hub for market research and statistical needs. For this reason, the market research insights included in Section 4.2 focuses on data gathered from nine Statista Industry Reports relevant to the discussion in this report. Each Statista report was carefully considered, and the most relevant data will be included throughout this section.

Furthermore, while the scope of the thesis is primarily focused on the US marketplace, removing the US from the global economy is challenging. As a key exporter of agricultural products, the US agricultural economy is deeply entwined in the global market. While many of the datasets are focused on the US marketplace, some Global data has also been determined to be relevant to the discussion and thus has been included in this section. This section will provide a range of quantitative secondary datasets to the conversation surrounding Smart AgTech solutions for further discussion in later chapters. The data from the nine industry reports in Section 4.2 has been organized into five individual categories, separated by a portion of the agriculture industry or relevant subsequent industries and their economic impacts.

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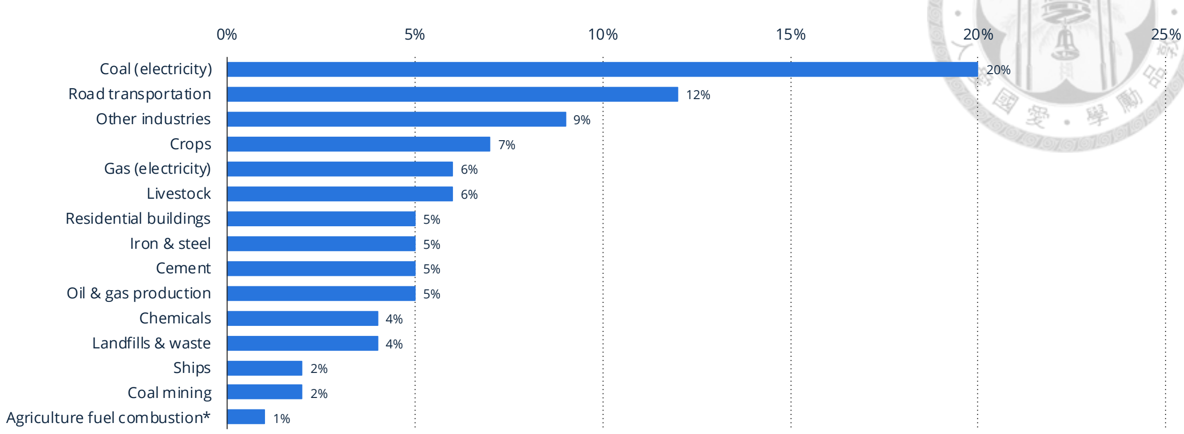
4.2.1 Agricultural Emissions Datasets

Figure 13: Distribution of GHG Emissions Worldwide, by Sub-sector



Note: 2020 Worldwide data; based on 47.3 billion metric tons of Carbon Dioxide equivalent.

Source: Statista. (2023a). Greenhouse gas emissions worldwide. In *Statista* | *Politics & Society*. Retrieved June 16, 2023, from https://www.statista.com/study/69601/greenhouse-gas-emissions-worldwide/

Considering the UN SDG initiatives and the agriculture industry's reputation for negative environmental impacts, research was conducted to determine what available data existed on the current state of GHG emissions that originate on farms. Figure 13, above, shows global data analyzed through its inclusion in a Statista report on worldwide GHG emissions. This chart shows that 14% of global GHG emissions stem from direct agriculture processes, with Crops accounting for 7%, Livestock 6%, and Agricultural Fuel Combustion 1%. This number may be a bit conservative, as the industry very likely has a role in other major factors on GHG emission levels, such as the road transportation industry, chemical uses, and waste created. Nevertheless, combining the industry factors explicitly included in the report would place the industry as the 2nd largest global contributor of GHG emissions behind Coal (electricity) and ahead of Road Transportation, if discussed by industry sub-sectors as this statistic depicts.

Taking a step further back and analyzing the GHG emissions by overall economic sectors places the agriculture industry as the 4th largest contributor of GHGs in the US economy. Figure 14, below, graphs emissions by economic sector and identifies the

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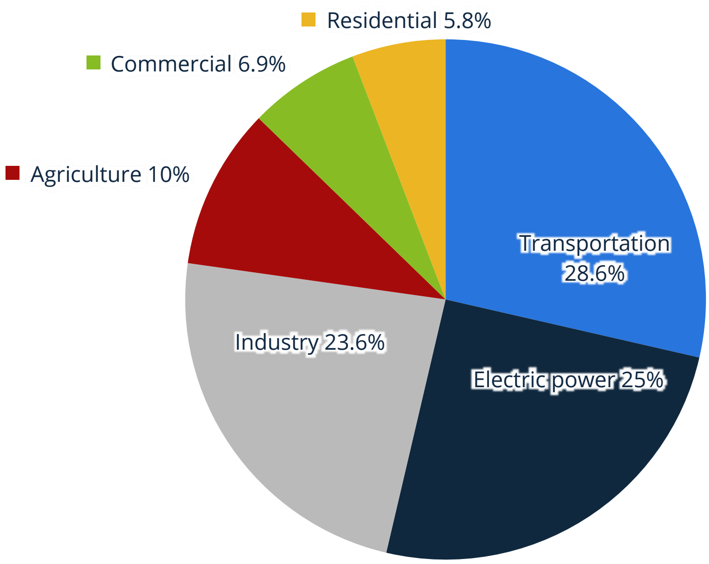
transportation industry as the largest contributor to the US economy at 28.6% of all national emissions, followed by electricity generation at 25%, industry at 23.6%, and agriculture at 10%. While this shows that agriculture is not the major emitter in the US, it is still a significant contributor to GHG emitted by the US economy. 10% of all GHG emissions is substantial, especially considering the size of the US economy and its GHG contributions. This chart shows that while much of the economy has work to do regarding GHG emissions, if the agriculture market can make an impact, it will certainly impact the overall emissions output by the US economy.

Figure 14: Distribution of GHG Emissions in the US, by Economic Sector



Note: 2021; based on 6,340.2 metric tons of Carbon Dioxide equivalent.

Source: Statista. (2022a). Emissions in the US. In *Statista* | *Politics & Society*. Retrieved June 16, 2023, from https://www.statista.com/study/40176/us-ghg-emissions-statista-dossier/

4.2.2. US Market Data

The US market is incredibly large in scale. When considering the potential of growth in the agricultural sector and armed with the knowledge that the global economy needs to significantly increase agricultural output to feed the growing population, there is an enormous opportunity for the US agriculture sector. The US is considered a major food producer and

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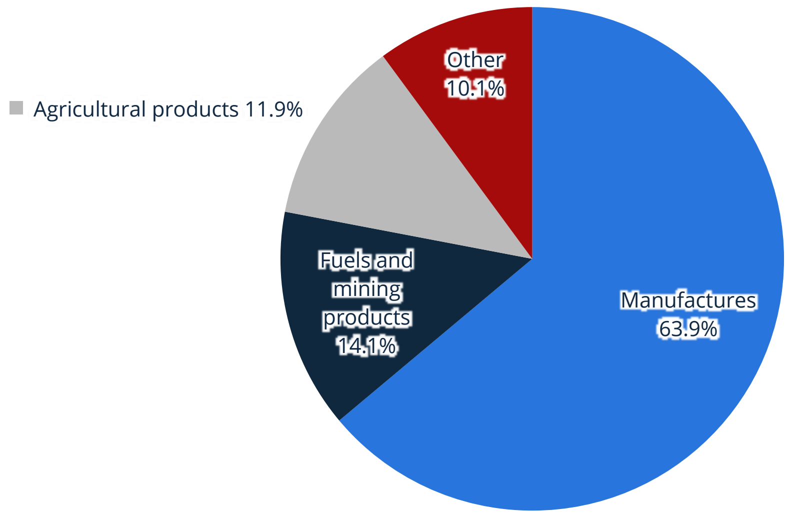
thus is in a prime position to capitalize on the needs of the global economy. Considering the current breakdown of exported goods in the US, Figure 15 depicts a breakdown of the major export sectors in the economy. Despite US commodity group exports being dominated by Manufactures, Agricultural products come in at 11.9% as the 3rd largest category. Even with a minority role, the contribution of Agricultural Products remains a significant portion of the US export economy.

Figure 15: Exported Goods from the US, by Commodity Group



Note: 2020

Source: Statista. (2022b). US Export. In *Statista | Industries & Markets*. Retrieved June 16, 2023, from https://www.statista.com/study/15278/us-exports-of-goods-and-services-statista-dossier/

Considering the agriculture market by commodity group in Figure 15 above gives an important glance at its share in the US export industry; however, percentages are difficult to gain a clear picture of value added by the sector. Figure 16, conversely, is a bar chart separated by product industry class rather than commodity group, but the value output is in billions of USD, which gives a more accurate picture of the export value in the agricultural market. The data places Agricultural products as the 9th largest industry class, with an export value of 94.38 billion USD in 2022. It is important to consider further that the industry data

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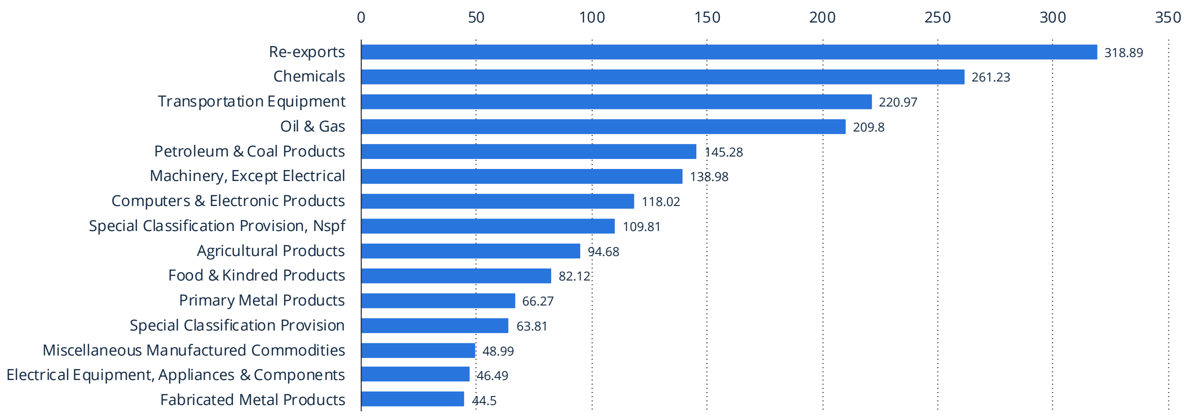
included and separated below has the potential to misrepresent the agriculture industry by only focusing on "agricultural products," as some products that may be classified as agricultural may fall into other categories when considered by product industry class.

Figure 16: US Exports of Trade Goods, by Product Industry Class



Note: 2022; Values in billion USD

Source: Statista. (2022b). US Export. In *Statista* | *Industries & Markets*. Retrieved June 16, 2023, from https://www.statista.com/study/15278/us-exports-of-goods-and-services-statista-dossier/

While exports are a good indication of the health of an industry or its impact on a larger economic system, employment is often considered a major factor indicating the health of an industry as well. The research was conducted along this frame of thought, and Figure 17, included on page 39, breaks down US employment by industry classification from a report on the US economy. The United States is primarily considered a service economy, contributing to the migration of people from rural communities into metropolitan and suburban areas, as discussed earlier. The employment chart, included in Figure 17, shows the effects of these changes on the US economy. The data included in the chart shows a heavy concentration of employment in education and health services and professional and business services, followed by wholesale and retail trade. Following these industries is a steep drop-off in employment numbers throughout the remainder of the economy. According to the chart, the agriculture sector accounts for roughly 2.3 million jobs. The research already completed indicates this may partially be due to the amount of labor and lack of amenities involved;

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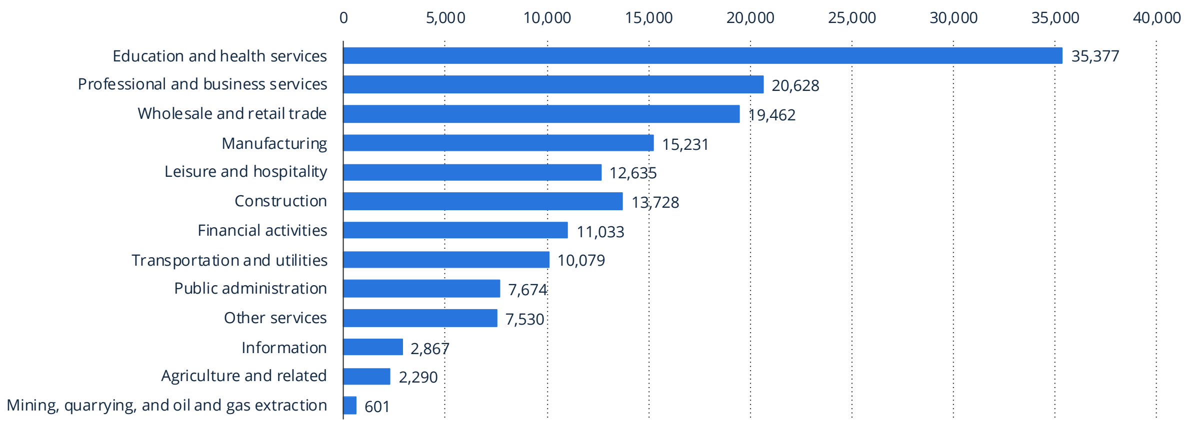
however, it leaves the industry critically understaffed. Further data analysis suggests that agriculture is the second smallest industry in the US economy, with only mining, quarrying, and oil and gas extraction creating fewer jobs, despite its position as the 4th largest value of US exports (Figure 16).

Figure 17: Total Employed Persons in the US, by Industry



Note: 2022; 16 years and older; Values in the 1,000s

Source: Statista. (2023b). US Employment. In *Statista* | *Politics & Society*. Retrieved June 16, 2023, from https://www.statista.com/study/108874/us-employment/

4.2.3 Telecommunications Industry & Equipment

This thesis has repeatedly discussed the telecommunications industry's impact on agriculture, as recently as the US government data from the USDA Census of Agriculture and the FCC in Section 4.1. Due to the critical nature of the industry on Smart AgTech implementations and its position in the middle of necessary data access, storage, and communication technologies, datasets on the industry impact and infrastructure from Statista reports will be included and broken down in section 4.2.3.

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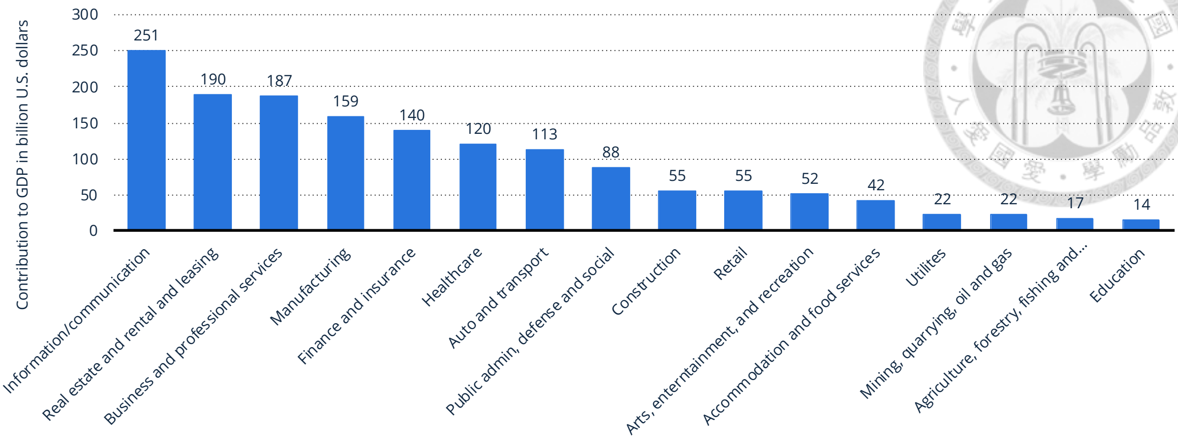
Figure 18: 5G Contribution to US GDP, by Industry



Notes: 2021-2025

Source: Statista. (2022c). Mobile communications in the US. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/12328/mobile-communications-industry-us-statista-dossier/

5G has been positioned as the key connectivity level for Industry 4.0 to succeed in most industries. Figure 18 above shows the contributions to various sectors contributing to the US GDP, which can be directly attributed to 5G. Interestingly, Agriculture is included in this chart, with 17 billion USD in GDP captured through 5G technologies. Given the earlier discussed connectivity rates within rural communities, this implies an opportunity exists within the space by implementing Agriculture 4.0 alongside the rest of the economy and Industry 4.0.

Rather than 5G connectivity, the government reporting already discussed has focused on broadband coverage in rural markets due to their focus on achieving the FCC baseline connectivity level for broadband connections (25mbps download speed/3mbps upload speed). Figure 19 below shows the breakdown of industry players in this space and their percentage of overall US coverage. This chart shows AT&T as the coverage leader with 12.17%, followed by Crown Castle at 11.59% and Verizon Fios at 10.74%, rounding out the top three coverage providers in the US.

