Opportunities and Challenges for AI in Agriculture Supply Chain: A Location Based Review Perspective

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The purpose of this paper is to examine the use of artificial intelligence (AI) in the agricultural supply chain (AgSC) and understand the different opportunities and challenges through the lens of an upstream-midstream-downstream location perspective. Through a literature review approach, AI applications in four AgSC domains, namely: operation, decision-making, risk management, and sustainability, along the AgSC are captured. A comparative analysis of the reviewed literature was conducted between the location, technology and business domains of the AgSC. The results captured the dynamics of how AI technologies are evolving and spreading from upstream to downstream and vice versa. In addition, the analysis led to some recommendations on how to draft the future research in this field, the investment map, the skill development plan as well as the sustainability agenda for AgSC.

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I. BACKGROUND

Artificial Intelligence (AI) has grown to become a widely accepted method for streamlining protocols and automating programs to create an efficient and effective means for conveying and executing on inputs given. Due to the rapid scalability of Artificial Intelligence's prevalence, AI has become adopted into many supply chains worldwide. It is undeniable that AI will become more and more prevalent in modern day technologies, specifically in the industry of supply chain. The benefits of artificial intelligence can be seen throughout financial, manufacturing, and consumer segments as costs continue to lower and transportation responsiveness is quickening.

One industry where artificial intelligence is not gaining traction as quickly, but requires it's assistance, is the agricultural supply chain (AgSC). As much as there is a high potential for AgSC to capture AI opportunities, there are many threats for that industry that will only grow more severe with the future. AgSC has many years until it catches up with its counterparts (compare for example with apparel supply chain), which leads to the crux of this papers' research objective.

In this paper we are trying, through a literature review approach, to better understand the AI opportunities and challenges in AgSC from a location perspective. The main reason behind such a stand is that there are many research efforts attempting to answer the *what, why and how* of AI in AgSC but to the authors' knowledge, none had captured the *where* question. By supply chain location, we refer to upstream, midstream and downstream activities as depicted in figure 1. Along this spectrum, we seek to focus on AI specific applications in selected AgSC domains, namely operation, decision-making, risk management, and sustainability. The selection of these domains was due to both their importance and their wide coverage of critical AgSC activities with potential AI application.

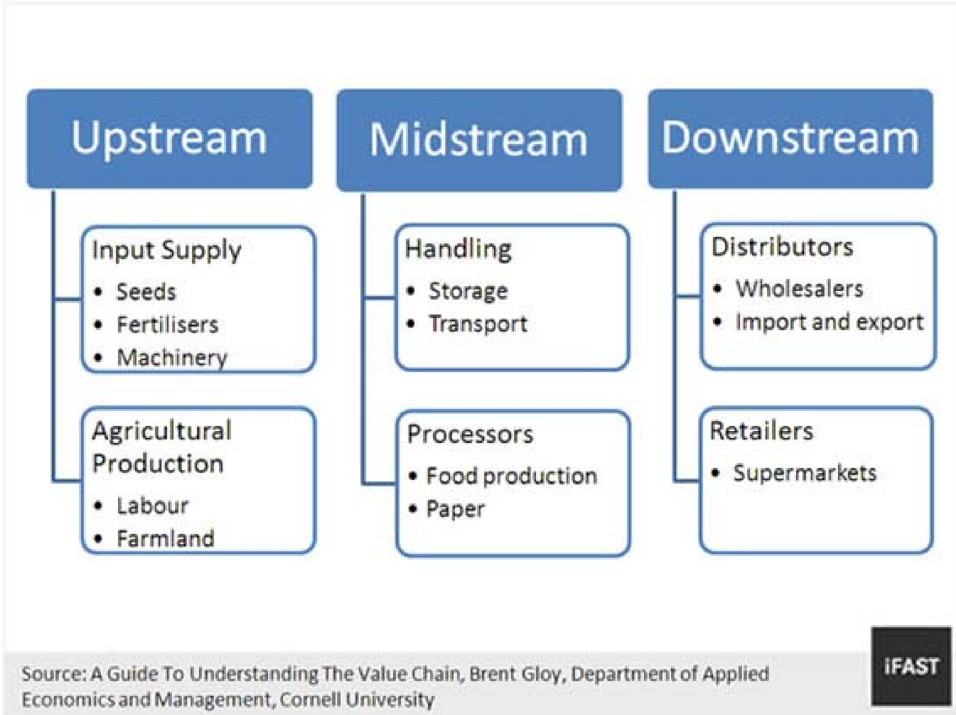

FIGURE 1. AGSC LOCATIONS AND THEIR ACTIVITIES

II. RESEARCH APPROACH

The research approach adopted in this paper was based on conducting a literature review followed by a descriptive and comparative analysis to that review. The review was not comprehensive; rather, focused on very recent work in the selected AgSC domains as well as specific AI technologies as outlined in figure 2. "ProQuest // ABI Inform" and "Google Scholar" databases were used. Primary results for "AI in AgSC" keyword exceeded 146K papers. When focusing on recent work in the last three years, this number decreased to 16500 papers. The scope was further focused on the four selected AgSC domains and AI applications using keywords like, "Automation", "Agriculture 4.0", "Neural Networks", "Robots", "Sustainability", "Machine Learning", and "Digital Twins" and thus the number of papers was decreased to approximately 2500. A representative selection from this final pool that fulfilled at least two of the previously stated keyword criteria in figure 2 and captured AI opportunities and challenges in AgSC was selected, decreasing the number considered in this study to 44 papers.

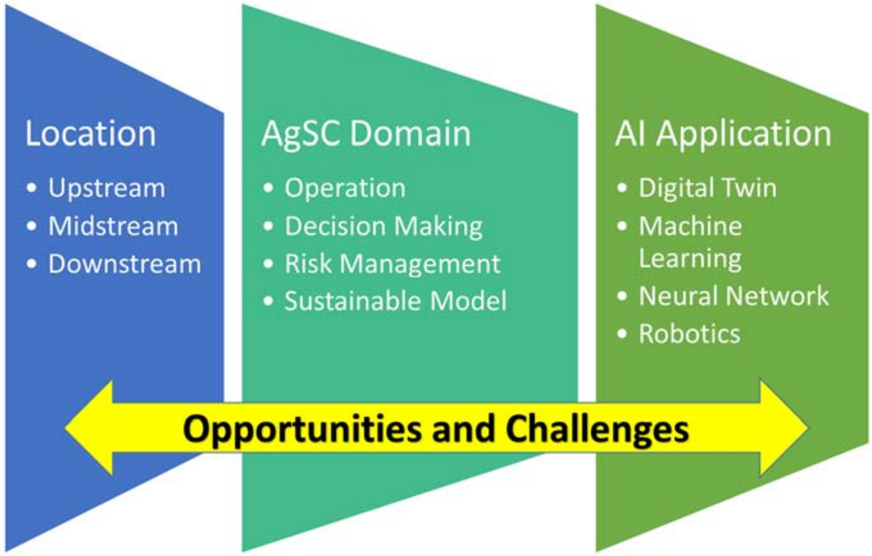

FIGURE 2. LITERATURE REVIEW SELECTION CRITERIA

III. AI APPLICATIONS IN SELECTED AGSC DOMAINS

In this section, we summarize some examples of the AI opportunities (through the review findings) as it relates to the selected four AgSC domains. This will be followed by a summary of some AI applications challenges along the same domains