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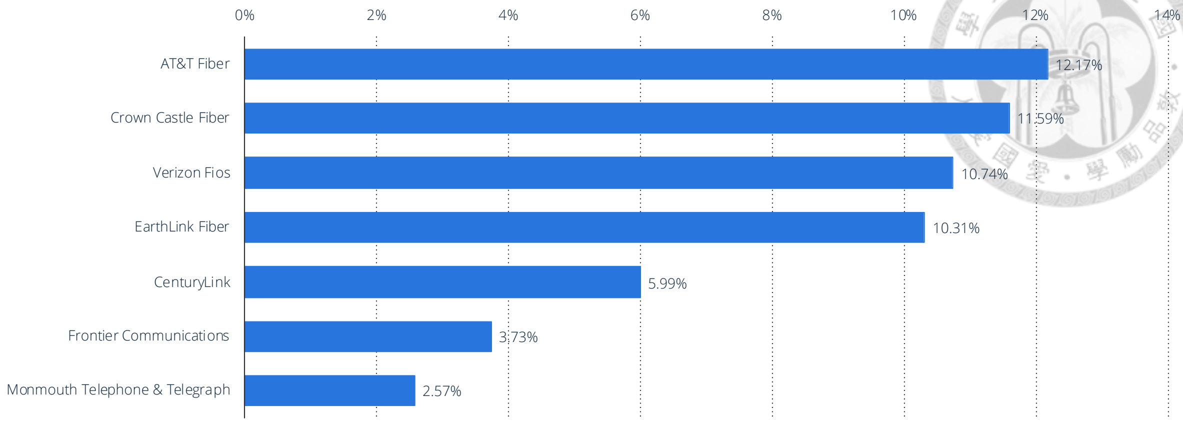
Figure 19: Fiber Broadband Coverage in the US, by Provider



Note: Data as of April 2022

Source: Statista. (2022g). Fiber broadband coverage in the United States by provider as of April 2022. In *Statista | Telecommunications*. Retrieved June 16, 2023, from https://www.statista.com/statistics/270581/us-fiber-broadband-coverage-by-provider/

While most government reporting focuses on broadband coverage and the extension of fixed-line fiber connections, mobile communications are also heavily relied upon in rural communities due to the portability of the connections or the lack of reliable fixed-line connections. Compared to the fixed-line broadband coverage considered above, Figure 20 below breaks down the telecom tower ownership in the US by company. This chart was surprising, as none of the big three major mobile communications players are listed in this dataset, as they were in the Fiber broadband coverage data. The largest players in the tower owner and operator space are American Tower, with 41,886 towers, and Crown Castle, with 40,567 towers. Both companies are public companies operating on the NYSE and lease towers to the major telecommunications players in the US, namely AT&T, Verizon, and T-Mobile. The major difference between them is that American Tower operates in 19 countries, while Crown Castle operates exclusively in the US market (Brumer-Smith, 2023).

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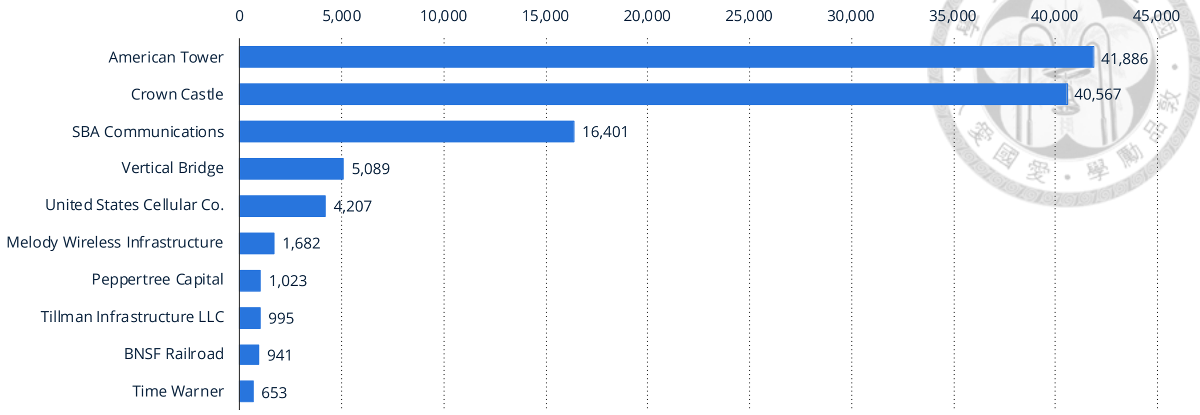
Figure 20: Number of Telecom Towers in the US, by Company



Note: Data as of July 2021

Source: Statista. (2021). Telecommunications infrastructure & equipment. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/22727/telecommunications-equipment-statista-dossier/

4.2.4 Agricultural Sector Data

Section 4.2.4 will include data and analysis of reports specifically covering the Agricultural and AgTech industries collected from Statista. The primary focus of the data is to provide a broader understanding of the industry, its challenges, and opportunities.

While various industry reports point to needing more farms rather than fewer throughout the world to maintain our populations and ensure food security, there is a trend in the US of farm and farmland reductions. Figure 21, below, depicts this shift beginning in the early 2000s and continuing through 2022. The drop visualized in the chart represents a reduction in 65 million acres of arable farmland in the US over the 22 years. This shift is not limited to farmland acreage either, as a similar picture is painted when analyzing historical farm figures included in the 2017 Census of Agriculture. According to the Census of Agriculture, the problem stems from the late 1990s. In their reporting, the USDA found that the number of farms may have peaked in 1997 at 2,215,876 and dropped consistently until the most recent Census places the total number of farms at 2,042,220 (Perdue & Hamer, 2019), which correlates with the reduction in farmland shown in Figure 21.

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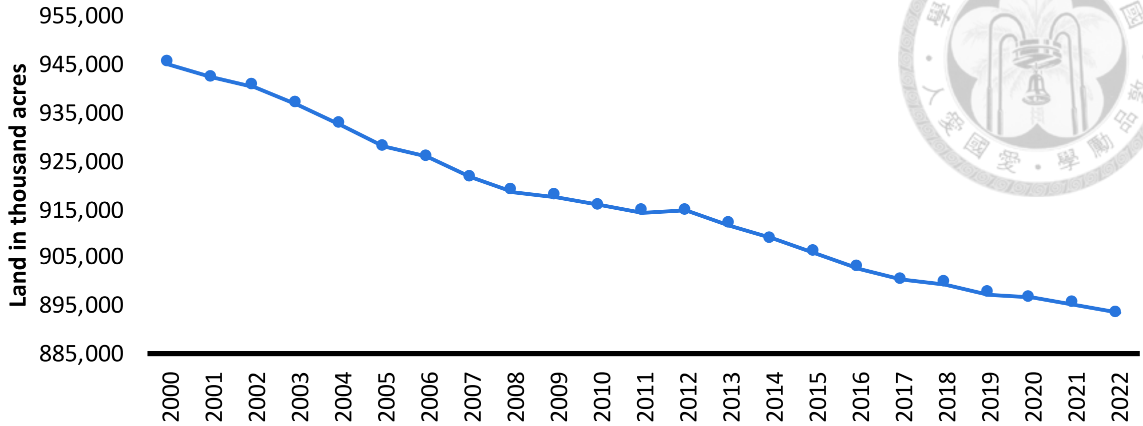
Figure 21: Total Area of Land in US Farms



Note: 2000-2022; Data values are in 1,000s of acres

Source: Statista. (2022d). US Agriculture. In *Statista | Industries & Markets*. Retrieved June 16, 2023, from https://www.statista.com/study/12270/us-agriculture-statista-dossier/

When considering the many areas Smart AgTech could impact US farms, distributions of existing expenses should be considered in discussions of implementations and investments. Figure 22, below, depicts just that; a breakdown of production expenses on US farms as of 2021, according to Statista report on US Agriculture, which gathers data from the NASS department of the USDA. The chart shows that if significant improvements could be made in labor, livestock, feeds, fuel use, chemical use, machinery, seeds, and fertilizers, then a considerable impact on overall farm operational costs could be reduced, along with the knock-on effects of more environmentally friendly practices aligning with the cost categories. According to the chart, the largest expenditure on farms in the US in 2021 was Feed, accounting for 16.6% of total expenses. It is important to note that these costs likely shift from year to year, and the inflationary pressures on the market combined with increased global conflict may have additional unaccounted-for impacts on the data in subsequent years following 2021. For example, a 2023 McKinsey Report stated that "prices for inputs such as fertilizer and crop protection have risen by 80 to 250 percent over the past few years" (Bland et al., 2023), marking a concerning trend. It is also worth noting that the report factors "self-propelled farm machinery" alongside tractors. This mention is the only data point directly

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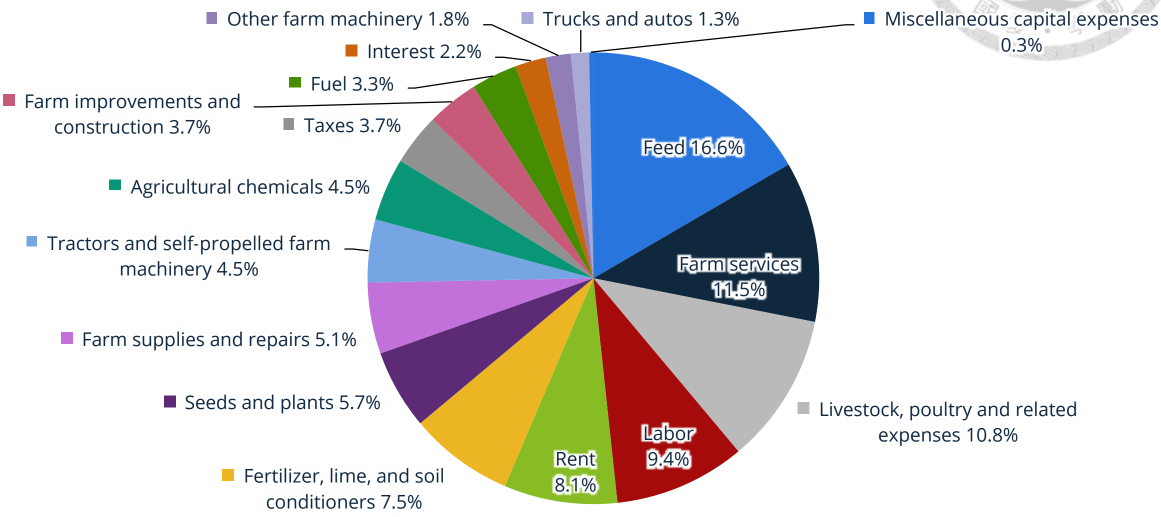
calling out a Smart AgTech solution in the report, though other categories may include other technologies and their associated costs.

Figure 22: Distribution of Total Farm Production Expenditures in the US, by Type



Note: 2021; Data excludes Alaska and Hawaii

Source: Statista. (2022d). US Agriculture. In *Statista | Industries & Markets*. Retrieved June 16, 2023, from https://www.statista.com/study/12270/us-agriculture-statista-dossier/

While Figure 22 does not show an accurate breakdown of expenditures on Smart AgTech solutions as of 2021, examining innovations in the space is worth considering further. As more players enter the space, new solutions are coming to the market annually. Globally, those innovations have centered around two categories thus far: the previously discussed IoT technologies and Robotics. Figure 23, below, depicts the worldwide share of the leading innovations within the AgTech space. This industry breakdown portrays that the sensors and data-generating technologies that culminate within IoT are leading the charge for Smart Agriculture. Robotics, AI, Drones, and Precision Agriculture technologies round out the top 5 contributors by share and collectively account for 74% of the AgTech innovations worldwide. Since it has already been established that connectivity may be a concern on American Farmsteads, there is a surprisingly small focus on the technologies that may help

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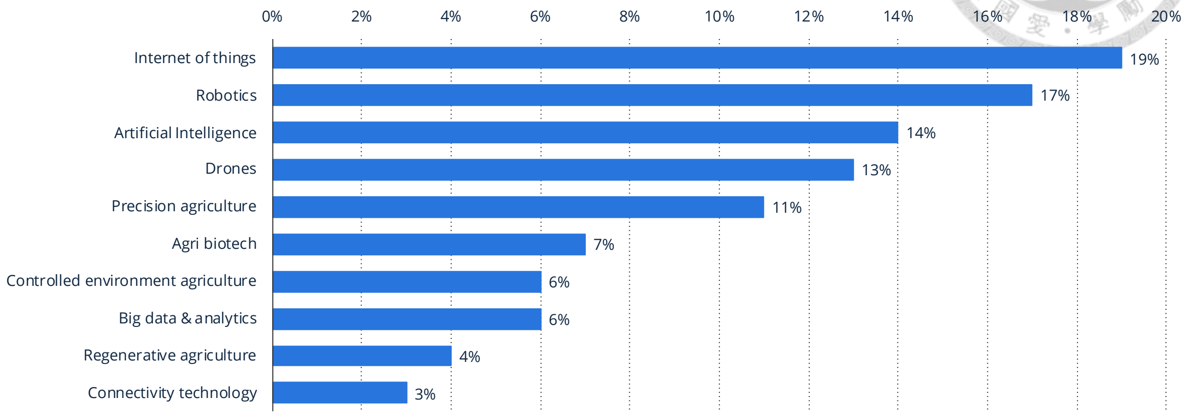
with these issues, compared to other technologies in the space, with Connectivity technologies only representing a 3% share.

Figure 23: Share of Leading AgTech Innovations, Worldwide



Note: 2022

Source: Statista. (2022e). Smart Agriculture. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/46794/smart-agriculture/

IoT market share leadership was further explored by examining the market value of the connected sensor technologies involved in the space. The study in Figure 24 broke the category down into four main classifications of Smart AgTech data-generating sensor technologies. The four main classifications chosen were: Water management, Soil management, Climate management, and Others. The study then provided two years of baseline data in 2020 and 2021 and a forecasted market value for 2026. The chart shows that soil management sensors are leading in the market overall, closely followed by water management sensors. According to the data generated, the market is expected to double in value between year-end 2021 and 2026, indicating an anticipated jump in the implementation of technologies over this timeframe.

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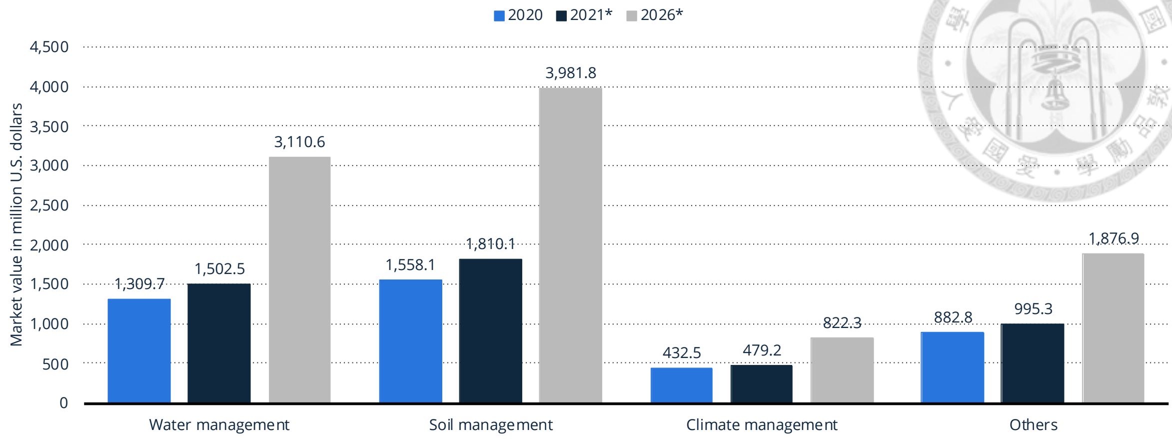
Figure 24: Global Market Value of Agriculture Sensors, by Application



Note: 2021-2026; Data values in millions of USD

Source: Statista. (2022e). Smart Agriculture. In *Statista* | *Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/46794/smart-agriculture/

The market's projected growth, expected to double in valuation by 2026, is creating a surge of interest and investment in the AgTech sector. Figure 25 offers a detailed view of this trend, showcasing the increasing flow of funding investments into AgTech from 2017 to 2021. Over these four years, investments have magnified by more than fourfold, a testament to the sector's burgeoning potential and the increasing confidence of investors. This upward trajectory is expected to persist as technological advancements and the mounting challenges the agricultural industry faces create a fertile ground for innovation. Investors are not merely drawn to the current capabilities of AgTech but are also captivated by its future potential to revolutionize agricultural practices, enhance sustainability, and increase productivity.

Furthermore, as global food demand continues to rise, the AgTech sector is recognized as a key player in ensuring food security, adding to its investment appeal. The steady escalation of funding investments is likely to fuel research and development in the sector, leading to breakthroughs that could reshape the future of agriculture. The robust growth in AgTech funding reflects a confluence of market optimism, technological progress, and a critical need for sustainable solutions in agriculture.

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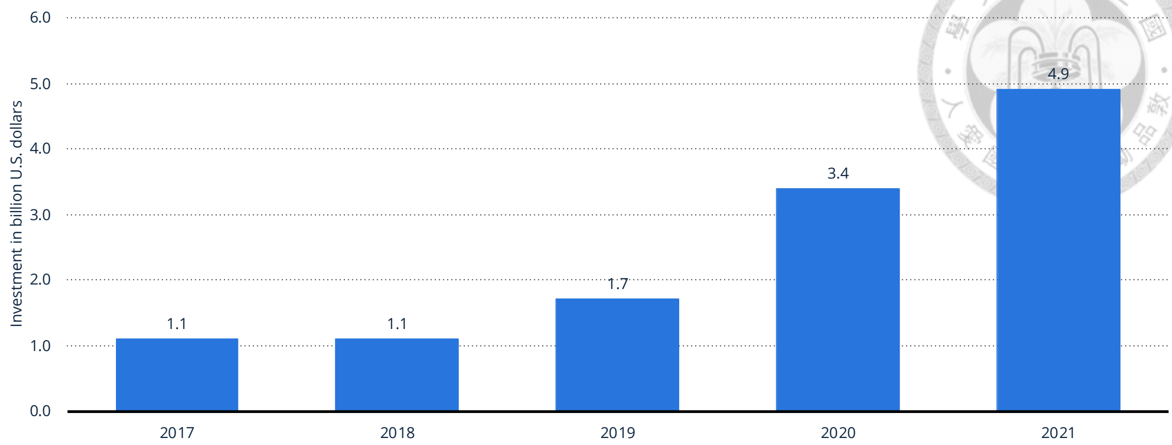
Figure 25: AgTech Funding Investments, Worldwide



Note: 2017-2021; Data values in billions of USD

Source: Statista. (2022e). Smart Agriculture. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/46794/smart-agriculture/

4.2.5 Big Data & Digital Transformation

The agricultural sector is poised to join the technological revolutions surrounding the power of big data and digital technologies. This process of transitioning from old business management styles to utilizing new technologies to generate and harness big data is traditionally known as digital transformation. All the technological advancements and opportunities previously discussed are only possible by using and understanding large-scale data to make more informed decisions about business operations. Section 4.2.5 will provide an overall picture of the Big Data analytics market and the spending on digital transformation technologies. The studies included in this section are global in scope. They provide context to the overall market and what may be expected as the Smart AgTech industry gains momentum.

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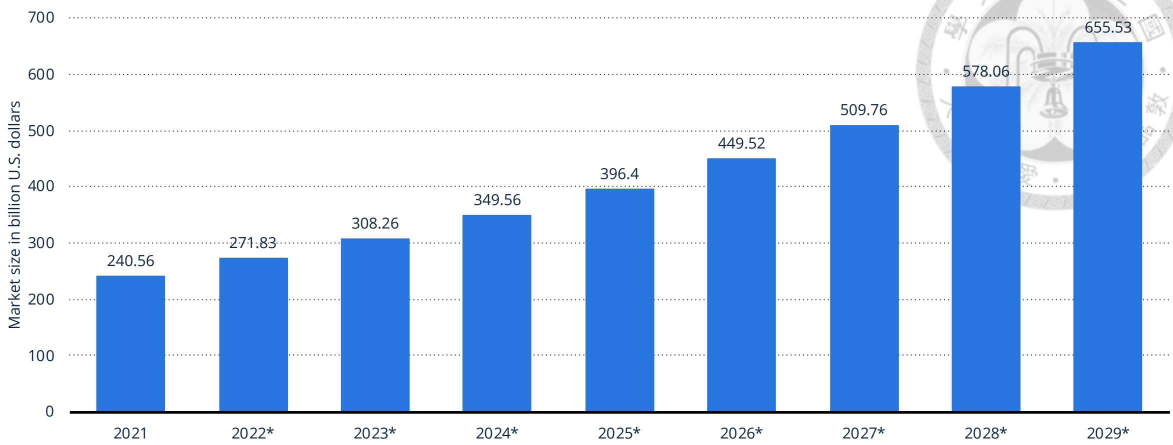
Figure 26: Size of Big Data Analytics Market, Worldwide



Note: 2021-2029; Data values in billion USD

Source: Statista. (2022f). Big Data. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/14634/big-data-statista-dossier/

While Big Data and the data generated itself are the primary topics of discussion in the space, research indicated that analysis of the data generated was an immediate need in the industry as it stands today (Javaid et al., 2022). As seen in other sectors with the implementation of IoT and Big Data solutions, the data requires significant analytics to ensure accuracy and determine advice or decision-making. Figure 26, above, depicts the size of the global data analytics market, starting in 2021 and generating forecasts through 2029. In 2021, which serves as the baseline indicator for this dataset, the big data analytics market was worth 240.56 billion USD. This value is forecasted to triple by the end of the decade, reaching 655.53 billion USD in 2029. This depicts a clear trend toward increasing the usage of big data across the global economy and insinuates that there is still significant uncaptured value in newer industries not already making widespread use of the technologies and services needed to support them.

Aside from simply discussing the need for big data services in Agriculture, the actual implementation of Smart AgTech will also require its own technologies. Referred to as digital transformation, these services, and technologies assist with getting individual sites up and running during new technology implementations. Figure 27 shows the spending on these

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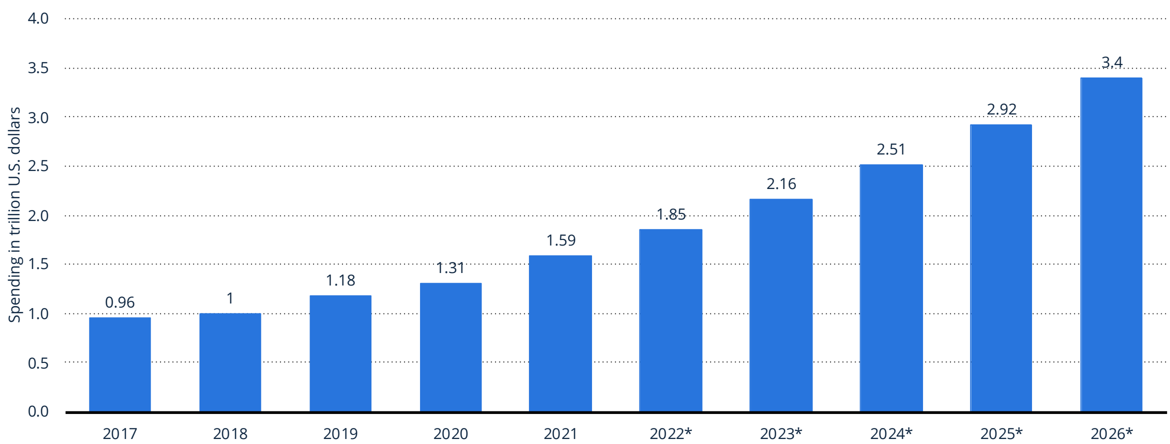
technologies worldwide, in trillions of USD, between 2017 and 2026. The data included shows 2022 as an estimated total due to the timing of the report and 2023-2026 as forecasted values. The chart depicts that following steady spending in 2017-2018 at around 1 trillion USD, spending has significantly picked up and is expected to continue at this rate as more industries come online with big data implementation projects. In the nine years, data provided for the spending on digital transformation technologies and services is expected to increase by over triple its 2017 number. These digital transformation services are often overlooked costs associated with new technology implementations and prove valuable considerations for the discussion on Smart Agriculture technologies.

Figure 27: Spending on Digital Transformation Technologies and Services, Worldwide



Note: 2017-2026; Data values in trillion USD

Source: Statista. (2022f). Big Data. In *Statista* | *Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/14634/big-data-statista-dossier/

4.3 Journals & Studies

The advent of smart agriculture, characterized by integrating advanced technologies such as IoT, big data, and machine learning, has the potential to revolutionize the agricultural sector. However, realizing this potential is contingent upon addressing several key challenges, as highlighted in this thesis, quantitative data, and four additional qualitative journals. These four journals and studies will serve as the basis of the qualitative data,

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providing discussion points in later chapters alongside the already presented quantitative data. The journals and studies will be broken out in section 4.3 by individual documents and reviewed in a document analysis fashion. The first, "Agriculture 4.0: The Future of Farming Technology," underscores the transformative potential of Agriculture 4.0 technologies in solving global food security issues (De Clercq et al., 2018). The second, “Enhancing Smart Farming Through the Applications of Agriculture 4.0 Technologies,” presents an analysis of the trends and technologies in the Smart AgTech field (Javaid et al., 2022). The third, "Federal Funding Challenges Inhibit a Twenty-first Century 'New Deal' for Rural Broadband," discusses the digital divide in the United States and the role of federal funding in addressing this issue (Greig & Nelson, 2022). Lastly, the fourth document, "A Case for Rural Broadband: Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technologies," emphasizes the importance of high-speed internet access in rural areas to advance precision agriculture practices and presents a comprehensive analysis of the potential benefits of expanding broadband infrastructure in rural America (USDA, 2019). These documents provide a comprehensive overview of the opportunities and challenges of implementing smart agriculture in rural areas. They will assist in building our case for investment opportunities in the space.

4.3.1 The Future of Farming Technology

This section will discuss the reporting in "Agriculture 4.0: The Future of Farming Technology." This report aims to present a comprehensive analysis of the future of agriculture, focusing on the challenges and potential solutions to those challenges. The main argument of the document surrounds the idea that the current agricultural model is under pressure due to four main developments: “demographics, scarcity of natural resources, climate change, and food waste” (De Clercq et al., 2018). In their report, De Clercq et al. argue that to meet these challenges head-on, a concerted international collaboration is

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required, focusing on "public/private/R&D partnerships where funding is measured on problem-solving outcomes and based on attracting the best talent to the industry" to create new goods, technologies, and market leaders (De Clercq et al., 2018). They also emphasize the role of governments in addressing these challenges. It argues that governments should improve the ecosystem and enable the development of the marketplace by offering "financial incentives, regulatory flexibility, and providing infrastructure at an affordable price" (De Clercq et al., 2018). They position that a major opportunity to drive change in the space surrounds the Smart AgTech-style technology adoption on farms worldwide. New technologies and innovations in farming practices are posed as the solution to the global hunger and food crisis. They will allow for higher profitability, efficiency, and safety, all while being more environmentally friendly (De Clercq et al., 2018).

The authors utilized several data points to support their arguments. According to their research, "the average farm will generate 4.1 million data points daily in 2050, up from 190,000 in 2014" (De Clercq et al., 2018). While this is an enormous opportunity in the space, the additional complex integrations will require technologies such as AI and ML to manage the influx of data (De Clercq et al., 2018). Further, the report cites major publications and research by the World Bank on food security and statistical analyses on deforestation and meat consumption to present some of the largest trials for the industry (De Clercq et al., 2018). Overall, the report provides a detailed analysis of their thoughts on the future of agriculture by highlighting the speedbumps and their potential solutions. De Clercq et al. stresses the need for international collaboration, governmental involvement, and the adoption of new technologies as critical to addressing the issues of hunger and food scarcity.

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Key findings:

1. The agriculture industry is under pressure from various factors, including population demographics, natural resources under stress, climate change, food waste, massive market inefficiency, and environmental threat (De Clercq et al., 2018).
2. Disruption of the system is possible by implementing new Smart Agriculture technologies and new growing techniques, using new vertical and urban farming technologies to bring food production closer to consumers, and incorporating cross-industry technologies and applications (De Clercq et al., 2018).
3. The report emphasizes the role governments need to play to bring about and facilitate changes in agriculture. The main ways suggested that governments react are through financial incentives, regulatory flexibility, and infrastructure investments (De Clercq et al., 2018).
4. Improving the collaborative efforts between businesses and the research community is imperative to success. They propose that governments facilitate innovation support projects to foster collaborations and develop new global champions with long-term partnerships (De Clercq et al., 2018).
5. Governments should invest in the entire food supply chain and identify supporting organizations emphasizing wider market synergies (De Clercq et al., 2018).

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Figure 28: Smart AgTech Solution Readiness

Smart AgTech Solutions	Ready Today	Future Technologies
Produce Differently with New Technologies	Hydroponics Algae Feedstock Bioplastics	Desert Agriculture Seawater Farming
Use New Technologies to Shorten Distances	Vertical Farming Urban Farming	Genetic Modification Cultured Meats 3D Printing
Incorporate Cross-Industry Technologies	Drone Technologies Data Analytics Internet of Things Precision Agriculture	Nanotechnology Artificial Intellegene Food Sharing & Crowdfarming Blockchain

Note: Timing from technologies available today through expected future technologies.

Source: De Clercq, M., Vats, A., & Biel, A. (2018). Agriculture 4.0: The Future of Farming Technology. *World Government Summit in Collaboration With Oliver Wyman*. Retrieved May 15, 2023, from https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2021/apr/agriculture-4-0-the-future-of-farming-technology.pdf

4.3.2 Enhancing Smart Farming with Agriculture 4.0 Technology

"Enhancing Smart Farming Through the Applications of Agriculture 4.0 Technologies" presents a comprehensive analysis of the role of Agriculture 4.0 as the future of farming. The authors argue that Agriculture 4.0, characterized by integrating technologies like IoT, blockchain, and drones, is an unstoppable trend that will revolutionize the agricultural industry (Javaid et al., 2022). They take a step further by identifying several domains of Agriculture 4.0 and smart farming, which they argue can increase efficiencies, reduce environmental impact, and improve the quality of life of farm operators through various critical technologies within the Agriculture 4.0 domain, such as sensors that monitor soil nutrition, temperature, moisture, and plant health (Javaid et al., 2022). Javaid et al. discuss the potential of these technologies to control the entire agricultural supply chain, thereby playing a significant role in transforming the overall agriculture industry (Javaid et

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al., 2022). The report asserts that Agriculture 4.0 technologies are an inevitable next step, as with Industry 4.0. The authors believe the worldwide interconnectedness via cell phones with communication and information technologies will integrate with the industry and facilitate a transformation within the strained agricultural industry (Javaid et al., 2022). They mention that a critical hurdle to the industry is communications infrastructure; however, they position the arrival of 5G and technologies such as space-based Internet as potential resolutions to the issue (Javaid et al., 2022). Data security is another critical issue, as many existing technologies lack safeguards (Javaid et al., 2022). The authors suggest that further research should be conducted surrounding Agriculture 4.0 and its potential impacts on food traceability, animal welfare, and the environmental effect of agricultural techniques (Javaid et al., 2022). Additionally, there is a need for significant investment from businesses to allow for digital transformation to continue (Javaid et al., 2022).

Key findings:

1. Agriculture 4.0, characterized by integrating technologies like IoT, blockchain, and drones, is an unstoppable trend (Javaid et al., 2022).
2. There are four main domains of Agriculture 4.0: monitoring, prediction, logistics, and control (Javaid et al., 2022).
3. Agriculture 4.0 uses drones for crop disease outbreaks, weed/pest problems, seed analysis, crop growth, soil nutrients, moisture, weather, and any factor changes in real-time (Javaid et al., 2022).
4. Critical hurdles remain for the industry, such as reliable internet connectivity and data security (Javaid et al., 2022).
5. There is a need for significant business investments in the space to facilitate changes and adapt to future challenges (Javaid et al., 2022).

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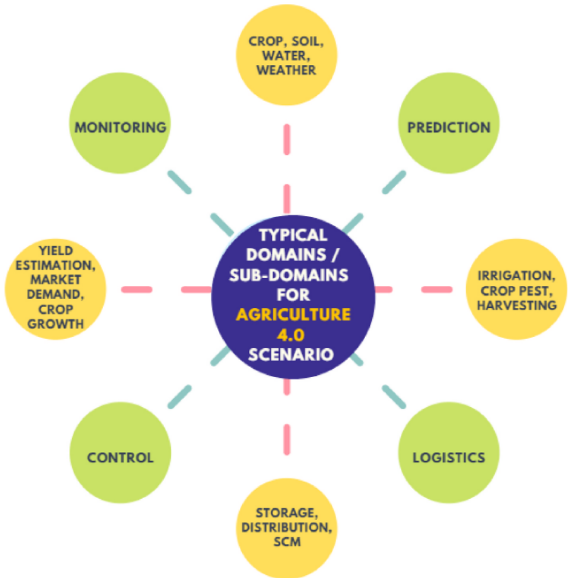
Figure 29: Agriculture 4.0 Domains



Note: Four Agriculture 4.0 domains comprise the technologies in the space alongside four sub-domains.

Source: Javaid, M., Haleem, A., Pratap Singh, R., & Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. *International Journal of Intelligent Networks*, *Volume 3 (2022)*, 150–164. Retrieved May 15, 2023, from https://www.sciencedirect.com/science/article/pii/S2666603022000173?via%3Dihub

4.3.3 Twenty-first Century "New Deal" for Rural Broadband

"Federal Funding Challenges Inhibit a Twenty-first Century "New Deal" for Rural Broadband" by Jamie Greig and Hannah Nelson presents a comprehensive analysis of the challenges faced by rural areas in obtaining federal funding for broadband infrastructure. The main argument of the document is that there are significant barriers for the regional players, such as electricity cooperatives, to invest in internet infrastructure expansion within rural areas (Greig & Nelson, 2022). Throughout the report, the authors highlight the importance of internet access in supporting precision agriculture practices, which could positively affect individual incomes and business revenues while contributing to sustainability by optimizing resource use and emissions (Greig & Nelson, 2022). They also emphasize the role of data in agriculture, suggesting that the lack of internet and related technologies could further marginalize farmers and other rural communities who lack reliable access to broadband services (Greig & Nelson, 2022). Greig and Nelson argue that the primary focus for solving the rural broadband issues should be based around the electric co-operatives created as a part

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of the Rural Electrification Administration (REA), a part of the New Deal stimulus created by President Franklin D. Roosevelt, during the Great Depression (Greig & Nelson, 2022). They argue that these co-operatives already operate in hard-to-reach areas of the US and “invest in advanced telecommunications infrastructure … to support their operations” (Greig & Nelson, 2022). Still, these installations have become overcomplicated by the Federal Government despite serving as a potential solution to rural connectivity issues.