3.1. AI application Opportunities

3.1.1. Operations domain:

There are many aspects of AI technologies that could improve the efficiency of the AgSC operations. Many papers brought up the applications of AI in traceability (Lakkakula, 2020) (Erkoyuncu, 2020), transparency, and efficiency (Trunk, 2020) (Walker, 2020). Accurate location recordings of products or stages in the supply chain would lower operational errors and increase cycle times (Denis, 2020). Furthermore, multiple human procedures could be automated using AI technology (Black, 2020). Data collection, transmission, and analysis (Calatayud, 2019) (Peppes, 2020) all can be expedited through the development of digitals and neural networks at a high level (Demestichas, 2020) (Tzachor, 2020) (Denis, 2020).

Digital Twins, an AI application that mirrors the physical reality in a virtual world for operation planning and control, will be revolutionary in the world of AgSC (Dash, 2019) (Sagarna, 2019) (Erkoyuncu, 2020) (Jones, 2020). Procurement and production would benefit greatly for upstream agricultural supply chain activities (Denis, 2020). Midstream, throughput, cycle time, and inventory optimization, transportation, warehousing would all improve due to a digital twin predictive and analysis model (Ahmed, 2015) (Toorajipour, 2020) (Denis, 2020) (Food Logistics 4.0, 2021). By creating a virtual space that near perfectly mimics the physical Ag space, multiple insights can be gained (Tzachor, 2020). Downstream, the information surrounding POS for finished goods would also be able to provide a wealth of data for future forecasting use (Denis, 2020). These uses include product mix selection, product introductions, and increased diversification of products offered (Dash, 2019) (Toorajipour, 2020) (Black, 2020).

Artificial Neural Networks (ANN) was shown to be beneficial to the AgSC through the speed at which massive amounts of information intake (Vaio, 2020) (Alzoubi, 2017) can be made available (An executive's guide to AI, 2018). Convolutional and recurrent neural networks have many applications such as identifying brand logos during processing and distribution operations and make the reconciliation process more effective, thereby reducing operation delay costs (Lakkakula, 2020) (Dash, 2019) (Toorajipour, 2020) (An executive's guide to AI, 2018) (Food Logistics 4.0, 2021) (Alzoubi, 2017). Farms' yield can be enhanced, through use of AI based solutions that improve process efficiency, reduce wastes, and increase the availability of information for farming decisions (Lakkakula, 2020) (Toorajipour, 2020) (Alzoubi, 2017).

3.1.2. Decision making domain:

Although it is related to the operation domain, however, AI allows AgSC management to go beyond operation domain and better understand the whole supply chain dynamics offering system wide insights (Ryan, 2020) that could not have been seen without it. Utilizing AI in conjunction with well-designed KPI dashboard will offer decision makers the capability to capture data (Dash, 2019) (Sagarna, 2019) real time (Toorajipour, 2020) and act accordingly. For instance, a farmer could track in real time the progression of a crop infection and react accordingly. Decision makers can also track the impact of their previous decisions (Trunk, 2020) (Davarzani, 2020) and then use these data to adjust and improve their course of action from upstream to downstream (Dash, 2019) (An executive's guide to AI, 2018) (Alzoubi, 2017) (Duvniak, 2020). The implementation of a new fertilizer on certain areas of fields can provide valuable feedback used in future planting decisions. AI can also analyze what choices employees have made in the past which allows management to determine the best coaching strategies. This action-reaction connection gives the management and employee a symbiotic relationship (Bălan, 2019), where both profit off this combined knowledge.

One of the most overlooked, yet most important aspects of AI application in AgSC is the avoidance of technological lock in (Carolan, 2020). The agricultural sector for the most part has been ingrained in certain ideals and methodologies for decades, many of which have been of detriment to the companies within the space (Black, 2020). AI can be used as a tool to assist with their transition out of 20th century technologies. AI can be employed throughout the entire supply chain, easing the uncertainty in the decision-making burden and reducing bullwhip effect (Vaio, 2020). With AI handling a great number of menial, trivial, and automatic decisions, executives will be able to put their time and energy into bigger picture thinking and taking the AgSC business to the next level.

Regarding the AI selected technologies, digital twins would be remarkably useful for the planning and prediction stages of agricultural development (Dash, 2019) (Jones, 2020). By entering relevant historical data and creating a virtual reality, farmers can better account for changes in weather patterns (Calatayud, 2019) (Food Logistics 4.0, 2021) or pest outbreaks in crops (Marani, 2021). ANNs would also be useful, as a functioning ANN could help in decisions that would seamlessly automate processes upstream and midstream of the supply chain (Peppes, 2020) (Fountas, 2020). The data collected by retailers downstream can additionally provide insights into demand forecasting decisions (Black, 2020) and dynamic pricing decisions (Dash, 2019) (Food Logistics 4.0, 2021).

3.1.3. Risk management domain:

Regarding risk management in AgSC, AI processes can play a vital role to capture, assess and mitigate multiple risks. For example, tracking and tracing disease outbreaks due to food contamination (Demestichas, 2020) can be done seamlessly with AI technologies. When such an outbreak happens, the contaminated food would need to have passed through all the distribution facilities and supplier warehouses (Black, 2020). AI can conduct thorough ingredient analyses during these stages to automatically detect diseased products (Tzachor, 2020), thereby reducing the odds of the product ever reaching consumption.

The agility and resilience of AgSC can be improved using digital twin technologies. With what the AgSC chain experienced for example lately due to the COVID19 pandemic, such resilience is becoming an inevitable future strategy for all AgSC (Food Logistics 4.0, 2021). To set a basis for such resilience, digitization and AI based solutions (like digital twins and ANN models) are required for all AgSC from upstream to downstream (Denis, 2020) (Jones, 2020).