The study employs a survey methodology, collecting data directly from 137 of the roughly 900 rural electric co-operatives that have applied for or received federal funding for broadband (Greig & Nelson, 2022). The study's findings revealed that co-operatives often lack the necessary support staff to keep up with each federal agency's compliance rules and that “70% of co-ops reported having “poor” or “very poor” experiences with federal funding processes” (Greig & Nelson, 2022). Greig and Nelson purport that giving potential relief and support to the challenges of rural co-operatives, either through training or reducing the post-award administrative burden, could encourage greater participation and “do for broadband in the twenty-first century as they did for rural electrification in the twentieth” (Greig & Nelson, 2022). Regarding recommendations, the authors suggest measures such as providing initial feedback to applicants early, reducing the volume of proposals that make it to the final round, and providing greater support to local providers, alongside the need for a concerted effort to improve the accuracy and validity of existing broadband service maps (Greig & Nelson, 2022).

Key findings:

1. The current federal funding process for rural broadband is complex and burdensome, often discouraging smaller entities from participating (Greig & Nelson, 2022).

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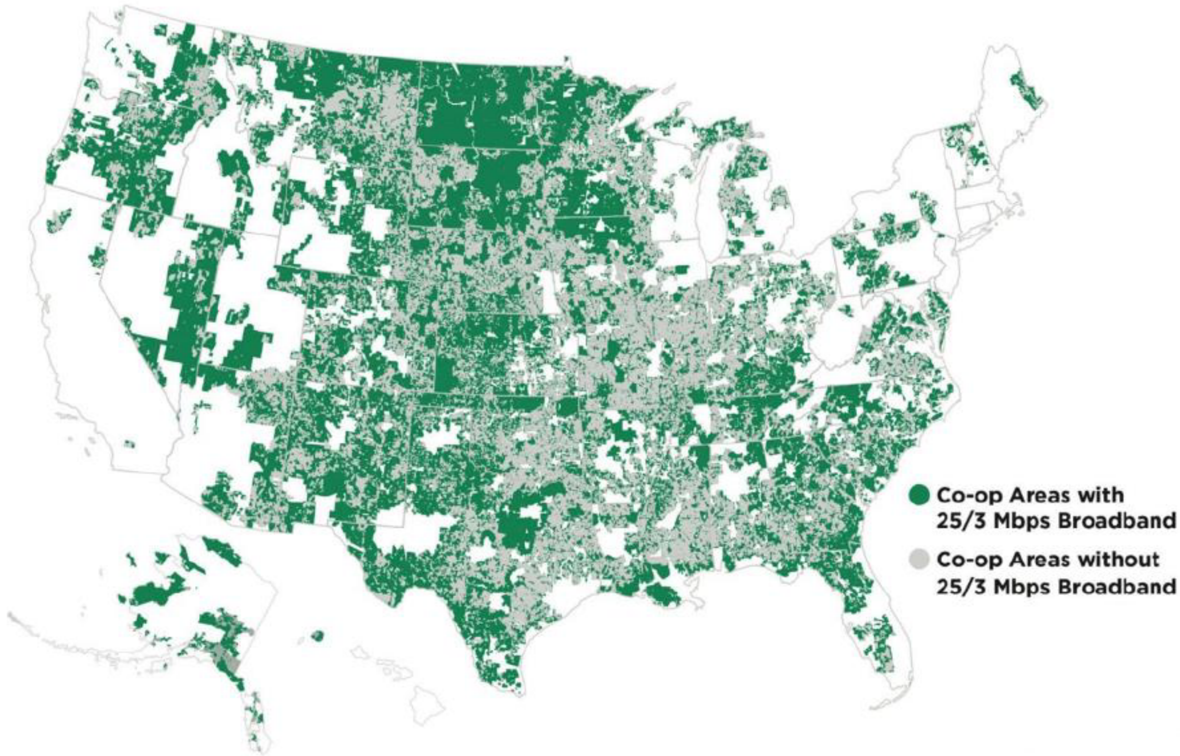
2. Rural electric co-operatives often lack the necessary support staff to keep up with each federal agency's compliance rules and often create focused subsidiaries to manage federal telecommunications projects (Greig & Nelson, 2022).
3. The broadband service maps used to determine funding eligibility are often inaccurate (Greig & Nelson, 2022).
4. The internal rate of return (IRR) for co-operatives in the included survey was between 8% and 13%, with an average of 10% (Greig & Nelson, 2022).
5. 80%-95% of cooperative fiber deployments are aerial via pole (Greig & Nelson, 2022).

Figure 30: Electric Co-Operative Areas with/without 25/3 Broadband Service



Note: Data from National Rural Electric Cooperative Association (2019)

Source: Greig, J., & Nelson, H. (2022). Federal Funding Challenges Inhibit a Twenty-first Century "New Deal" for Rural Broadband. *Choices, 3rd Quarter 2022*, *Vol. 37*(No. 3), 1–10. Retrieved June 16, 2023, from https://www.jstor.org/stable/10.2307/27201706

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4.3.4 Rural Broadband Infrastructure and Next-Gen AgTech

The USDA report titled "A Case for Rural Broadband: Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technologies" serves as the USDA's response to the Trump Administration's creation of the American Broadband Initiative. The study analyzes the potential benefits of expanding broadband infrastructure in rural America and encouraging the adoption of next-generation precision agriculture technologies (USDA, 2019). The document's main argument is that expanding broadband connectivity in rural areas is crucial for the modernization of agriculture and the overall economic development of these regions, with the potential to create significant value through digital transformation in the agricultural sector (USDA, 2019). Interestingly, the report notes that "attempts to increase broadband deployment have not replicated the nationwide rural electrification effort of the last century" (USDA, 2019), tying in directly with the analysis in Section 4.3.3. The USDA further highlights the need for coordination across public programs to use taxpayer funds and develop new partnerships more effectively by "offsetting high up-front costs through direct [investments]" in operations (USDA, 2019). The USDA report uses a variety of data and evidence to support its arguments, including onsite "research visits to 31 [locations] in seven agriculture-rich states" to hold discussions with producer association leaders, AgTech executives, researchers, and telecommunication providers about the next generation in smart agriculture technologies (USDA, 2019).

The report's implications are significant, suggesting that investments like those made for the nationwide rural electrification effort of the last century may be required to unlock the economic gains from connectivity for rural businesses and households (USDA, 2019). It also emphasizes the need to build the capability to significantly scale up the adoption of new technologies and realize value from these investments (USDA, 2019). The USDA argues that this will require a multi-stakeholder approach across industries, governments, researchers,

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educators, incubators, and financers to succeed (USDA, 2019). The report highlights the limitations of its findings, noting that it does not calculate the cost of implementing these smart agriculture technologies due to the “lack of clear, accurate, and publicly available data sources” (USDA, 2019). The report notes that it is challenging to determine if these technologies will have effects on the marketplace in the same way as the economic benefits of rural electrification did in the 1930s; however, what they do know is that other technological shifts have shown similar productivity increases to electrification, and thus Smart Agriculture may as well (USDA, 2019).

Key findings:

1. “Low population [density] in rural areas and … high cost[s] of installing and operating Internet infrastructure present a non-viable proposition …, disincentivizing large-scale private investment in rural … infrastructure” (USDA, 2019).
2. Similar investments to rural electrification efforts in the twentieth century are likely needed to increase connectivity rates in rural communities adequately (USDA, 2019).
3. Expanding broadband connectivity will likely promote increased technology usage on farms, address labor shortages, and improve compliance with government requirements (USDA, 2019).
4. The report indicates that there could be improvements in both efficiency and quality of life, such as better access to healthcare and educational facilities for rural communities (USDA, 2019).
5. Stakeholders must engage “digital natives” to accelerate the adoption of Smart Agriculture Technologies, and broadband connectivity will facilitate their involvement in the space (USDA, 2019).

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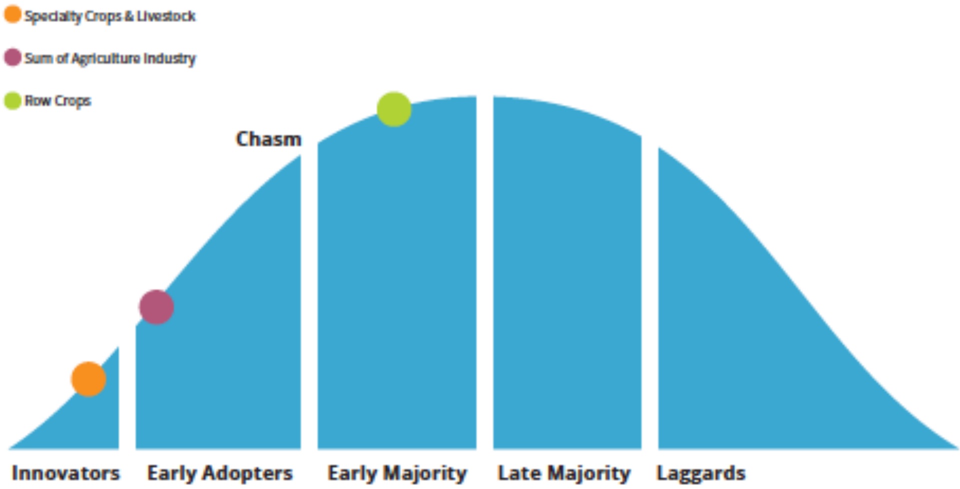
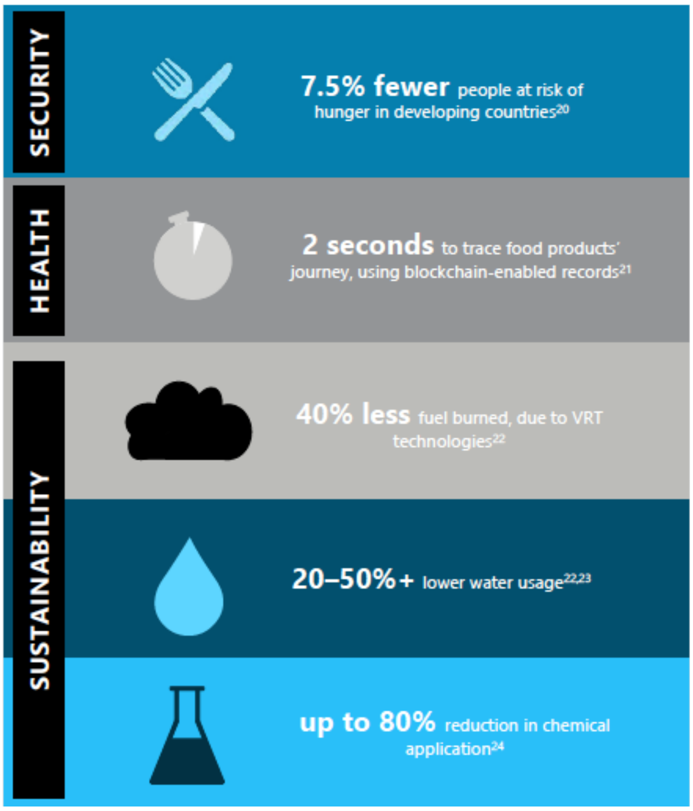
Figure 31: Estimation of Agriculture on the Technology Adoption Curve



Source: USDA. (2019). A Case for Rural Broadband: Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technology. In *USDA*. from https://www.usda.gov/sites/default/files/documents/case-for-rural-broadband.pdf

Figure 32: Societal Benefits of Smart Agriculture



Source: USDA. (2019). A Case for Rural Broadband: Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technology. In *USDA*. from https://www.usda.gov/sites/default/files/documents/case-for-rural-broadband.pdf

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Chapter 5: Discussion

In Chapter 4, qualitative and quantitative datasets were introduced to the discussion to provide the basis for analyzing the Smart AgTech industry and whether there is an investment opportunity in the space for US Telecommunications organizations and individual investors. The data included aimed to give a holistic view of the industry, and the existing trends and patterns, which provide valuable insights into the Smart AgTech field. This chapter will collectively discuss and interpret the findings based on the research questions.

5.1 Findings

5.1.1 USDA Census of Agriculture Data

Analyzing the USDA Census of Agriculture data quickly pointed to a few noticeable trends from the literature review: an aging population of owner-operators, an industry operating on persistent losses, and an improving but slow permeation of internet access to farms and rural communities. Research showed that between the 2012 and 2017 USDA Census of Agriculture, the average age of producers in the US increased by 1.2 years to 57.5 years old and showed that the Midwest had the youngest average age of producers in the US (USDA NASS, 2017a). This suggests that fewer producers in younger generations are joining the industry or that they are leaving the industry at a higher rate than older producers. Given the propensity of more youthful generations toward urban metropolises along with better optics, amenities, economic opportunities, and outcomes (Lloyd, 2019), it is more likely that fewer are joining at all. A more surprising finding was that based on US tax reporting, more US farms have functioned with operating losses yearly from 2000-2020 than have operated with positive net income every year of the 20 years (USDA ERS, n.d.). This paints a concerning picture of the industry, which certainly affects the overall views of this critical function of the economy. Many of the additional sources point to internet access, or the lack thereof, as a major potential contributor to these issues and indicate it will be necessary to

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remedy for improvements to come to the industry. Since 2007, the USDA has included data on farm internet access in its Census of Agriculture reports, though internet technology has vastly shifted. Basing their reporting on the FCC recommendations surrounding broadband access qualifications, which are annually offered to Congress, the USDA data shows that internet access has improved overall accessibility and speeds between 2007 and 2017 (USDA NASS, 2017b). Despite widespread access improving, there are still over 14.5 million, mostly rural, Americans without basic access to the Internet (Commissioner Carr, 2021). Aside from simply accessing the vast markets within the US, stable broadband access is necessary to implement Smart Agriculture digital transformations, and even the FCC baseline broadband access may not be sufficient. While the USDA and FCC focus on Broadband 25/3 access, industry reporting suggests that download/upload speeds will likely need to be 300 Mbps for efficient functionality of some Smart AgTech machinery (Vittek, 2022). Furthermore, it is important to note at this juncture that this study chose to focus on fixed-line terrestrial broadband services, in line with FCC reporting to Congress. While mobile services are an important part of the telecommunications landscape, and rural community access to the internet, there is wide variability in the availability and speed of such connections. The FCC also utilizes a much lower benchmark for analysis in this sector, at 5/1mbps or 10/3mbps, deemed too low and variable to be viable options for Smart AgTech implementations as a part of this study (Commissioner Carr, 2021). Similarly, satellite communications methods, such as Starlink (operated by Space X), were deemed to have too low an adoption rate at this time and may be significantly impacted by capacity constraints (Commissioner Carr, 2021) or be overly reliant on weather conditions for reliable usage. These tools may continue to improve and could be reliable alternatives in the future; however, in line with FCC reporting, this study has chosen to stick to considerations surrounding fixed-line terrestrial broadband access as the basis of industry needs.

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5.1.2 Smart Agriculture Industry Datasets

While the USDA data started to point to the needs of the Smart AgTech industry, further research was required to build a case for the overall industry. Industry datasets from Statista, a major statistics and industry data organization, were included and analyzed to establish a comprehensive view of market opportunities. GHG emissions must be considered to frame investment opportunities in the space as having positive ESG outcomes for potential stakeholders. Currently, the Agriculture industry is the 4th largest contributor to the US economy (Statista, 2022a). While this represents an enormous GHG output, data suggests Smart Agriculture Technologies could significantly reduce the industry's environmental impact (USDA, 2019), suggesting that investing in new technologies will result in positive ESG implications. Despite the Agriculture industry's negative effects on the environment, it remains a major and critical segment of the US and Global economies. Even with the importance of the industry as the 4th largest value of US exports (Statista, 2022b), it creates the second-fewest jobs in the economy (Statista, 2023b). This should indicate a potential for high-profit margins; however, as earlier USDA data pointed out, an above-average number of US farms operate with losses annually (USDA ERS, n.d.).

According to a report on the telecommunications industry in the US, 5G connectivity has contributed 17 billion USD to the US GDP (Statista, 2022c), which was a surprising statistic based on the levels of rural connectivity versus more urban settings found throughout the research. It is worth considering that many of the reports surrounding connectivity focus on fixed-line broadband access rather than mobile or satellite wireless communication methods, which are considered less reliable than fixed-line service. While wireless communications are more likely to have connection issues than fixed line services, mobile communication services are critical in rural communities as residents may have access via cellular service providers using one of the 113,444 telecom towers around the US (Statista,

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2021), where there may be no available reliable broadband service providers. As noted in the prior section, these connections utilize a different benchmark for connection levels and are difficult to obtain reliable first-party speed data from, so are typically considered separately from fixed-line services (Commissioner Carr, 2021).