Recently, cyberattacks on AgSC have grown faster than predicted (Food Logistics 4.0, 2021). An organization with malicious intent can effortlessly take control of a nation's food supply (Ryamarczyk, 2020) (Liu, 2020) if they tap into weaknesses within a supplier's IoT system for example. AI solutions can defend against this threat by using machine learning and AI authentication processes to correctly validate user access (Peppes, 2020) (Eteris, 2020) (Liu, 2020). Support vector machines, self-organizing maps, and neural networks models can be employed to identify and facilitate defense functions against antagonistic threats to the supply chain structure (Trunk, 2020). Not only in regard to defense systems, but AI can be applied to negotiations, ensuring all stakeholders are in possession of accurate contracts (Dash, 2019) (Vaio, 2020) (Eteris, 2020). A neural network solution could detect a falsified contract, code, or user, and take corrective actions as programmed to stop the threat (Demestichas, 2020) (Toorajipour, 2020). Validation, not trust, will be the defining factor in agricultural contracts moving forward.

3.1.4. Sustainable business models domain:

Sustainable Business Models (SBMs) have long been sought after as an AgSC business competitive advantage. The triple bottom line framework of sustainability: economic, environmental, and social are well present in AI applications in AgSC, with environmental and social often under the most scrutiny from agricultural advocates (Vaio, 2020). For example, to make smarter decisions from the environmental perspective, executives must first know what questions to ask and what data sets to prioritize (Perry, 2020). Artificial Intelligence offers a way to track data and provide insight (Calatayud, 2019) (Peppes, 2020) that can better guide executives towards a more sustainable method of operation (Jones, 2020) (Trunk, 2020).

The literature points to many ways that AI can be used to drive a company's sustainable development goals. Firstly, analysts can examine past data collections from their supply chain to route trucking and shipping paths (Ahmed, 2015) (Dash, 2019) in the most efficient way possible (Food Logistics 4.0, 2021) (Davarzani, 2020). Fertilizers, pesticides, and individualized irrigation schemes can be utilized throughout different times to radically lower water consumption in farming (Vaio, 2020) (Davarzani, 2020). Ventilation and moisture management are another two major issues that can be resolved with the implementation of an AI based system (Tzachor, 2020) (Food Logistics 4.0, 2021). Distribution warehouses can also be completely overhauled using machine learning algorithms to completely automate the receiving and shipping of various products (Carolan, 2020) (Kopteva, 2019). Personnel contentment increases with the improved transparency that AI brings (Bell, 2020). Emissions can be radically lowered through a series of neural networks, calculating and reporting the most efficient routes for shipping equipment and product (Toorajipour, 2020) (Vaio, 2020) (Anandan, 2020).

On the social level, some work suggested that AI can also be used to create a smarter and more inclusive organizational structure in the agricultural sector. Communication between all levels of an organization can be vertically integrated into a company's flow with AI through vendor managed inventories, efficient consumer response, collaborative planning, forecasting and replenishment, or decentralized enterprise resource planning systems (Food Logistics 4.0, 2021) (Black, 2020). This can lead to smarter hiring processes, order fulfillments, and flexibility in distribution (Jones, 2020) (Kriebitz, 2020) (Black, 2020) (Ryamarczyk, 2020). In the case of a worldwide disaster, in which traditional AgSC supply channels from farm to client are interrupted, AI can equip executives with a portfolio of solutions (Walker, 2020), thereby increasing the chance of a successful pivot. Agile AgSC frameworks have grown in popularity and can certainly be enhanced by AI implementation (Calatayud, 2019) (Toorajipour, 2020) (Sagarna, 2019). Also, the combination of AI and Agile methods in the context of prototyping of new agricultural genes that are more environmentally friendly can provide results with speed and frugality (Denis, 2020).

3.2. AI application Challenges

3.2.1. Costs and Investment Uncertainty domain:

The AI opportunities described earlier come with some challenges in the AgSC, both in terms of the implementation and the technology behind it. Costs associated with developing AI solutions like in the case of digital twin or a neural network expand outside of the technology itself and would come on the top of this challenges list (Vaio, 2020). While those costs are high, the cost of training staff, technicians, and executives on the usage, implementation, and interpretation of AI systems is large as well (Food Logistics 4.0, 2021) (Ryamarczyk, 2020) (Eteris, 2020). Educational courses and practices will need to be invested in so that employees of experience can develop functioning, automatic digital systems (Eteris, 2020). The exact economic returns are uncertain in the majority of cases, resulting in executive buy-in as one of the only impactful drivers of AI investments (Ryamarczyk, 2020).

3.2.2 Creation of potential vulnerabilities domain:

As mentioned earlier, AI solutions in AgSC can greatly reduce the risk of security threats by creating predictive and preventative models to account for antagonistic threats. However, if a security threat were to gain access to a neural network or a key AI system, the fallout could be immense (Peppes, 2020) (Liu, 2020). The theme of heavy crop consolidation (Peppes, 2020), which has become more common in relation with Agriculture 4.0, leaves many vertically integrated supply chains vulnerable to a cyberattack. Blockchain and IoT can pair with AI as added security levels, but there can't be any guarantees when connecting the entire supply chain into a single network. If an attack were to be successful, it is still undecided how to identify the responsible party when data is distributed so broadly. With so many stakeholders involved in a neural network, digital twin, or AI system in general, the concept of data ownership and privacy has yet to be unanimously defined (Demestichas, 2020) (Ryamarczyk, 2020).

3.2.3. Distinguishing data relevancy domain:

For AI to be successfully deployed into a system, there must be precise and relevant historical data (Trunk, 2020) (Davarzani, 2020). While precise data is present in many large organizations, deciding what is and is not relevant can only be found through numerous trials by engrained individuals. The difference in data used in an AI system can determine whether a crop's yield is average or exceptional. It is difficult to mix hard and soft skills/variables into a single program as well (Bălan, 2019). An overemphasis on one or the other could lead to wildly inaccurate results. This can be especially difficult in the agricultural sector, as tradition is emphasized heavily in comparison to other industries. Ensuring that the data is properly structured by a qualified stakeholder is necessary for a valid implementation (Kopteva, 2019) (Eteris, 2020).

IV. REVIEW ANALYSIS OF AI APPLICATION IN AGSC

In this section, the outlined review outcomes are further analyzed using multiple comparative approaches. The comparative analysis aims at summarizing the captured review (using tabular and figurative approaches) as well as offering multiple insights regarding AI application in AgSC from mainly a location perspective followed by technology perspective.

4.1. An AgSC Location Perspective:

An overview of AgSC location focus distribution of reviewed papers is displayed in Figure 3. The majority of the papers focused on AI applications at the upstream sector of the AgSC (41.8%) while 29.7% of papers focused on the midstream and 28.6% of the papers focused on the downstream AI applications.

Table 1 depicts the covered literature review work for different AI applications within the selected four AgSC domains along the AgSC locations.

Table 1 conforms that in general, the sheer weight of research focused on the upstream processes. Furthermore, operation management domain in that upstream focus is shown to have the largest AI application in AgSC, followed closely by the decision-making domain (especially upstream). Sustainable business models had the least research focus in the context of this review, pointing towards clear opportunities for future research in this domain.

In Tables 2, 3, and 4, we list the opportunities and challenges offered by the specific AI applications considered in this review (digital twin, machine learning, robotic solutions and neural network models) along AgSC upstream, midstream and downstream respectively. An opportunity is viewed as a potential benefit from the application and a challenge is anything that may hinder the application's implementation/acceptance.

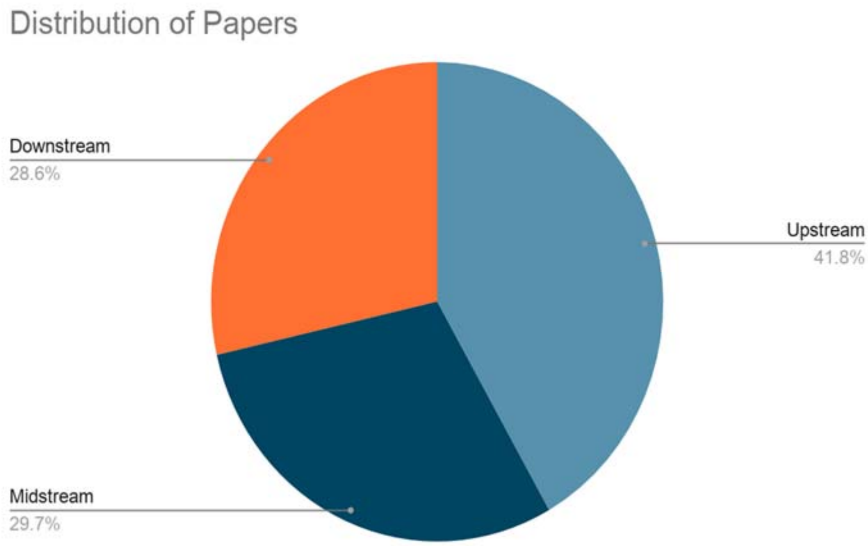

FIGURE 3. DISTRIBUTION OF REVIEWED PAPERS BY AGSC LOCATION

TABLE 1: IMPROVING THE AG SUPPLY CHAIN USING AI-BASED SOLUTIONS - DOMAIN CATEGORIZATION BY Location

	Upstream	Midstream	Downstream
Operational Management	Automated tooling equipment in smart farming (Carolan, 2020) (Kopteva, 2019) Plant gene predictive models (Carolan, 2020) Transparency, traceability, and efficiency (Lakkakula, 2020) (Erkoyuncu, 2020) (Trunk, 2020) (Walker, 2020) (Black, 2020) (Liu, 2020) Faster data collection, transmission, and analysis (Calatayud, 2019) (Peppes, 2020) Automatic irrigation systems based on environmental factors (Peppes, 2020) (Shi, 2019) (Zounemat-Kermani, 2020) Expedite Procurement and Production (Denis, 2020) (Davarzani, 2020)) (Ryan, 2020) Opportunities for rapid scalability (Denis, 2020) Data mapping and simulations using Digital Twin (Erkoyuncu, 2020) Maximize asset utilization (Bell, 2020)	DES to estimate on hand inventory levels (Ahmed, 2015) Reduces Transportation Costs using ANNs (Ahmed, 2015) (Dash, 2019) (Food logistics 4.0, 2021) (Davarzani, 2020)) Lowers delay costs and quickens the reconciliation process (Lakkakula, 2020) (Food logistics 4.0, 2021) (Fountas, 2020) Machine Health Monitoring and predictive/preventative maintenance (Dash, 2019) (Jones, 2020) Efficient lot sizing to maximize utilization of resources (Toorajipour, 2020) (Ryan, 2020) Detection of defective products using CNNs (An executive's guide to AI,	Customization enhancement and resource coherence (Bourke, 2019) (Ryan, 2020) Reduce inventory holding costs to increase inventory size, leading to increases profits (Ahmed, 2015) (Food logistics 4.0, 2021) Reactions in Agile and Lean methodologies (Calatayud, 2019) (Toorajipour, 2020) (Sagarna, 2019) Assists in product introductions (Dash, 2019) Product Mix / Line optimization (Toorajipour, 2020) Output of adaptive feedback reports using RNNs (An executive's guide to AI, 2018) (Food logistics 4.0, 2021)