A snapshot of farm production expenditures gave an interesting insight into potential opportunities. Based on available reporting from 2021, 41.2% of farm expenditures (Statista, 2022d) are in expense categories that Smart AgTech solutions have the potential to impact. Further, a McKinsey reports purports that some inputs, such as fertilizers, have increased in price by up to 250% since 2021 (Bland et al., 2023). These significant inflationary pressures on agriculture create the market necessity for more widespread adoption of smarter distribution practices, which are promised by those operating within Smart AgTech. These technologies thus have the potential to both reduce input costs and environmental impacts due to their use. This style of Precision Agriculture technology, alongside the artificial intelligence technologies likely used to run the system, is in the top 5 AgTech innovations worldwide by share (Statista, 2022e). By far, the largest share of innovations globally is in the IoT space, which in Smart AgTech is largely driven by the connected sensor technologies that generate much of the information on-site (Statista, 2022e). The market value contribution of Smart AgTech sensors is poised to double over the next three years (Statista, 2023e), indicating a significant increase in implementation in the coming years. An industry forecast to double the value in each sensor category in such a short period suggests a positive shift in the market conditions surrounding Smart AgTech. This idea is further strengthened by a trend of increasing investment value in the AgTech space every year since 2018 (Statista, 2022e).

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5.1.3 Journals & Studies

The four Journals and Studies included as qualitative datasets all provide unique viewpoints on the Smart AgTech industry and give a varying scope of the future needs and opportunities in the space. “Agriculture 4.0: The Future of Farming Technology” argues that the current agricultural model is under tremendous stress, which will require new partnerships to solve (De Clercq et al., 2018). A need for innovation and collaboration to bring about changes to the market may incentivize larger investments in the space. The authors reinforce the position that implementing Agriculture 4.0 can revolutionize the industry and significantly increase farm efficiencies; however, they argue that there must be a multi-stakeholder partnership approach to achieve real results (De Clercq et al., 2018). They note that governments need to step in and assist in market development through direct investments in the ecosystem and offers of financing, regulatory flexibility, and infrastructure (De Clercq et al., 2018). Should governments step-up investments to further incentivize digital transitions within agriculture, the value of Smart AgTech-related projects, research, and organizations will significantly increase, further aligning with the findings in this study.

“Enhancing Smart Farming Through the Applications of Agriculture 4.0 Technologies” positions Smart AgTech innovation as an unavoidable inevitability, underlining the significant momentum surrounding the movement (Javaid et al., 2022). This momentum suggests an opportunity exists for new entrants to invest in the space, which aligns with this study's research findings. They believe the widespread use of cell phones and ease of technology access will play a role in the industry transformation (Javaid et al., 2022). A key challenge highlighted within the report is communications infrastructure, which is critical to the industry's success (Javaid et al., 2022) and echoes earlier discussions within this thesis. Without access to reliable broadband service, Smart AgTech cannot exist.

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"Federal Funding Challenges Inhibit a Twenty-first Century "New Deal" for Rural Broadband" centers around rural electrical co-operatives and accessing federal funding to expand Broadband service to more rural communities (Greig & Nelson, 2022). Since telecommunications companies have been positioned at the center of this industry in this study, and prior data has shown that there are a significant number of Americans without access to the internet, this report brought a new perspective to this thesis discussion. Greig and Nelson position the issue of Broadband connectivity on the rural electric co-operatives created as a part of the New Deal rather than simply as a lack of investment by large traditional telecommunications providers in hard-to-reach areas (Greig & Nelson, 2022). Granted, despite a seeming willingness to install and operate the connections, federal regulations, and stipulations to receive grant money make it incredibly difficult to maintain, leaving many to avoid trying altogether (Greig & Nelson, 2022). Survey results as a part of the study also show that these infrastructure investments have an average IRR of 10% (Greig & Nelson, 2022). This further suggests that, given proper assistance from the federal government, these investments could net higher returns, either for these electric co-operatives or other investors.

"A Case for Rural Broadband," unlike the other three studies, is a USDA government report on Smart AgTech and the necessity for more widespread broadband access to incentivize the adoption of new Smart Agriculture technologies (USDA, 2019). Going beyond agriculture, the report suggests that economic development in rural communities also hinges on more reliable connections (USDA, 2019). Again, this report places telecommunications operators at the center of the industry, in line with the discussions in this thesis. The data from the report comes from various government and industry sources and direct visits to several locations around the country for industry discussions on Smart AgTech, which included telecommunications providers (USDA, 2019). Like the findings of

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Greig and Nelson, as discussed prior, the USDA concluded that a New Deal style approach to broadband may be necessary to incentivize internet access expansion adequately (USDA, 2019). One of the report's most interesting points surrounded the discussion of rural electrification and its unintended economic benefits, further noting that all technological shifts since have resulted in very similar productivity shifts (USDA, 2019). If the trend continues with the adoption of Smart AgTech innovations, the industry is poised for significant benefits and would mark a positive investment opportunity.

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Chapter 6: Recommendations & Conclusion

In Chapter 6, the research included in this thesis will be concluded, alongside recommendations for further study on this topic and a discussion of study limitations. This chapter will seek to provide an answer to the research questions and conclude the discussion.

6.1 Conclusion

The agriculture industry has been a testament to humanity's unceasing drive for innovation throughout history. Smart AgTech is the next step in this unending push for more efficiency and sustenance for ever-growing populations. While many sectors are undergoing rapid transformations with the advanced tools and technologies becoming available through innovations, there is a distinct surge of momentum in the agricultural industry surrounding Smart AgTech. This momentum is largely driven by the large North American agriculture economies, particularly within the United States. The US is known for pioneering new industries and driving technological advances, and once again has positioned itself at the forefront in the global drive to push the boundaries of what is possible through the merging of technology and agriculture. This thesis initially set out to prove that there was a latent and overarching investment opportunity in the Smart AgTech sector and the opportunities current research points to through its implementations. As more and more research and data were compiled, it became very clear that there was a vast opportunity for an unexpected, although major, player in the space. Report upon report pointed to an underlying synergistic and potentially pivotal role for telecommunications operators within this growing space. Historically, agriculture and telecommunications operated out of at least semi-siloed portions of the economy, separated by economies of scale and high operating costs outside the densely populated urban centers. This difference in business operations costs and the lack of nationalized providers within the privatized US telecommunications economy created the conditions necessary for the "digital divide" to persist and grow. As technology has continued

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to march forward, parts of the country were left behind, only slowly gaining access to reliable internet connections and the baseline needs to join the revolutions occurring in other sectors of the economy, albeit significantly later. Much of the research investigated pointed to the fact that for Smart AgTech to have the opportunity to flourish, to truly revolutionize the way we farm, a robust telecommunications backbone is not only advantageous but essential. Of course, this will require a rethink of the industry, the costs involved, and likely the stakeholders needed to facilitate such a change, meaning there is ample opportunity for value creation. Other researchers similarly found that insights from the New Deal era in US history are imperative to truly appreciate the opportunity at hand. The government-driven rural electrification projects that connected rural America and its farmland to the electric grid served as the catalyst for far-reaching impacts across the American economy. Similarly, reliable internet connectivity will ultimately open the door for further Smart AgTech expansions, driving a digital transformation across the industry and presenting a once-in-a-generation investment prospect.

Modern investment opportunities must also include considerations outside of financial metrics as well. Investments in Smart AgTech can thus be positioned as more than capital allocations; they can represent a commitment to a trifecta of ESG principles: Environmental resilience, Social equity, and good Governance. By funneling resources into Smart AgTech, stakeholders boldly commit to championing more sustainable agricultural practices, bringing more opportunities to underserved rural communities, and ensuring more ethical and transparent practices in the sector. Aside from the draw of significant potential returns and ethical imperatives, the world is racing against time. The complex interplay of geopolitical tensions, such as the current war in Ukraine, the alarming pace of climate change, and the looming challenge of feeding an ever-expanding global populace, creates an urgent backdrop for the industry. Research suggests that by 2050, the agricultural sector will be tasked with

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upping its current output by an astounding 70%, while also requiring a significant reduction in emissions and pollution. The tools, technologies, and methods under the Smart AgTech umbrella are thus not simply innovations for profit; they are necessities in our collective quest for human survival. The Smart AgTech sector is a testament to human ingenuity and a call for collective action. The industry offers a rare blend of promising investment returns, positive ethical engagements, and tangible solutions to some of the world's most pressing challenges. Potential investors will choose to be spectators in the coming revolution or actively participate and shape a more sustainable and prosperous future for all.

6.2 Recommendations for Further Study

There are ample opportunities for future studies on Smart AgTech by building on the foundations of this research. First and foremost, more primary research could be employed, particularly in the form of in-depth interviews or ethnographic studies with farmers and agricultural workers directly impacted by smart agriculture technologies. Such research could provide a deeper understanding of their experiences, perceptions, and potential resistance or acceptance of these technologies and shed light on the value of the real opportunity in the market. Further studies could also delve into the economic implications of smart agriculture more deeply, particularly in terms of cost-benefit analyses, if greater access to industry data became available. This could provide an understanding of the economic viability of Smart Agriculture Technologies for farmers of different scales, from small operators to large agri-businesses. This type of data would be highly valuable in the decision-making process of Smart AgTech implementations. Other areas of consideration could be around the impacts of increasingly centrally owned technologies and data models on the industry and the impacts of removing the "human touch" from the industry through agribot and AI usage. Additionally, agriculture-specific internet protocols as potential solutions could be studied alongside other types of connectivity, such as mobile and satellite communications. Finally, future research is

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needed into policy and regulatory frameworks surrounding Smart AgTech; as these technologies continue to develop and proliferate, they will undoubtedly raise new legal, ethical, and regulatory challenges. Studies exploring these aspects would not only advance academic understanding but could also inform policymaking and industry practices. Given the rapid pace of technological change and the crucial role of agriculture in our society and economy, smart agriculture is a field ripe for future investments and academic exploration. This research is but one step in what should be a broader and ongoing conversation about how to harness technology for a sustainable, efficient, and equitable future for food production.

6.3 Limitations of Study

While this research offers valuable insights into the market potential and challenges of Smart AgTech, it also must acknowledge certain limitations. Firstly, the findings rely heavily on secondary data and literature reviews, which may not capture all the nuances and complexities of real-world farming operations and the impacts of Smart AgTech implementations. Also, utilizing the document analysis method could have left out some critical aspects that a more direct, primary research approach may have revealed. Secondly, the rapidly evolving nature of smart agriculture technologies is a limitation as the research was conducted over a specific period; it is possible that more recent technological developments have yet to be included due to a lack of data availability. This dynamic nature of the industry also introduces a degree of uncertainty to future predictions and trends included in secondary datasets. Thirdly, this study has a broad scope encompassing a market-wide perspective on smart agriculture. However, due to the need for more specific and accurate data sources on the industry, potential investment returns and other financial considerations could not be included. Lastly, the study does not delve into how different farming communities may perceive and adopt smart agriculture technologies. As such, the

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social and cultural factors influencing the acceptance of smart agriculture still need to be fully explored, which is a critical aspect of technology implementation.

Despite these limitations, this research lays the groundwork for further explorations into Smart AgTech, and the numerous investment opportunities in the fledgling industry.

doi:10.6342/NTU202304035

Bibliography

(2020, March). *Future of Mobile | How Telcos can Unlock New Value Through Total Societal Impact*. GSMA. Retrieved November 30, 2022, from https://www.gsma.com/betterfuture/the-future-of-mobile

(2021, March 8). *Blockchain In Agriculture And Food Supply Chain Global Market Report 2021: COVID-19 Growth And Change.* GlobeNewswire News Room. Retrieved November 30, 2022, from https://www.globenewswire.com/news-release/2021/03/08/2188585/0/en/Blockchain-In-Agriculture-And-Food-Supply-Chain-Global-Market-Report-2021-COVID-19-Growth-And-Change.html

AeroFarms - Vertical Farming, Elevated Flavor.TM. (2023, April 17). *About AeroFarms 🌱 The Vertical Farming, Elevated Flavor Company.* AeroFarms. Retrieved April 12, 2023, from https://www.aerofarms.com/about-us/

Ag, I. (n.d.). *Improving sustainability and profitability in agriculture | Indigo Ag*. Retrieved April 12, 2023, from https://www.indigoag.com/about

Agriculture, Executive Yuan, R.O.C.(Taiwan), C. O. (2021, February 2). *Council of Agriculture, Executive Yuan, R.O.C.(Taiwan)*. Smart Agriculture in Taiwan－Council of Agriculture, Executive Yuan, R.O.C.(Taiwan). Retrieved November 30, 2022, from https://eng.coa.gov.tw/ws.php?id=2505648

Agriculture, Executive Yuan, R.O.C.(Taiwan), C. O. (n.d.). *Council of Agriculture, Executive Yuan, R.O.C.(Taiwan).* Statistics－Council of Agriculture, Executive Yuan, R.O.C.(Taiwan). Retrieved November 30, 2022, from https://eng.coa.gov.tw/ws.php?id=2505449&page=3

Aminetzah, & Magnin-Mallez. (2022, October 16). *A renewed call for food security on World Food Day*. McKinsey & Company. Retrieved November 30, 2022, from https://www.mckinsey.com/featured-insights/themes/a-renewed-call-for-food-security-on-world-food-day

Basu, P., & Chakraborty, J. (2017). New technologies, old divides: linking internet access to social and locational characteristics of US farms. *GeoJournal, Vol. 76*(No. 5 (2011)), 469–481. Retrieved June 16, 2023, from https://www.jstor.org/stable/41308635

Bland, R., Ganesan, V., Hong, E., & Kalanik, J. (2023, May 31). *Trends driving automation on the farm*. McKinsey & Company. Retrieved June 1, 2023, from https://www.mckinsey.com/industries/agriculture/our-insights/trends-driving-automation-on-the-farm#/

Bock, Wilms, Woods, & Young. (2020, July 20). *The Multitrillion-Dollar Social Impact Opportunity for Telcos*. BCG Global. Retrieved November 30, 2022, from https://www.bcg.com/publications/2020/multitrillion-dollar-social-impact-opportunity-for-telcos

Bonivel, J., Jr. (2022). The Data Divide: How Emerging Technology and its Stakeholders can Influence the Fourth Industrial Revolution. *Atlantic Council (2022).* Retrieved June 16, 2023, from https://www.jstor.org/stable/resrep43399.3

Brock, T. (2022, February 23). *Environmental, social and governance (ESG) criteria*. Investopedia. Retrieved December 15, 2022, from https://www.investopedia.com/terms/e/environmental-social-and-governance-esg-criteria.asp

doi:10.6342/NTU202304035

Brown, R., Barram, D., & Irving, L. (1995). Falling Through the Net: A Survey of the "Have Nots" In Rural and Urban America. In *NTIA.gov*. Retrieved May 27, 2023, from https://ntia.gov/page/falling-through-net-survey-have-nots-rural-and-urban-america

Brumer-Smith, L. (2023, March 16). Better Buy: American Tower or Crown Castle? *The Motley Fool*. Retrieved June 16, 2023, from https://www.fool.com/real-estate/2023/03/16/better-buy-american-tower-or-crown-castle

Chairman Martin & Commissioners Copps. (2007). Development of Nationwide Broadband Data to Evaluate Reasonable and Timely Deployment of Advanced Services to All Americans, Improvement of Wireless Broadband Subscriber Data, and Development of Data on Interconnected Voice over Internet Protocol (VoIP) Subscribership. *In FCC.gov (FCC 07-17)*. Retrieved May 20, 2023, from https://docs.fcc.gov/public/attachments/FCC-07-17A1.pdf

Chen, M., Mao, S., Liu, Y., (2014). Big Data: a survey. *Mobile Netw Appl 19*, 171–209.

Climate Change Impacts on Agriculture and Food Supply | US EPA. (2022, December 13). US EPA. Retrieved December 15, 2022, from https://www.epa.gov/climateimpacts/climate-change-impacts-agriculture-and-food-supply

Cole, J.B., Newman, S., Foertter, F., Aguilar, I., Coffey,M., (2012). Breeding and Genetics Symposium: really Big Data: processing and analysis of very large data sets. *J. Anim. Sci. 90*, 723–733.