	Automatic harvesting protocols (Anandan, 2020) (Shi, 2019) Precision sensors to for automated guided vehicles (Anandan, 2020) (Food logistics 4.0, 2021) (Rymarczyk, 2020) (Marani, 2021) Improved working conditions for employees on site (Food logistics 4.0, 2021) Efficient crop cultivation through soil analyses (Majumdar, 2019) (Milunović, 2018) Increased yields (Fountas, 2020) (Ryan, 2020) (Marani, 2021) Remote Sensing to track crop yields (Fountas, 2020) (Ryan, 2020) (Marani, 2021) Rapid Crop identification (Perry, 2020) Tracking and reduction of water usage (Zounemat-Kermani, 2020) (Duvniak, 2020) Detection of crop color to identify ripeness (Marani, 2021) The agricultural drone for field assessment (Carolan, 2020) (Shi, 2019)	2018) (Food logistics 4.0, 2021) Detect company logos or codes for sorting (An executive's guide to AI, 2018) Throughput, Cycle time, and Inventory optimization (Denis, 2020) Enhance flexibility (Jones, 2020) (Black, 2020) (Rymarczyk, 2020) Reduce downtime (Bell, 2020) Supply chain network resilience (Black, 2020) Lower levels of operational/capacity slack (Black, 2020)	Efficient POS for finished goods (Denis, 2020) Model Based Predictive Controls, Future Earnings Modeling using Digital Twins (Jones, 2020) Upgrade effectiveness of fleet management (Bell, 2020) Increase volume, variety, and velocity of product sold (Food logistics 4.0, 2021) Greater diversification in products that can be sold (Black, 2020) Comparisons of cost/benefit plans using AI (Duvniak, 2020)
Decision Making	Avoidance of technical / knowledge lock-in (Carolan, 2020) Decision support system for farm and crop management qualitative traceability (Tzachor, 2020) (Peppes, 2020) Assists with data accuracy and outputs (Demestichas, 2020) Utilizes real-time KPIs for instantaneous feedback (Dash, 2019) (Sagarna, 2019) Sift through unambiguous, complex data to drive smart reporting methods (Bell, 2020) (Duvniak, 2020) Improve organization structures (Trunk, 2020) AI can augment human capabilities and vice versa (Trunk, 2020) Prediction of water and irrigation revenues and costs (Zounemat-Kermani, 2020) (Duvniak, 2020) Agricultural technology providers can provide insights using big data (Ryan, 2020) Can address stressors in farmers (Beseler, 2020)	Creates data chains decision makers can follow (Carolan, 2020) DSNs to facilitate production planning that matches market demand (Calatayud, 2019) (Trunk, 2020) Can enable a symbiotic relationship between manager and employee (Bălan, 2019) Enables accountability when working with multiple stakeholders (Dash, 2019) Language translations for Multinational Corporations (An executive's guide to AI, 2018) Collaborative Planning, Forecasting and Replenishment (Food logistics 4.0, 2021)	Automation of commodity trading (Lakkakula, 2020) (Black, 2020) Provide information bank for executives to balance hard and soft objectives (Bălan, 2019) Auto-generating suggestions to clients based on previous orders (Bălan, 2019) Provide information on client consumption patterns and perceptions (Dash, 2019) (An executive's guide to AI, 2018) (Alzoubi, 2017) (Duvniak, 2020) Increase demand forecast accuracy (Dash, 2019) (Food logistics 4.0, 2021) (Black, 2020) Implement dynamic pricing (Dash, 2019) (Food logistics 4.0, 2021)

	Creates a strong portfolio of solutions (Walker, 2020)	Leaner logistics planning through decentralized decision making (Food logistics 4.0, 2021)	
Risk Management	Traceability of food production (Calatayud, 2019) (Peppes, 2020) (Shi, 2019) Response to changing weather patterns (Calatayud, 2019) (Food logistics 4.0, 2021) Simulating and evaluating the degradation of the biophysical environment (Tzachor, 2020) Simulating future yield performances (Tzachor, 2020) Properly store and manage data vulnerabilities from security threats (Peppes, 2020) (Liu, 2020) Tracing of water supply quality (Duvniak, 2020)	Distributed Ledgers for expedited contracts (Demestichas, 2020) Pinpoint where asset maintenance is needed in case of a breakdown (Calatayud, 2019) Ensure data integrity from theft (Peppes, 2020) Increase ability to pivot quickly regarding natural disasters (Black, 2020)	Tracking and internal / external tracing (Demestichas, 2020) (Tzachor, 2020) (Peppes, 2020) Ingredient analysis for diseases (Demestichas, 2020) Detecting real time disease outbreaks (Tzachor, 2020) Assess the likelihood that a transaction is fraudulent (An executive's guide to AI, 2018)
Sustainable Business Models	Automatic food sorting (Vaio, 2020) Insurance of hygiene standards and practices (Vaio, 2020) Optimize fertilizers, pesticides and systemized irrigation (Vaio, 2020) (Davarzani, 2020) Ventilation and moisture management (Tzachor, 2020) (Food logistics 4.0, 2021)	Improve market correspondence (Vaio, 2020) (Bell, 2020) (Food logistics 4.0, 2021) Reduce overall emissions (Toorajipour, 2020) (Vaio, 2020)(Anandan, 2020) Can balance between economic, environmental, and social priorities (Vaio, 2020) Create effective SDGs (Vaio, 2020)(Kriebitz, 2020)	Reduce the cost of food recalls (Lakkakula, 2020) AI literate executives will facilitate an AI centered supply chain (Bălan, 2019) (Trunk, 2020)

TABLE 2: OPPORTUNITIES AND CHALLENGES OF AI APPLICATIONS IN UPSTREAM AGRICULTURE

Upstream AgSC	Opportunities	Challenges
Digital Twin	Sweeping cost reductions (Jones, 2020) Reduce risk, design & reconfiguration times (Jones, 2020) Maintenance decision making (Jones, 2020) Modularity to fit different environments (Rymarczyk, 2020) Ability to Imagine, Design, Realize, Support, Retire (Jones, 2020)	Digital Twins are heavily specified, no general software or standard (Jones, 2020) Understanding what level of fidelity is difficult to define (Jones, 2020) Training of existing staff may be costly (Food logistics 4.0, 2021)

	Preset agile frameworks (Denis, 2020) (Sagarna, 2019) Efficient Prototyping (Rymarczyk, 2020)	
Machine Learning	Utilizing Chat-bots to educate rural communities (Ekanayake, 2020) Fruit detection and counting (Marani, 2021) Able to increase shelf life of products (Food logistics 4.0, 2021) Rule based expert systems for manufacturing contracts (Toorajipour, 2020) Reduction in delay costs and the reconciliation process (Lakkakula, 2020) Predict and analyze the mental health of farm workers (Beseler, 2020)	Overemphasis on AI might lead to focus on knowledge storage over knowledge flow (Trunk, 2020) Technological knowledge of stakeholders is generally low (Demestichas, 2020) (Ekanayake, 2020)
Robots	Automated Guided Vehicles (Food logistics 4.0, 2021) (Ryan, 2020) (Marani, 2021) Remote Sensing (Fountas, 2020) (Marani, 2021)	Decrease in demand for unskilled labor (Rymarczyk, 2020) (Eteris, 2020)
Neural Networks	Noninvasive identification of grapevine pests and disease (Marani, 2021) Can perceive the surrounding environments and make automatic decisions based on computational algorithms (Toorajipour, 2020) (Alzoubi, 2017) Land use simulation to track changes (Duvniak, 2020) Forest Modeling to track wildlife (Duvniak, 2020)	The sheer scale/scope is hard to maintain (Perry, 2020) Must accurately define the project's parameters for success (Sagarna, 2019) Security threats posed by malware or antagonistic intruders (Peppes, 2020) (Liu, 2020) High investment commitment (Food logistics 4.0, 2021)

TABLE 3: OPPORTUNITIES AND CHALLENGES OF AI APPLICATIONS IN MIDSTREAM AGRICULTURE

Midstream AgSC	Opportunities	Challenges
Digital Twin	Solution Design, Process / Capability Embedding, and Technical Implementation (Denis, 2020) Assembly and disassembly systems (Bell, 2020) Simulation, Modeling and Optimization (Jones, 2020)	Digital privacy will be not easy to navigate (Jones, 2020) (Eteris, 2020) People remain the greatest implementation challenge (Bălan, 2019) (Food logistics 4.0, 2021) (Kopteva, 2019)
Machine Learning	Minimization of consumption (Rymarczyk, 2020)	Effective construction and mobility (Eteris, 2020) Balancing the soft and hard objectives within a ML process (Bălan, 2019) (Mwitondi, 2020)
Robots	Automatic packaging and palletizing (Food logistics 4.0, 2021)	

Neural Networks	Many software-based calculators that are deeply interconnected and capable of in taking massive amounts of data (An executive's guide to AI, 2018) Improvement in Coherence, Convergence, and Conditionalization (Trunk, 2020)	Finding the right AI to pair with which logistics systems (Food logistics 4.0, 2021) Identifying solutions between human-AI interface (Food logistics 4.0, 2021)

TABLE 4: OPPORTUNITIES AND CHALLENGES OF AI APPLICATIONS IN DOWNSTREAM AGRICULTURE

Downstream AgSC	Opportunities	Challenges
Digital Twin	Enhancing flexibility & competitiveness (Jones, 2020) Reduces likelihood of sunk cost effects (Trunk, 2020) Reprogrammability (Rymarczyk, 2020)	Uncertainty in economic benefit (Rymarczyk, 2020)
Machine Learning	ABS models to mitigate supply chain risk (Toorajipour, 2020) (Alzoubi, 2017)	The major digital gap between developed and developing countries (Demestichas, 2020) (Mwitondi, 2020) (Ekanayake, 2020)
Robots	Smart Retailing with robots and process improvements (Dash, 2019)	
Neural Networks	Real time pricing for demand management (Toorajipour, 2020) Rapid scalability (Denis, 2020)	Data ownership and management (Demestichas, 2020) (Rymarczyk, 2020) Reliance on historical data limits AI (Trunk, 2020) (Davarzani, 2020)

Aligning with Table 1 findings, the opportunities were very prevalent upstream of the AgSC according to the covered research work. Digital twins' technology is leading the way for the highest AI technology impact on AgSC. The descriptive, prescriptive as well as predictive nature of digital twins and in many cases the neural networks models made them especially useful in the multiple and complicated activities of upstream uses. It is important to note also that due to the traditional nature of robotic application in the AgSC and since this paper focused more on the very recent research work, robotic technology is not fairly represented in in these tables in all three AgSC locations. Meanwhile in Table 4, it is interesting to see that there were few challenges listed. This is because downstream AgSC is generally a latecomer in terms of AI solutions relative to upstream and downstream, making this a good topic for future research.

4.2. An opportunities and challenges perspective

In this section, we pay extra attention to AI applications in the AgSC domains of risk management and sustainability to better understand their opportunities and challenges. Also, we relate the opportunities and challenges perspective to the AgSC location for some specific application categories.

Table 5, lists the opportunities and challenges of AI application in AgSC risk management. Subcategories of cyber, environmental and health were chosen to the preponderance of research surrounding risk sources in the AgSC. Cyber is defined as risk management in relation to the internet and connectivity, environmental is defined as risk management in relation to the surrounding geographical location, and health is defined as risk management in relation to the wellbeing and safety of employees.

TABLE 5. OPPORTUNITIES AND CHALLENGES OF AI IN RISK MANAGEMENT

Risk Management	Opportunities	Challenges
Cyber	Decreasing overall costs due to malpractice or theft (Peppes, 2020) Identification of phishing (Food logistics 4.0, 2021) Managing of international supply chain in case of emerging infectious diseases (Black, 2020) Privacy preserving solutions, data integrity solutions, authentication solutions, access control solutions, data confidentiality solutions, blockchain-based solutions and consensus algorithms (Peppes, 2020) (Eteris, 2020) (Liu, 2020) Radio Frequencies, computer systems, & sensors (Food logistics 4.0, 2021)	Data and information theft (Peppes, 2020) (Food logistics 4.0, 2021) (Rymarczyk, 2020) (Liu, 2020) Potential for intellectual property could be stolen through malicious attacks (Food logistics 4.0, 2021) (Rymarczyk, 2020) (Liu, 2020)
Environmental	Collection of environmental parameters and big data resources (Peppes, 2020) (Duvniak, 2020) (Marani, 2021) Can provide better insight into weather pattern effects on the supply chain (Calatayud, 2019) (Food logistics 4.0, 2021) Precision Agriculture (Peppes, 2020) (Fountas, 2020) (Marani, 2021) Contingency Planning (Black, 2020) Automatic processes streamlining crops (Peppes, 2020) (Fountas, 2020) (Marani, 2021)	The increasing dominance of farm and crop consolidation (Peppes, 2020)
Health	Improved safety of workers (Food logistics 4.0, 2021) Human Rights Advocacy (Kriebitz, 2020)	Increasing dependence on components in food related systems (Peppes, 2020) (Liu, 2020)

In Table 5, it is clear that the opportunities for AI potential in AgSC risk management are outweighing their implementation challenges. The scope and depth of challenges in the Cyber, Environmental, and Health domains, while important, are overshadowed by the potential opportunities. Many of the opportunities revolved around securing the AgSC from threats and providing insights to better mitigate the risks and improve crop and employee efficiency. The challenges warned of the growing dependences on crop consolidation and the reliance on supply chain networks for food security.

Table 6 highlights the review focus on AI opportunities and challenges in the AgSC sustainability domain. The subcategories of sustainability topics captured are sustainable development goals, collaboration, and optimization. Sustainable development goals are a set of 17 goals set by the United Nations to drastically reduce hunger, poverty, disease, and illiteracy. Collaboration is defined as the communication of entities in relation to sustainable business models, and optimization is defined as the betterment of processes in relation to sustainable business models.