Columbus, L. (2021, February 17). 10 Ways AI Has The Potential To Improve Agriculture In 2021. *Forbes*. Retrieved December 18, 2022, from https://www.forbes.com/sites/louiscolumbus/2021/02/17/10-ways-ai-has-the-potential-to-improve-agriculture-in-2021/?sh=375f5ea07f3b

Commissioner Carr. (2021). Fourteenth Broadband Deployment Report. *In FCC.gov (FCC 21-18)*. Retrieved May 20, 2023, from https://docs.fcc.gov/public/attachments/FCC-21-18A1.pdf

De Clercq, M., Vats, A., & Biel, A. (2018). Agriculture 4.0: The Future of Farming Technology. *World Government Summit in Collaboration With Oliver Wyman.* Retrieved May 15, 2023, from https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2021/apr/agriculture-4-0-the-future-of-farming-technology.pdf

ESG Evaluation | S&P Global Ratings. (n.d.). www.spglobal.com. Retrieved November 30, 2022, from https://www.spglobal.com/ratings/en/products-benefits/products/esg-evaluation

European Space Agency, (2016). *Fish farms guided by Sentinels and the cloud.* Retrieved May 27, 2023 from http://www.esa.int/Our_Activities/Observing_the_Earth/Fish_farms_guided_by_Sentinels_and_the_cloud

Faulkner, A., Cebul, K., & McHenry, G. (2014). Agriculture gets smart: the rise of data and robotics. *Cleantech Agriculture Report.*

Ferguson. (2022, November 2). *Labor Shortages Continue to Impact Farmers. Labor Shortages Continue to Impact Farmers*. Retrieved November 30, 2022, from https://www.fb.org/viewpoints/labor-shortages-continue-to-impact-farmers

Ganesan, V., Katz, J., Mannion, P., Bengston, O., Feng, S., Kitchel, H., Prabhala, P., Richter, A., Roen, W., & Vleck, J. (2023, June 27). *The agricultural transition: Building a sustainable future*. McKinsey & Company. Retrieved June 30,

doi:10.6342/NTU202304035

2023, from https://www.mckinsey.com/industries/agriculture/our-insights/the-agricultural-transition-building-a-sustainable-future

Getting Started. (n.d.). Federal Aviation Administration. Retrieved April 15, 2023, from https://www.faa.gov/uas/getting_started

Grand View Research. *Smart Agriculture Market Size, Share & Trends Analysis Report By Type (Precision Farming, Livestock Monitoring, Smart Greenhouse, Others)*, By Application, By Region, And Segment Forecasts, 2023 - 2030. (n.d.). Retrieved May 2, 2023, from https://www.grandviewresearch.com/industry-analysis/smart-agriculture-farming-market

Greig, J., & Nelson, H. (2022). Federal Funding Challenges Inhibit a Twenty-first Century "New Deal" for Rural Broadband. *Choices, 3rd Quarter 2022*, Vol. 37(No. 3), 1–10. Retrieved June 16, 2023, from https://www.jstor.org/stable/10.2307/27201706

Grobart, S., (2012). *Dairy industry in era of Big Data: new gadgets help farmers monitor cows and analyze their milk.*

Grow Pesticide-Free Produce & Multiple Crops at Once | Plenty. (2022, November 2). Plenty. Retrieved April 12, 2023, from https://www.plenty.ag/mission/

Harnden, R., Hoang, N., & Lafond-Wise, L. (2022, May 27). Smart Agriculture as a Social Impact Investment Opportunity [Unpublished presentation]. College of Management, GMBA, National Taiwan University. Retrieved November 30, 2022

Internet of Things for Smart Agriculture. (n.d.). *In Internet of Things for Smart Agriculture*. Chunghwa Telecom. https://smartcity.org.tw/b2b/upload/ecatalog/supplier_pdf_en_8_767.pdf

IOT TRANSFORMING THE FUTURE OF AGRICULTURE | IOT Solutions World Congress | MAY 21 – 23 BARCELONA. (2019, July 10). IOT Solutions World Congress | MAY 21 – 23 BARCELONA. Retrieved November 30, 2022, from https://www.iotsworldcongress.com/iot-transforming-the-future-of-agriculture/

Javaid, M., Haleem, A., Pratap Singh, R., & Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. *International Journal of Intelligent Networks, Volume 3 (2022),* 150–164. Retrieved May 15, 2023, from https://www.sciencedirect.com/science/article/pii/S2666603022000173?via%3Dihub

Jayaram, K., Pais, G., & Frost, C. (2023, February 28). *What climate-smart agriculture means for smallholder farmers*. McKinsey & Company. Retrieved June 2, 2023, from https://www.mckinsey.com/industries/agriculture/our-insights/what-climate-smart-agriculture-means-for-smallholder-farmers

Li, P., Wang, J., (2014). Research progress of intelligent management for greenhouse environment information. Nongye Jixie Xuebao = Transactions of the Chinese Society for *Agricultural Machinery* 45, 236–243.

Lloyd, J. (2019). From Farms to Food Deserts: Food Insecurity and Older Rural Americans. *Generations: American Society on Aging, Vol. 43(No. 2)*, 24–32. Retrieved June 16, 2023, from https://www.jstor.org/stable/10.2307/26760111

Luo, H., Yang, P.L., Li, Y.K., Xu, F.P., (2012). An intelligent controlling system for greenhouse environment based on the architecture of the internet of things. *Sens. Lett. 10*, 514–522.

doi:10.6342/NTU202304035

Natale, F., Gibin, M., Alessandrini, A., Vespe, M., Paulrud, A., (2015). Mapping fishing effort through AIS data. *PLoS One 10*, e0130746.

National Energy and Utility Affordability Coalition. (2022). LIHEAP State by State Metrics. In *NEUAC*. https://neuac.org/liheap-state-by-state-metrics/

National Rural Electric Cooperative Association. (2019). Electric Co-ops Part of Solution to Expand Rural Broadband. In *NRECA | America's Electric Cooperatives*. https://communitynets.org/sitewww.muninetworks.org/files/2019-04-NRECA-Broadband-Fact-Sheet.pdf

Noyes, K., (2014). Big Data Poised to Change the Face of Agriculture. *Fortune Data*. Retrieved May 27, 2023, from http://fortune.com/2014/05/30/cropping-up-on-every-farm-big-data-technology/

NRECA. (2023, April 13). Electric Co-op Facts & Figures - America's Electric Cooperatives. America's Electric Cooperatives. https://www.electric.coop/electric-cooperative-fact-sheet

NRTC, NRECA, & Ericsson. (2018). The Value of a Broadband Backbone for America's Electric Cooperatives: A Benefit Assessment Study. In *Cooperative.com*. https://www.cooperative.com/topics/telecommunications-broadband/Documents/TheValueofaBroadbandBackbone.pdf

Origin | SMART AGRI. (n.d.). Origin | SMART AGRI | Agricultural Challenges. Retrieved November 30, 2022, from https://www.intelligentagri.com.tw/en/xmdoc/cont?xsmsid=0J182348648885145053

Perdue, S., & Hamer, H. (2019). 2017 Census of Agriculture. In *United States Summary and State Data: Volume 1 | Geographic Area Series | Part 51* (AC-17-A-51). USDA/NASS. Retrieved June 20, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

Polansek, T. (2018, March 20). Monsanto backs new company focused on gene editing, not GMOs. *U.S.* Retrieved December 20, 2022, from https://www.reuters.com/article/us-monsanto-crops-investment

Proudly Farmers First®. (n.d.). Farmers Business Network. Retrieved April 12, 2023, from https://www.fbn.com/about

Reffell, C. (2022). Climate-smart Agriculture on a BOLD Path to a Bright Future. *BOLD Awards*. Retrieved March 24, 2023, from https://bold-awards.com/climate-smart-agriculture-bold-path-bright-future/

Renée Johnson & Jim Monke, Farm Bill Primer: What Is the Farm Bill? (2023, February 22). In *Congressional Research Service*. Retrieved April 20, 2023, from https://crsreports.congress.gov/product/pdf/IF/IF12047

Smart Farming Solutions - IoT Based Future of Agriculture Sector. (n.d.). Smart Farming Solutions - IoT Based Future of Agriculture Sector. Retrieved November 30, 2022, from https://www.biz4intellia.com/iot-smart-farming-solutions/

Sonka, S., (2014). Big Data and the Ag sector: more than lots of numbers. *International Food and Agribusiness Management Review 17*, 1.

Statista. (2021). Telecommunications infrastructure & equipment. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/22727/telecommunications-equipment-statista-dossier/

Statista. (2022a). Emissions in the US. In *Statista | Politics & Society*. Retrieved June 16, 2023, from https://www.statista.com/study/40176/us-ghg-emissions-statista-dossier/

doi:10.6342/NTU202304035

Statista. (2022b). US Export. In *Statista | Industries & Markets*. Retrieved June 16, 2023, from https://www.statista.com/study/15278/us-exports-of-goods-and-services-statista-dossier/

Statista. (2022c). Mobile communications in the US. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/12328/mobile-communications-industry-us-statista-dossier/

Statista. (2022d). US Agriculture. In *Statista | Industries & Markets*. Retrieved June 16, 2023, from https://www.statista.com/study/12270/us-agriculture-statista-dossier/

Statista. (2022e). Smart Agriculture. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/46794/smart-agriculture/

Statista. (2022f). Big Data. In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/14634/big-data-statista-dossier/

Statista. (2022g). Fiber broadband coverage in the United States by provider as of April 2022. In *Statista | Telecommunications*. Retrieved June 16, 2023, from https://www.statista.com/statistics/270581/us-fiber-broadband-coverage-by-provider/

Statista. (2023a). Greenhouse gas emissions worldwide. In *Statista | Politics & Society*. Retrieved June 16, 2023, from https://www.statista.com/study/69601/greenhouse-gas-emissions-worldwide/

Statista. (2023b). US Employment. In *Statista | Politics & Society*. Retrieved June 16, 2023, from https://www.statista.com/study/108874/us-employment/

Statista. (2023c). Software as a Service (SaaS). In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/31317/software-as-a-service-statista-dossier/

Sun, J., Zhou, Z., Bu, Y., Zhuo, J., Chen, Y., Li, D., (2013a). Research and development for potted flowers automated grading system based on internet of things. *Journal of Shenyang Agricultural University 44*, 687–691.

Sun, Z., Du, K., Zheng, F., Yin, S., (2013b). Perspectives of research and application of Big Data on smart agriculture. *J. Agric. Sci. Technol. 15*, 63–71.

Taiwan smart agriculture & precision farming. (2020, June 26). International Trade Administration | Trade.gov. Retrieved November 30, 2022, from https://www.trade.gov/market-intelligence/taiwan-smart-agriculture-precision-farming

This new approach to farming is transforming agriculture while protecting the environment. (n.d.). Environmental Defense Fund. Retrieved December 18, 2022, from https://www.edf.org/ecosystems/resilient-agriculture/precision-agriculture

Thurman, M. (2022). Climate-Smart Agriculture Certification. *Columbia Law Review, Vol. 122*(No. 3 (April 2022)), 37–60. Retrieved June 16, 2023, from https://www.jstor.org/stable/10.2307/27132238

Tita, & Bunge. (2022, September 11). *Deere Invests Billions in Self-Driving Tractors, Smart Crop Sprayers*. WSJ. Retrieved November 30, 2022, from https://www.wsj.com/articles/deere-invests-billions-in-self-driving-tractors-smart-crop-sprayers-11662904802

United Nations. (2015). *The 17 Sustainable Development Goals*. United Nations. Retrieved December 15, 2022, from https://sdgs.un.org/goals

doi:10.6342/NTU202304035

US Census Bureau. (2023, March 21). *Nation's Urban and Rural Populations Shift Following 2020 Census*. Census.gov. Retrieved March 23, 2023, from https://www.census.gov/newsroom/press-releases/2022/urban-rural-populations.html

USDA ERS. (n.d.). Farm income and losses of US farm sole proprietors reported for tax purposes, 2000-20. In *USDA | ERS*. USDA. Retrieved June 18, 2023, from https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=81953

USDA NASS. (2007). *Percent of Farms with High-Speed Internet Access.* 2007 Ag Census Library at Cornell University | USDA/NASS. Retrieved June 20, 2023, from https://agcensus.library.cornell.edu/wp-content/uploads/2007-Ag_Atlas_Maps-Farms-07-M251-RGBChor-largetext.pdf

USDA NASS. (2017a) *Average Age of Producers, 2017*. In 2017 Ag Census Web Maps | USDA/NASS. Retrieved July 10, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Ag_Census_Web_Maps/index.php

USDA NASS. (2017b). *Percent of Farms with Internet Access: 2017*. 2017 Ag Census Web Maps | USDA/NASS. Retrieved June 20, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Ag_Census_Web_Maps/index.php

USDA. (2013). Rural Broadband At A Glance: 2013 Edition. In *USDA | ERS* (Economic Brief Number 23). Retrieved May 10, 2023, from https://www.usda.gov

USDA. (2019). A Case for Rural Broadband: Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technology. In *USDA*. Retrieved May 27, 2023, from https://www.usda.gov/sites/default/files/documents/case-for-rural-broadband.pdf

USDA. (2021). US Counties with high levels of poverty, 1960-2019. In *USDA | ERS*. Retrieved June 23, 2023, from https://www.ers.usda.gov/webdocs/charts/105426/Poverty-measures.png

Verdouw, C.N., Beulens, A.J.M., van der Vorst, J.G.A.J., (2013). Virtualization of floricultural supply chains: a review from an internet of things perspective. *Comput. Electron. Agric*. 99, 160–175.

Vilsack, T., & Clark, C. Z. F. (2009). 2007 Census of Agriculture. In *United States Summary and State Data: Volume 1 | Geographic Area Series| Part 51* (AC-07-A-51). USDA/NASS. Retrieved June 20, 2023, from https://agcensus.library.cornell.edu/wp-content/uploads/2007-United_States-State-usv1.pdf

Vittek, S. (2022). Missed Connections: How a Lack of Reliable Internet Access Hinders Rural Farmers. *Ambrook*. Retrieved May 20, 2023, from https://ambrook.com/research/technology/internet-access-broadband-rural-smart-farming

Wamba, S.F.,Wicks, A., (2010). RFID deployment and use in the dairy value chain: applications, current issues and future research directions. *Technology and Society (ISTAS), 2010 IEEE International Symposium on. IEEE*, 172–179.

Whitacre, B. E. (2021). COVID-19 and Rural Broadband. *Agricultural & Applied Economics Association, Choices, 3rd Quarter 2021, Vol. 36*(No. 3 (3rd Quarter 2021)), 1–10. Retrieved June 16, 2023, from https://www.jstor.org/stable/10.2307/27098595

doi:10.6342/NTU202304035

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. (2017). Big Data in Smart Farming – A review. *Agricultural Systems, 153*, 69–80. Retrieved May 27, 2023, from https://doi.org/10.1016/j.agsy.2017.01.023

Xiong, H., Dalhaus, T., Wang, P., & Huang, J. (2020). Blockchain Technology for Agriculture: Applications and Rationale. *Frontiers in Blockchain, Blockchain for Good, Volume 3 (2020)*. Retrieved June 16, 2023, from https://www.frontiersin.org/articles/10.3389/fbloc.2020.00007/full

Yan, B., Shi, P., Huang, G., (2013). Development of traceability system of aquatic foods supply chain based on RFID and EPC internet of things. *Transactions of the Chinese Society of Agricultural Engineering 29*, 172–183.

doi:10.6342/NTU202304035

Appendix 1: US Census of Agriculture: Historical Highlights

Table 2: Historical Highlights: 2017 and Earlier Census Years

All farms	2017	2012	2007	2002	1997	Not adjusted for coverage		
						1997	1992	1987
Farms ... number	2,042,220	2,109,303	2,204,792	2,128,982	2,215,876	1,911,859	1,925,300	2,087,759
Land in farms ... acres	900,217,576	914,527,657	922,095,840	938,279,056	954,752,502	931,795,255	945,531,506	964,470,625
Average size of farm ... acres	441	434	418	441	431	487	491	462
Estimated market value of land and buildings [1]:								
Average per farm ... dollars	1,311,808	1,075,491	791,138	537,833	416,007	449,748	357,056	289,387
Average per acre ... dollars	2,976	2,481	1,892	1,213	967	933	727	627
Estimated market value of all machinery and equipment [1] ... $1,000	272,297,744	243,966,688	194,783,471	136,624,880	119,302,923	110,256,802	93,316,496	85,801,360
Average per farm ... dollars	133,363	115,706	88,357	66,570	53,861	57,678	48,605	41,227
Farms by size:								
1 to 9 acres	273,325	223,634	232,849	179,346	205,390	153,515	166,496	183,257
10 to 49 acres	583,001	589,549	620,283	563,772	530,902	410,833	387,711	412,437
50 to 179 acres	564,763	634,047	660,530	658,705	694,489	592,972	584,146	644,849
180 to 499 acres	315,017	346,038	368,368	388,617	428,215	402,769	427,648	478,294
500 to 999 acres	133,321	142,555	149,713	161,552	179,447	175,690	186,387	200,058
1,000 to 1,999 acres	87,666	91,273	92,656	99,020	103,007	101,468	101,923	102,078
2,000 acres or more	85,127	82,207	80,393	77,970	74,426	74,612	70,989	66,786
Total cropland ... farms	1,475,627	1,551,654	1,685,339	1,751,450	1,857,239	1,661,395	1,697,137	1,848,574
acres	396,433,817	389,690,414	406,424,909	434,164,946	445,324,765	431,144,896	435,365,878	443,318,233
Harvested cropland ... farms	1,245,548	1,288,875	1,328,004	1,362,608	1,545,681	1,410,606	1,491,786	1,643,633
acres	320,041,858	314,964,600	309,607,601	302,697,252	318,937,401	309,395,475	295,936,976	282,223,880
Irrigated land ... farms	294,235	296,303	301,028	299,583	308,818	279,442	279,357	291,628
acres	58,013,907	55,822,231	56,599,305	55,311,236	56,289,172	55,058,128	49,404,030	46,386,201
Market value of agricultural products sold (see text) ... $1,000	388,522,695	394,644,481	297,220,491	200,646,355	201,379,812	196,864,649	162,608,334	136,048,516
Average per farm ... dollars	190,245	187,097	134,807	94,245	90,880	102,970	84,459	65,165
Crops, including nursery and greenhouse crops ... $1,000	193,546,699	212,397,074	143,657,928	95,151,954	100,668,794	98,055,656	75,228,256	58,931,085
Livestock, poultry, and their products ... $1,000	194,975,996	182,247,407	153,562,563	105,494,401	100,711,018	98,808,993	87,380,078	77,117,431
Farms by value of sales:								
Less than $2,500	791,701	788,310	900,327	826,558	693,026	496,514	422,767	490,296
$2,500 to $4,999	185,341	191,422	200,302	213,326	265,667	228,477	231,867	262,918
$5,000 to $9,999	208,074	214,245	218,531	223,168	267,575	237,975	251,883	274,972
$10,000 to $24,999	228,218	244,954	248,285	256,157	293,639	274,040	301,804	326,166
$25,000 to $49,999	144,113	152,873	154,732	157,906	179,629	170,705	195,354	219,636
$50,000 to $99,999	119,434	129,366	125,456	140,479	163,510	158,160	187,760	218,050
$100,000 to $499,999	218,771	232,955	240,873	240,746	282,422	277,194	286,951	263,698
$500,000 or more	146,568	155,178	116,286	70,642	70,408	68,794	46,914	32,023
Farms by legal status for tax purposes:								
Family or individual	1,751,126	1,828,946	1,906,335	1,909,598	1,922,590	1,643,424	1,653,491	1,809,324
Partnership	130,173	137,987	174,247	129,593	185,607	169,462	186,806	199,559
Corporation	116,840	106,716	96,074	73,752	90,432	84,002	72,567	66,969
Other - estate or trust, prison farm, grazing association, American Indian Reservation, etc.	44,081	35,654	28,136	16,039	17,247	14,971	12,436	11,907
Total farm production expenses [1] ... $1,000	326,390,640	328,939,354	241,113,666	173,199,216	157,752,357	150,590,993	130,779,261	108,138,053
Selected farm production expenses [1]:								
Livestock and poultry purchased or leased ... $1,000	44,934,482	41,586,018	38,003,682	27,420,965	22,213,229	21,614,559	23,043,431	19,344,645
Feed purchased ... $1,000	62,625,223	75,706,467	49,095,106	31,694,850	34,749,048	32,759,966	24,084,507	19,163,364
Fertilizer, lime, and soil conditioners purchased [2] ... $1,000	23,543,177	28,532,713	18,107,194	9,751,460	9,999,752	9,597,128	8,204,324	6,684,944
Gasoline, fuels, and oils purchased ... $1,000	13,474,121	16,573,188	12,912,179	6,675,419	6,715,936	6,371,515	6,120,452	5,277,227
Hired farm labor ... $1,000	31,635,981	26,986,669	21,877,661	18,568,446	15,457,896	14,841,036	12,961,639	10,866,236
Interest expense ... $1,000	12,396,094	12,123,573	10,880,731	9,571,577	9,392,431	8,928,107	8,111,337	8,158,268
Chemicals purchased ... $1,000	17,585,163	16,459,840	10,074,914	7,608,921	7,934,936	7,581,424	6,133,705	4,690,243
Livestock and poultry:								
Cattle and calves inventory ... farms	882,692	913,246	963,669	1,018,359	1,188,659	1,046,863	1,074,349	1,176,346
number	93,648,041	89,994,614	96,347,858	95,497,994	99,907,017	98,989,244	96,135,825	95,847,299
Beef cows ... farms	729,046	727,906	764,984	796,436	899,756	804,595	803,241	841,778
number	31,722,039	28,956,553	32,834,801	33,398,271	34,193,965	34,066,615	32,545,976	31,652,593
Milk cows ... farms	54,599	64,098	69,890	91,989	125,041	116,874	155,339	202,068
number	9,539,631	9,252,272	9,266,574	9,103,959	9,139,812	9,095,439	9,491,818	10,084,697
Cattle and calves sold ... farms	711,827	740,978	798,290	851,971	1,121,003	1,011,809	1,034,189	1,150,523
number	69,812,061	69,759,776	74,071,936	73,509,165	75,005,184	74,089,046	70,562,908	72,603,841
Hogs and pigs inventory ... farms	66,439	63,246	75,442	78,895	124,889	109,754	191,347	243,398
number	72,381,007	66,026,785	67,786,318	60,405,103	61,188,149	61,206,236	57,563,118	52,271,120
Hogs and pigs sold ... farms	64,871	55,882	74,789	82,028	112,377	102,106	188,167	238,819
number	235,282,860	199,115,305	206,807,181	184,997,686	142,956,569	142,611,882	111,326,807	96,569,359
Layers inventory (see text) ... farms	232,500	198,272	145,615	98,315	(NA)	(NA)	(NA)	(NA)
number	368,241,393	350,715,978	349,772,508	334,435,155	(NA)	(NA)	(NA)	(NA)
Broilers and other meat-type chickens sold ... farms	32,751	32,935	27,091	32,006	27,737	23,937	23,949	27,645
number	8,889,759,283	8,463,194,794	8,914,828,122	8,500,313,357	7,366,526,456	6,741,927,110	5,428,589,485	4,361,975,630
Selected crops harvested:								
Corn for grain ... farms	304,801	348,530	347,760	348,590	450,520	430,711	503,935	627,602
acres	84,738,562	87,413,045	86,248,542	68,230,523	71,088,454	69,796,716	69,339,869	58,701,505
bushels	14,773,403,430	10,333,410,157	12,738,519,330	8,613,061,814	8,732,478,098	8,578,634,770	8,697,362,804	6,725,001,837
Corn for silage or greenchop ... farms	59,500	86,365	84,317	103,621	123,325	119,308	(NA)	(NA)
acres	6,109,414	7,196,628	5,979,661	6,683,995	5,771,666	5,727,594	(NA)	(NA)
tons	120,443,839	113,153,064	104,224,795	97,132,738	89,219,954	88,380,934	(NA)	(NA)
Wheat for grain, all ... farms	104,792	147,632	160,810	169,528	252,922	243,568	292,464	352,237
acres	38,811,620	49,040,226	50,932,969	45,519,976	62,084,743	58,836,344	59,089,470	53,224,174
bushels	1,788,456,593	2,185,108,114	1,993,648,378	1,577,005,140	2,329,807,815	2,204,026,684	2,206,729,476	1,887,103,964
Durum wheat for grain ... farms	3,093	3,515	3,723	5,325	7,070	6,887	(NA)	(NA)
acres	2,206,169	2,139,150	2,138,734	2,717,841	3,202,949	3,099,732	(NA)	(NA)
bushels	63,273,647	86,110,218	73,201,303	81,170,077	88,251,199	85,802,466	(NA)	(NA)
Other spring wheat for grain (see text) ... farms	20,076	25,794	28,733	30,333	47,193	46,268	(NA)	(NA)
acres	10,419,033	12,177,715	13,008,266	13,498,842	18,024,687	17,488,113	(NA)	(NA)
bushels	440,770,319	521,904,259	475,906,637	391,500,672	537,892,213	519,176,940	(NA)	(NA)

...continued

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Historical Highlights: 2017 and Earlier Census Years (continued)

All farms		2017	2012	2007	2002	1997	Not adjusted for coverage		
							1997	1992	1987
Selected crops harvested: - Con.									
Wheat for grain, all - Con.									
Winter wheat for grain	farms	86,596	126,085	136,103	141,062	(NA)	(NA)	(NA)	(NA)
	acres	26,186,417	34,723,361	35,785,969	29,303,293	(NA)	(NA)	(NA)	(NA)
	bushels	1,284,412,628	1,577,093,637	1,444,540,438	1,104,334,391	(NA)	(NA)	(NA)	(NA)
Oats for grain	farms	19,842	35,038	42,558	63,763	94,811	89,606	(NA)	(NA)
	acres	814,140	1,078,698	1,509,149	1,996,916	2,739,810	2,680,958	(NA)	(NA)
	bushels	50,406,624	65,646,178	89,508,669	109,840,449	154,654,269	151,327,329	(NA)	(NA)
Barley for grain	farms	11,188	18,667	19,848	24,747	43,269	41,930	(NA)	(NA)
	acres	2,206,808	3,283,905	3,521,957	4,015,654	6,108,682	5,944,951	(NA)	(NA)
	bushels	161,624,924	215,059,358	207,089,232	214,800,035	346,413,080	336,435,009	(NA)	(NA)
Sorghum for grain	farms	15,339	20,037	26,242	33,172	50,860	49,397	(NA)	(NA)
	acres	5,070,159	5,142,099	6,769,834	6,755,326	8,647,643	8,470,353	(NA)	(NA)
	bushels	354,737,072	264,337,547	482,452,865	333,485,523	569,984,239	559,070,136	(NA)	(NA)
Sorghum for silage or greenchop	farms	3,064	5,288	5,625	7,042	7,962	7,918	(NA)	(NA)
	acres	335,647	466,645	450,041	406,031	384,320	382,024	(NA)	(NA)
	tons	4,434,915	5,639,863	5,763,450	3,904,834	4,669,985	4,640,291	(NA)	(NA)
Soybeans for beans	farms	303,191	302,963	279,110	317,611	367,300	354,692	381,000	441,899
	acres	90,149,480	76,104,780	63,915,821	72,399,844	67,773,274	66,147,726	56,351,304	55,291,205
	bushels	4,356,024,186	2,926,822,777	2,582,423,697	2,707,719,216	2,560,330,804	2,504,307,294	2,053,163,265	1,838,053,979
Dry edible beans, excluding chickpeas and limas (see text)	farms	5,408	6,896	6,236	8,647	11,348	10,911	(NA)	(NA)
	acres	1,470,136	1,642,797	1,455,549	1,691,775	1,731,898	1,691,899	(NA)	(NA)
	cwt	30,625,986	31,424,290	25,353,900	29,687,475	27,888,555	27,223,851	(NA)	(NA)
Cotton, all	farms	16,149	18,155	18,605	24,805	33,640	31,493	34,812	43,046
	acres	11,401,965	9,384,080	10,493,238	12,456,162	13,897,404	13,235,236	10,961,720	9,826,081
	bales	20,413,180	16,534,302	18,898,128	17,145,345	18,706,703	17,878,743	15,370,310	13,280,143
Tobacco	farms	6,237	10,014	16,234	56,977	93,530	89,706	124,270	136,682
	acres	331,552	342,932	359,846	428,631	837,363	838,530	831,231	633,310
	pounds	715,446,022	766,609,252	778,301,825	873,350,412	1,744,192,909	1,747,702,321	1,697,831,562	1,215,221,360
Forage - land used for all hay and haylage, grass silage, and greenchop (see text)	farms	799,627	813,583	869,534	884,831	(NA)	(NA)	(NA)	(NA)
	acres	56,858,622	55,775,162	61,455,483	64,041,337	(NA)	(NA)	(NA)	(NA)
	tons, dry equivalent	140,229,237	127,345,016	155,393,762	154,976,932	(NA)	(NA)	(NA)	(NA)
Rice	farms	4,637	5,591	6,084	8,046	9,627	9,291	(NA)	(NA)
	acres	2,395,054	2,693,759	2,758,792	3,197,641	3,161,576	3,122,120	(NA)	(NA)
	cwt	176,274,671	200,239,288	198,538,690	210,358,014	184,412,536	182,231,457	(NA)	(NA)
Sunflower seed, all	farms	3,389	4,953	6,403	7,506	11,176	11,067	(NA)	(NA)
	acres	1,324,030	1,877,145	2,000,153	1,833,435	(D)	2,534,708	(NA)	(NA)
	pounds	2,086,855,236	2,728,794,260	2,820,962,445	2,042,510,240	(D)	3,198,790,249	(NA)	(NA)
Sugarbeets for sugar	farms	3,496	3,913	4,022	5,027	7,057	7,102	(NA)	(NA)
	acres	1,150,682	1,249,481	1,253,817	1,365,769	1,449,819	1,453,824	(NA)	(NA)
	tons	35,488,911	35,417,494	31,937,325	27,793,126	29,740,760	29,775,479	(NA)	(NA)
Sugarcane for sugar	farms	627	666	692	953	1,079	973	(NA)	(NA)
	acres	843,454	(D)	846,666	978,393	890,193	875,180	(NA)	(NA)
	tons	30,949,944	30,269,684	31,127,405	35,319,767	31,986,258	31,549,377	(NA)	(NA)
Peanuts for nuts	farms	6,379	6,561	6,182	8,640	12,788	12,221	(NA)	(NA)
	acres	1,786,767	1,621,631	1,200,564	1,223,093	1,377,097	1,352,155	(NA)	(NA)
	pounds	7,114,985,199	6,660,492,899	3,703,138,887	3,137,586,781	3,434,648,039	3,377,142,874	(NA)	(NA)
Vegetables harvested for sale [3] (see text)	farms	74,276	72,045	69,172	54,391	60,631	53,727	61,969	60,819
	acres	4,365,149	4,492,086	4,682,588	3,698,744	3,906,983	3,773,219	3,782,358	3,467,563
Potatoes	farms	16,554	21,079	15,014	9,408	11,649	10,523	(NA)	(NA)
	acres	1,133,128	1,168,199	1,131,963	1,266,087	1,372,458	1,355,241	(NA)	(NA)
Sweet potatoes	farms	4,798	2,202	1,910	2,366	1,976	1,770	(NA)	(NA)
	acres	172,983	125,726	105,284	92,310	80,953	77,384	(NA)	(NA)
Land in orchards [4]	farms	111,955	106,488	115,935	113,649	123,420	106,069	116,207	120,434
	acres	5,665,600	5,199,729	5,039,476	5,330,439	5,349,292	5,158,064	4,770,778	4,560,163

[1] Data for 2002 and prior years are based on a sample of farms.
[2] Data for 1997 and prior years exclude cost of lime and manure.
[3] Data for 2002 and prior years exclude potatoes, sweet potatoes, and ginseng.
[4] Data for 2012 and prior years exclude pineapples.

Note: Full data table depicting historical highlights from the 2017 USDA Census of Agriculture

Source: Perdue, S., & Hamer, H. (2019). 2017 Census of Agriculture. In *United States Summary and State Data: Volume 1 | Geographic Area Series | Part 51* (AC-17-A-51). USDA/NASS. 7-8. Retrieved June 20, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

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Appendix 2: US Census of Agriculture: Land

Table 3: Land: 2017 and 2012

All farms		2017 Total	2017 Percent of total in 2017	2012
LAND USE				
Farms	number	2,042,220	100.0	2,109,303
Land in farms	acres	900,217,576	100.0	914,527,657
Total cropland	farms	1,475,627	72.3	1,551,654
	acres	396,433,817	44.0	389,690,414
Harvested cropland	farms	1,245,548	61.0	1,288,875
	acres	320,041,858	35.6	314,964,600
Farms by acres harvested:				
1 to 49 acres		677,806	33.2	683,338
1 to 9 acres		268,261	13.1	239,546
10 to 19 acres		164,125	8.0	175,117
20 to 29 acres		109,443	5.4	119,652
30 to 49 acres		135,977	6.7	149,023
50 to 99 acres		156,198	7.6	172,123
100 to 199 acres		126,504	6.2	136,341
200 to 499 acres		127,738	6.3	136,252
500 to 999 acres		72,578	3.6	78,343
1,000 to 1,999 acres		50,870	2.5	52,320
2,000 acres or more		33,854	1.7	30,158
Other pasture and grazing land that could have been used for crops without additional improvement	farms	137,707	6.7	141,537
	acres	13,825,975	1.5	12,802,847
Other cropland	farms	498,647	24.4	489,250
	acres	62,565,984	7.0	61,922,967
Cropland idle or used for cover crops or soil-improvement, but not harvested and not pastured or grazed	farms	374,252	18.3	381,453
	acres	36,003,378	4.0	36,382,032

All farms		2017 Total	2017 Percent of total in 2017	2012
LAND USE - Con.				
Total cropland - Con.				
Other cropland - Con.				
Cropland on which all crops failed or were abandoned	farms	79,334	3.9	97,248
	acres	9,542,580	1.1	11,395,368
Cropland in summer fallow (see text)	farms	94,106	4.6	61,442
	acres	17,020,026	1.9	14,145,567
Total woodland	farms	794,789	38.9	840,399
	acres	73,092,054	8.1	77,012,907
Woodland pastured	farms	326,279	16.0	350,761
	acres	26,009,273	2.9	27,999,006
Woodland not pastured	farms	575,911	28.2	606,279
	acres	47,082,781	5.2	49,013,901
Permanent pasture and rangeland, other than cropland and woodland pastured	farms	1,130,063	55.3	1,176,156
	acres	400,771,178	44.5	415,309,280
Land in farmsteads, homes, buildings, livestock facilities, ponds, roads, wasteland, etc	farms	1,183,307	57.9	1,338,485
	acres	29,920,527	3.3	32,515,057
CONSERVATION AND CROP INSURANCE				
Land enrolled in Conservation Reserve, Wetlands Reserve, Farmable Wetlands, or Conservation Reserve Enhancement Programs	farms	238,041	(X)	291,706
	acres	22,959,083	(X)	27,485,000
Land enrolled in crop insurance programs	farms	380,236	(X)	360,673
	acres	284,359,292	(X)	245,501,827

Note: Full data table depicting land in farmland from the 2017 USDA Census of Agriculture

Source: Perdue, S., & Hamer, H. (2019). 2017 Census of Agriculture. In *United States Summary and State Data: Volume 1 | Geographic Area Series | Part 51* (AC-17-A-51). USDA/NASS. 17. Retrieved June 20, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