TABLE 6. OPPORTUNITIES AND CHALLENGES OF AI IN RELATION TO SUSTAINABLE BUSINESS MODELS

Sustainability	Opportunities	Challenges
Sustainable Development Goals (Vaio, 2020) (Mwitondi, 2020) (Eteris, 2020)	The inclusion of all stakeholders from farm to fork (Vaio, 2020) (Eteris, 2020) Overall reduction in poverty (Kriebitz, 2020) Accurately calculate energy consumptions of a project (Alzoubi, 2017) Green Growth development (Eteris, 2020) Increase efficiency leading to a sustainable supply chain (Vaio, 2020) Personnel job contentment (Bell, 2020)	Little awareness of SDGs in education and science sectors (Eteris, 2020) Moral or socially correct behaviors are subjective and cannot be programmed easily (Trunk, 2020) Deciding what authority is morally responsible for an AI application (Trunk, 2020)
Collaboration	Can increase visibility and robustness (Black, 2020) Decentralized and predictive Enterprise Resource Planning Systems (Black, 2020) Vendor Managed Inventories (Food logistics 4.0, 2021) (Black, 2020) Efficient Consumer Response (Food logistics 4.0, 2021) Collaborative Planning, Forecasting and Replenishment (Food logistics 4.0, 2021) (Black, 2020) Improve manufacturing environments (Bell, 2020)	Unqualified personnel (Kopteva, 2019) (Eteris, 2020) AI literacy and transparency is a major obstacle (Trunk, 2020) (Peters, 2020) (Eteris, 2020) Buy in from stakeholders (Vaio, 2020) (Food logistics 4.0, 2021) Initial investments can be high cost (Vaio, 2020) (Rymarczyk, 2020) (Eteris, 2020)
Optimization	Vertical integration through AI adaptability / compatibility for sustainability practices (Anandan, 2020) (Black, 2020) Better practices in hiring procedures (Kriebitz, 2020) Able to use less resources & attain similar outputs (Anandan, 2020)	Underdeveloped space monitoring (Kopteva, 2019) Unstructured data and information (Kopteva, 2019)

Table 6 offered several insights into the opportunities associated with AI implementation with sustainable business models in the AgSC. Artificial Intelligence in particular contributed greatly to sustainable development goals. In terms of optimizations, there are many upsides to optimization, although structuring and monitoring still present a challenge.

Figures 4 and 5 depict respectively the number of papers within the literature considered that focused on opportunities and challenges of AI potential in 4 specific categories along the AgSC location. These categories are *security*, which is defined as the safety and protection of AgSC's employees, data, and product, *sustainability* along the triple bottom line definition, *cost* which is defined as the expenses and expenditures involved in an AgSC and lastly, *quality* is defined as the precision of processes and standards of product.

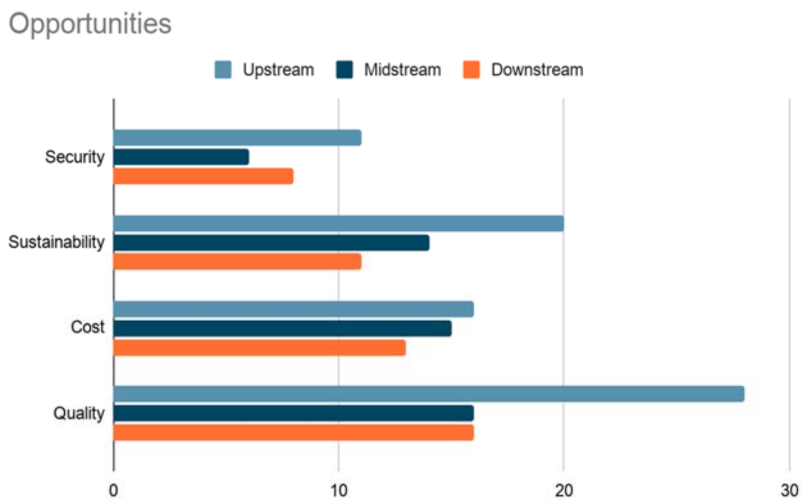

FIGURE 4. OPPORTUNITIES CATEGORIZED BY TOPIC AND SUPPLY CHAIN SEGMENT

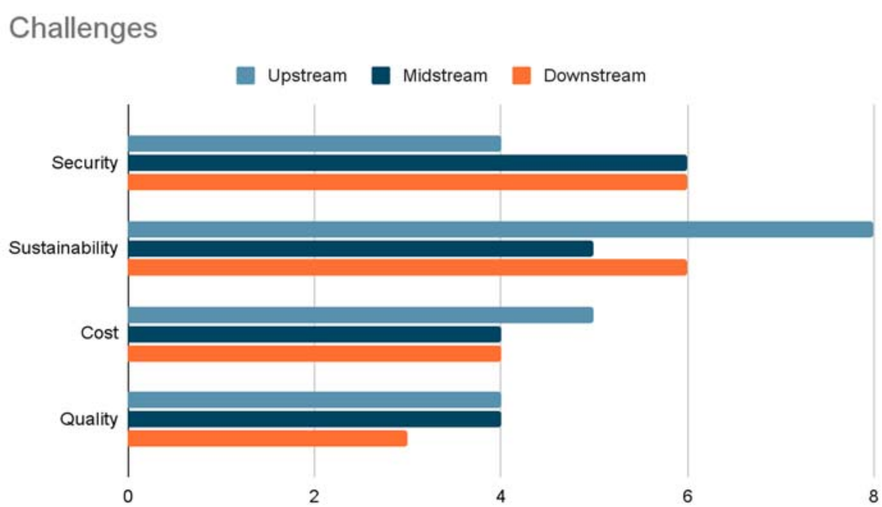

FIGURE 5. CHALLENGES CATEGORIZED BY TOPIC AND SUPPLY CHAIN SEGMENT

Figures 4 and 5 demonstrate the stark contrast between the research focus on opportunities versus challenges of AI application in AgSC suggesting that the former outweigh the later. Quality within the operation domain in AgSC upstream has the greatest potential for growth and opportunity, while sustainability effort also in the upstream poses the greatest challenges. This research finding aligns with the current implementation of AI in AgSC as operation implementation of AI solutions to improve quality of processes are far ahead of AI solutions implementation to enhance sustainability. It is also worth noting that the research focusing on the opportunities along the security and risk management domain is modest compared to other domains opening a door for a further research need along this important AgSC aspect. Finally, it is clear from the research focus that direct cost reduction as an opportunity is not on the top of the AI benefits list. This can be due to the nature of AI applications that usually have an upfront-fixed costs as well as their focus on data and information usage to improve decisions that indirectly influence production costs.

V. DISCUSSION OF MAIN OPPORTUNITIES AND CHALLENGES FINDINGS

The conducted literature analysis demonstrated the high potential of opportunities with their associated challenges of AI implementation in all levels of the agricultural supply chain. The analysis focused mainly on the location perspective and results showed that upstream by far had the most opportunities for AI impact, while downstream was clearly lagging behind in terms of AI application. This research finding aligns with the current AgSC practice.