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Appendix 3: US Census of Agriculture: Age

Table 4: Selected Producer Characteristics: 2017 and 2012

Characteristics	2017 [1]				2012 [2]	
	All producers (see text)	All principal producers (see text)	All non-principal producers (see text)	Primary producer (see text)	All operators	Principal operator
Producers ....number	3,399,834	2,740,453	659,381	2,042,220	3,180,074	2,109,303
Sex of producers:						
Male	2,172,373	1,941,953	230,420	1,553,220	2,210,402	1,821,039
Female	1,227,461	798,500	428,961	489,000	969,672	288,264
Hired managers (see text)	158,298	111,154	47,144	70,723	(NA)	67,939
Primary occupation:						
Farming	1,416,848	1,207,375	209,473	964,477	1,412,077	1,007,904
Other	1,982,986	1,533,078	449,908	1,077,743	1,767,997	1,101,399
Place of residence:						
On farm operated	2,530,442	2,075,954	454,488	1,562,320	2,411,419	1,621,591
Not on farm operated	869,392	664,499	204,893	479,900	768,655	487,712
Days of work off farm:						
None	1,311,334	1,079,884	231,450	859,347	1,202,256	823,659
Any	2,088,500	1,660,569	427,931	1,182,873	1,977,818	1,285,644
1 to 49 days	285,477	224,278	61,199	172,209	266,715	169,761
50 to 99 days	151,972	121,190	30,782	92,576	149,195	92,876
100 to 199 days	282,056	226,974	55,082	168,777	283,044	180,407
200 days or more	1,368,995	1,088,127	280,868	749,311	1,278,864	842,600
Years on present farm:						
2 years or less	201,061	144,005	57,056	100,947	132,528	68,180
3 or 4 years	268,316	200,307	68,009	140,359	186,511	103,370
5 to 9 years	495,022	379,110	115,912	269,230	501,875	297,548
10 years or more	2,435,435	2,017,031	418,404	1,531,684	2,359,160	1,640,205
Years operating any farm (see text):						
5 years or less	474,198	344,001	130,197	237,838	(NA)	(NA)
6 to 10 years	434,076	330,939	103,137	234,522	(NA)	(NA)
11 years or more	2,491,560	2,065,513	426,047	1,569,860	(NA)	(NA)
Age group:						
Under 25 years	50,943	20,121	30,822	10,518	47,337	10,714
25 to 34 years	234,496	162,294	72,202	111,236	210,117	109,119
35 to 44 years	390,345	295,388	94,957	207,348	371,153	214,106
45 to 54 years	614,654	488,006	126,648	351,677	739,512	466,036
55 to 64 years	955,354	783,241	172,113	580,769	896,181	608,052
65 to 74 years	757,936	643,314	114,622	498,595	600,945	443,571
75 years and over	396,106	348,089	48,017	282,077	314,829	257,705
Average age	57.5	58.6	52.8	59.4	56.3	58.3
Young producers (see text)	321,261	208,462	112,799	139,427	(NA)	(NA)
Producers of Hispanic, Latino, or Spanish origin	112,451	90,344	29,748	66,727	99,734	67,000
Producers by race:						
American Indian or Alaska Native	58,199	46,210	11,989	35,494	58,475	37,851
Asian	22,016	16,978	5,038	11,955	22,140	13,669
Black or African American	45,508	38,447	7,061	31,071	44,629	33,371
Native Hawaiian or other Pacific Islander	3,018	2,306	712	1,662	2,448	1,468
White	3,244,344	2,614,526	629,818	1,945,696	3,035,413	2,012,652
More than one race reported	26,749	21,986	4,763	16,342	16,969	10,292
Military service (see text):						
Never served	3,029,215	2,402,342	626,873	1,768,912	(NA)	(NA)
Served	370,619	338,111	32,508	273,308	(NA)	(NA)
Number of persons living in producers' households (see text)	6,577,050	5,853,225	723,825	4,627,167	6,496,604	5,455,325
On farm involvement in decisionmaking (see text):						
Day-to-day decisions	2,950,329	2,542,377	407,952	1,956,523	(NA)	(NA)
Land use and/or crop decisions	2,530,154	2,220,778	309,376	1,740,659	(NA)	(NA)
Livestock decisions	2,095,061	1,817,718	277,343	1,412,420	(NA)	(NA)
Record keeping and/or financial management	2,541,028	2,197,589	343,439	1,738,799	(NA)	(NA)
Estate planning or succession planning	1,911,680	1,664,323	247,357	1,283,838	(NA)	(NA)

[1] Data were collected for a maximum of four producers per farm.
[2] All operator data are for a maximum of three operators per farm; principal operator data are for one operator per farm.

Note: Full data table depicting land in farmland from the 2017 USDA Census of Agriculture

Source: Perdue, S., & Hamer, H. (2019). 2017 Census of Agriculture. In *United States Summary and State Data: Volume 1 | Geographic Area Series | Part 51* (AC-17-A-51). USDA/NASS. 62. Retrieved June 20, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

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Appendix 4: US Census of Agriculture: Internet Access

Table 5: Selected Farm Characteristics by Race

Characteristics	Any producer reporting race as -					
	American Indian or Alaska Native only	American Indian or Alaska Native alone or in combination with other races	Asian only	Asian alone or in combination with other races	Black or African American only	Black or African American alone or in combination with other races
OTHER FARM CHARACTERISTICS - Con.						
Farms by- - Con.						
Operation's legal status for tax purposes (see text): - Con.						
Partnership	1,565	2,396	1,610	1,816	1,457	1,627
Corporation	810	1,559	1,947	2,193	1,133	1,331
Other - estate or trust, prison farm, grazing association, American Indian Reservation, etc.	2,132	2,469	366	451	631	699
Number of producers (see text):						
1 producer	17,850	23,474	5,263	5,984	19,815	20,721
2 producers	20,073	30,044	8,339	9,713	10,225	11,553
3 producers	2,733	3,763	1,297	1,536	1,598	1,750
4 producers	1,514	2,061	618	717	726	840
5 or more producers	535	741	309	388	546	606
Number of male producers (see text):						
1 producer	30,297	44,241	11,884	13,778	26,070	28,055
2 producers	3,369	4,893	1,992	2,273	2,753	2,994
3 producers	786	1,106	401	463	775	830
4 producers	234	278	129	150	179	209
5 or more producers	87	96	88	121	126	131
Number of female producers (see text):						
1 producer	27,054	38,520	9,669	11,278	12,322	13,820
2 producers	2,642	3,546	837	1,017	1,023	1,217
3 producers	523	634	149	189	268	289
4 producers	136	169	64	76	117	142
5 or more producers	66	93	23	30	100	101
Farms reporting-						
Internet access	25,717	39,554	11,547	13,634	20,032	22,018
Dial-up	675	1,102	277	316	748	795
DSL	4,872	8,275	2,838	3,390	4,878	5,348
Cable modem	3,073	5,512	3,582	4,206	4,301	4,788
Fiber-optic	1,903	2,995	700	859	1,077	1,211
Mobile internet service for a cell phone or other device (see text)	12,607	18,606	4,200	5,024	8,306	9,102
Satellite	5,605	8,751	1,778	2,104	4,487	4,852
Don't know (see text)	1,878	2,802	794	893	1,531	1,699
Other internet service	823	1,418	485	592	411	489
Farms by number of households sharing in net income of operation:						
1 household	34,631	49,550	11,896	14,015	27,380	29,574
2 households	5,329	7,222	2,707	2,973	4,050	4,308
3 households	1,311	1,658	558	636	746	814
4 households	807	943	386	406	391	418
5 or more households	627	710	279	308	343	356

...continued

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Selected Farm Characteristics by Race (continued)

Characteristics	Any producer reporting race as - con.				
	Native Hawaiian or Other Pacific Islander only	Native Hawaiian or Other Pacific Islander alone or in combination with other races	White only	White alone or in combination with other races	More than one race reported
OTHER FARM CHARACTERISTICS - Con.					
Farms by- - Con.					
Operation's legal status for tax purposes (see text): - Con.					
Partnership	199	354	126,481	126,947	1,287
Corporation	176	310	113,896	114,347	1,201
Other - estate or trust, prison farm, grazing association, American Indian Reservation, etc.	76	151	41,334	41,551	493
Number of producers (see text):					
1 producer	729	1,251	881,194	887,772	6,948
2 producers	1,486	2,480	908,735	911,425	12,815
3 producers	167	329	108,411	108,695	1,600
4 producers	100	159	45,971	46,067	786
5 or more producers	55	122	18,975	19,047	385
Number of male producers (see text):					
1 producer	2,014	3,365	1,561,600	1,568,978	17,754
2 producers	260	444	187,939	188,409	2,187
3 producers	46	102	40,369	40,459	480
4 producers	27	41	8,530	8,572	108
5 or more producers	14	33	4,242	4,255	53
Number of female producers (see text):					
1 producer	1,628	2,791	1,023,341	1,027,458	14,761
2 producers	169	285	66,869	67,137	1,354
3 producers	19	56	10,327	10,344	196
4 producers	11	27	2,615	2,641	68
5 or more producers	2	5	1,341	1,344	38
Farms reporting-					
Internet access	1,933	3,420	1,494,076	1,501,372	18,031
Dial-up	36	61	47,247	47,483	513
DSL	408	742	378,987	380,703	4,433
Cable modem	567	1,035	290,523	292,013	3,616
Fiber-optic	130	262	151,135	151,675	1,441
Mobile internet service for a cell phone or other device (see text)	762	1,392	574,126	577,242	7,673
Satellite	356	578	290,898	292,328	3,853
Don't know (see text)	138	241	110,685	111,211	1,185
Other internet service	67	115	45,273	45,510	791
Farms by number of households sharing in net income of operation:					
1 household	2,014	3,483	1,627,710	1,636,235	19,192
2 households	408	652	247,016	247,873	2,490
3 households	63	112	52,347	52,572	512
4 households	33	59	21,385	21,470	202
5 or more households	19	35	14,828	14,856	138

Note: Full data table depicting land in farmland from the 2017 USDA Census of Agriculture

Source: Perdue, S., & Hamer, H. (2019). 2017 Census of Agriculture. In *United States Summary and State Data: Volume 1 | Geographic Area Series | Part 51* (AC-17-A-51). USDA/NASS. 74-75. Retrieved June 20, 2023, from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

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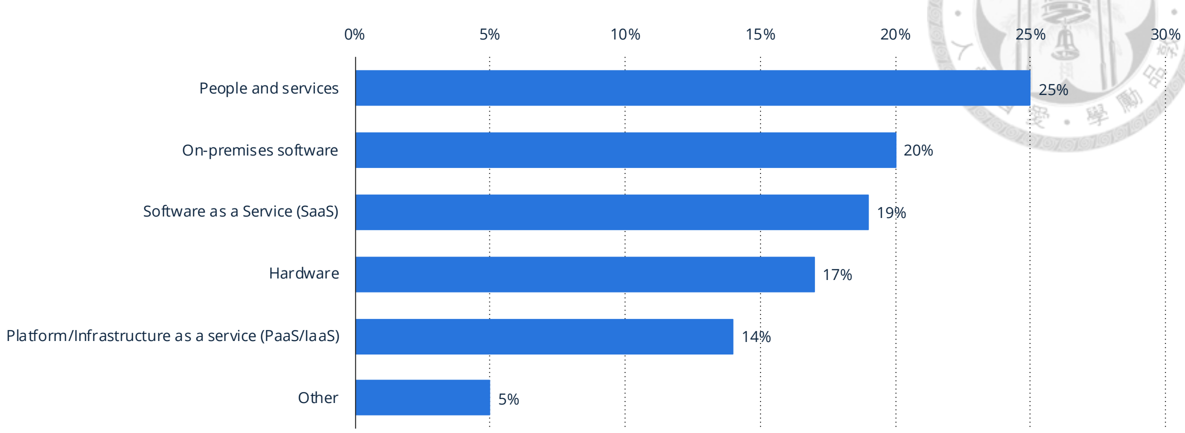
Appendix 5: IT Spend Breakdown in Global Companies

Figure 33: IT Spend Breakdown in Global Companies, by Category



Note: 2022; Data represents global companies in North America & Europe with 2,000 employees or more

Source: Statista. (2023c). Software as a Service (SaaS). In *Statista | Digital & Trends*. Retrieved June 16, 2023, from https://www.statista.com/study/31317/software-as-a-service-statista-dossier/

While this is relevant data to the industry, it did not fit within the narrative of the overall discussion within this thesis document. The chart labeled Figure 33 shows the typical breakdown in spending on IT products, people, and services. While this is not currently how the IT spending is typically broken down within the Agricultural industry, as the space continues to grow and more Smart Agriculture technologies are implemented, these costs will likely begin to affect these operations similarly to other industries and thus were deemed relevant for inclusion in the Appendix of this thesis.

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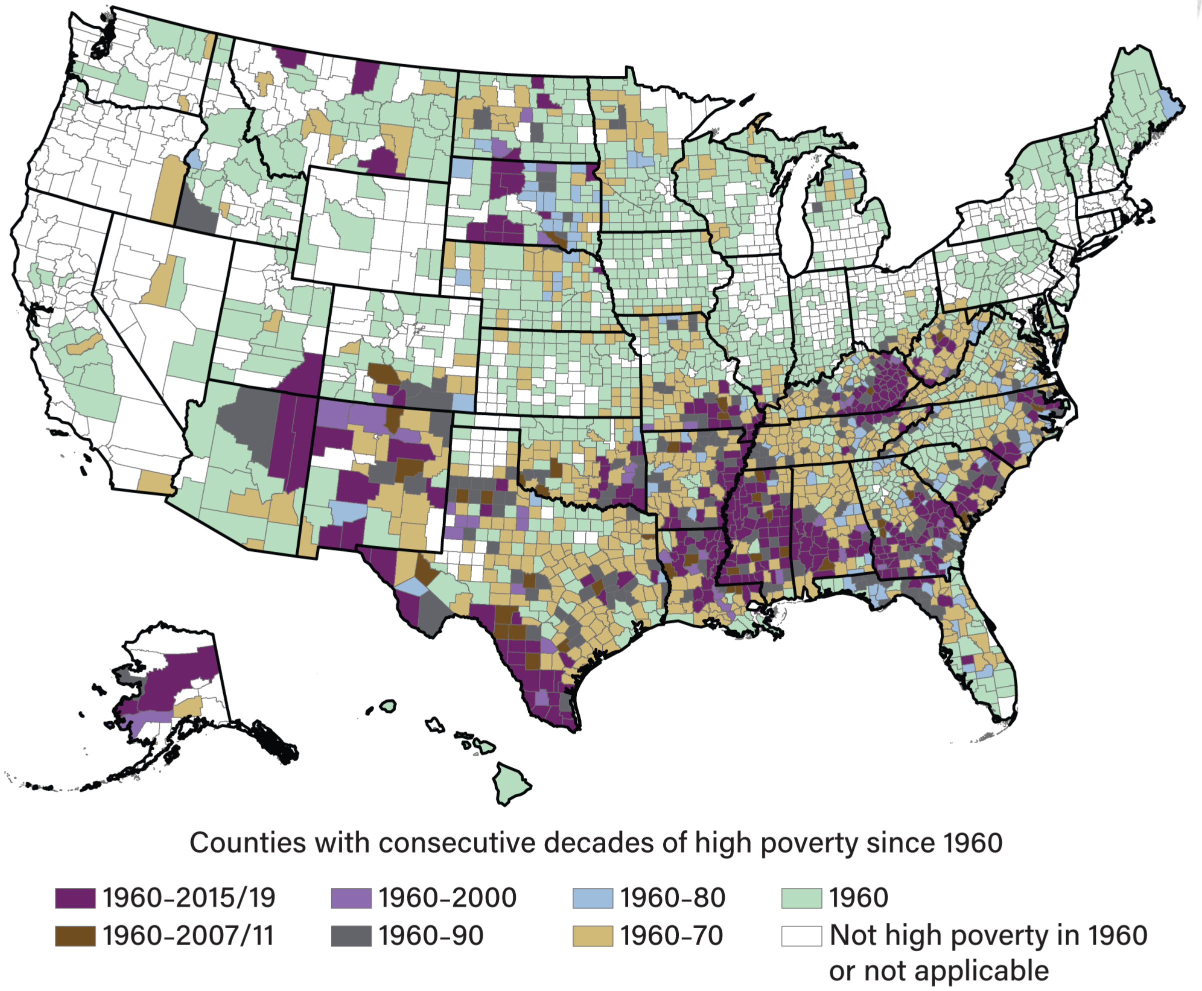
Appendix 6: Counties with Continuous Poverty, 1960-2019

Figure 34: US Counties with Continuous High Poverty Rates, 1960-2019



Note: Data accounts for 3,110 of the current 3,142 counties; due to boundary changes, other data factored into "Not high poverty in 1960 or not applicable."

Source: USDA. (2021). US Counties with high levels of poverty, 1960-2019. In *USDA | ERS*. Retrieved June 23, 2023, from https://www.ers.usda.gov/webdocs/charts/105426/Poverty-measures.png

This thesis did not consider poverty rates in the discussion of investment opportunity; however, USDA data seems to point to a correlation between Rural communities and continuously high poverty rates, which may result from some of the underinvestments in access and infrastructure in these communities, which could be explored further.

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