The operation domain upstream the AgSC had the highest emphasis in the considered research work. Due to the unpredictable and highly variable nature of upstream operation processes, AI technologies like neural networks and digital twins can provide a formula to better prepare and adapt to these challenging situations. The review highlighted the role of AI in prediction and adaptation to manage upstream operation and decision complexity. Examples included weather patterns that affect AgSC upstream yield and downstream during transportation of goods. Field resource management was another area of research emphasis in upstream AgSC. AI based solutions can offer management models for smarter water management, precise pesticide distribution and efficient disease control to name some applications. Along the whole AgSC (from upstream to downstream) product tracing and tracking is also a clear addition that AI can bring to the agricultural sector. This will in turn save on costs due to better integration while maintaining a sustainable and secure AgSC. Finally, yet importantly, AI can improve farms' yield through automation and data collection as important elements for precise farming and future AgSC 4.0.

In the AgSC risk management domain, research also confirmed that AI applications' opportunities outweigh their challenges. Most of the work in this area focused on the role of AI in securing the upstream AgSC, not only from the environment, but from threats and malpractice as well. AI technologies' ability to detect malware or security breaches can strengthen the supply chain's integrity and provide stability in regions of turmoil. One challenge that stood out in this area of research work was the risk associated with the rise of crop consolidation worldwide. If a new breed of pest or disease gains dominance over one of the four major crops in production, the whole food supply may be in danger. Predictive and monitoring AI solutions are suggested to mitigate such risk. In addition, the scale difference risk in AgSC was another interesting finding where many smaller farmers and producers do not have the means to develop pesticides or repellents to make their crops resistant, leaving it to the large corporations. AI solutions was suggested to mitigate such risk through information sharing and integrated neural networks. Finally, resilience against environment uncertainty (whether nature or market dynamics) was a major advantage for AI in AgSC through offering intelligent and efficient alternatives for many of these difficult scenarios and how to prepare for them. One major challenge of this risk management domain that was discussed in the review was data ownership and data sharing regulations and how the enterprises' size and power can be a disadvantage for smaller and rural businesses in this regard.

Regarding the sustainable business models domain, the research work pointed to the ability to make informed eco-friendly for resource management decisions upstream and midstream as a key contribution to AI in AgSC. Therefore, it was emphasized that executives must be competent with AI-based solutions to make better decisions along the three-bottom line of their AgSC activities. This leads into a major challenge however, since the current AI skill level among AgSC managers and executives are still below the required level. Some research work also discussed aspects of the social impact of AI in AgSC with regard to workers employment risk through automation as well as the role of AI in better hiring practices versus implicit bias that can be embedded within the used data.

VI. SUMMARY AND RECOMMENDATIONS

This paper attempted to contribute to filling an important gap in the AgSC research with regard to the application of AI through focusing on a location perspective or the how question of this AI application dynamics. A literature review for the very recent work in this area was conducted, summarized, and analyzed from a location perspective as intended. The analysis highlighted various opportunities and challenges for AI along the different AgSC locations and business domains.

Results from the reviewed body of literature showed that in general more focus was given to AI application in upstream of the AgSC (compared to other locations) and that the operation domain of AgSC and especially at upstream has the highest potential of AI opportunities (compared to the other considered domains). These findings are interesting in understanding AI implementation dynamics in AgSC since academic research usually leads the way to the practical application in most modern technologies, especially AI. Such findings point to a distinguishing characteristic of AgSC in comparison to other supply chains, where one can find AI application is either levelled along the whole supply chain or may be more centered midstream. One reason for this location characteristic is related to the diversity and complexity of the activities (especially the operation activities) at the upstream of the AgSC. AI solutions can provide a plethora of information and prediction models that can reduce and manage such complexity at that location.

The comparative analysis conducted to the body of the literature reviewed in this paper can suggest the following practical and research recommendation regarding AI application in AgSC:

- From a location perspective, AgSC managers should study and leverage the success of many of the AI potential upstream to increase and extend AI application midstream and downstream.
- There are clear AI technologies that stand out as a successful solution for many of the AgSC challenges. Among these technologies is the digital twin that has the ability to manage different aspects of the AgSC using descriptive, prescriptive and predictive models. However, the AI models in this emerging technology are facing upstream challenges of farming processes' dynamics, midstream processing and transportation complexity and downstream demand uncertainties. More research is required to investigate these challenges and pave the road for successful digital twin implementation.

- The AI skill gap was highlighted in various research as a challenge across all AgSC locations and application domains. There should be an effort to bridge this gap by companies, universities and public policies. To keep up with the current need, this effort can follow the captured AI implementation distribution in this paper, meaning, developing skills for upstream AI application as a priority followed by midstream then downstream.
- AgSC stakeholders should pay attention to the data management challenge in AI implementation. They should focus on the construction of an integrated data platform to enable the integration of relevant information from upstream to downstream and vice versa. This will require cooperation to achieve standardization levels, discuss data ownership as well as interoperability issues. This digitization integration either can help to realize the full potential of AI technology in AgSC or can act as a hurdle in front of this technology.
- Related to the location perspective and sustainability domain, there is an opportunity at upstream of the AgSC to develop a shared neural network that can provide an overarching strategy for rural farmers. Rural, traditionally agricultural communities have been the slowest group for Ag 4.0 adoption. Clustering these farmers upstream under such strategy will not only increase their food production, but stimulate their economies as well.
- Tracking the end-to-end lifecycle of Ag products from upstream to downstream is a major potential highlighted in the literature. This can be a good example of how AI successful implementation upstream can be extended to midstream and downstream. Many studies have been conducted analyzing snapshots or periods within a specific domain, but little to none have studied the full lifecycle of Ag products from beginning to end.

The future work of this research should extend the location mapping of AgSC beyond AI to cover other AgSC 4.0 elements. This should include the digitization effort through the integration of IoT and digital twins from upstream to downstream. In addition, the automation of processes through the usage of wireless communication and the new blockchain technology need to be investigated. Furthermore, the push for intelligence regarding big data and cloud computing is an important feature to be also explored.

In conclusion, capturing the dynamics of how AI technologies are evolving and spreading from upstream to downstream and vice versa will help in drafting the investment map, the skill development plan as well as the sustainability agenda for AgSC. This paper attempted to shed some light on such dynamics revealing various AI opportunities and challenges from a location perspective.

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