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Integration of Agriculture 4.0: Barriers and Opportunities for Small-and-Medium Farms in Canada

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Résumé

L'agriculture mondiale et canadienne fait face à deux défis majeurs : le changement climatique et la croissance de la demande alimentaire. L'agriculture 4.0 (A4.0), une sous-catégorie de l'Industrie 4.0 (I4.0), définie par la mise en œuvre de technologies numériques avancées telles que l'intelligence artificielle (IA), l'informatique en nuage (CC), l'analyse de mégadonnées (BDA) et l'Internet des objets (IdO), a le potentiel de relever les défis auxquels sont confrontés les agriculteurs au Canada, en soutenant une productivité améliorée et une durabilité écologique. Malgré les avantages potentiels la mise en œuvre de l'A4.0 fait face à d'importants obstacles. Il existe encore un écart significatif dans la littérature en termes de compréhension du concept et de recherche empirique. L'objectif de cette recherche est d'obtenir des informations sur l'état de la mise en œuvre de l'A4.0 au sein des agriculteurs canadiennes. À travers une revue systématique de la littérature, une compréhension générale du concept de l'A4.0 a été développée en définissant l'A4.0, en identifiant ses technologies clés et les obstacles à sa mise en œuvre. Grâce à une analyse statistique descriptive les données collectées lors d'une enquête en ligne auprès d’agriculteurs canadiens, il a été déterminé qu'il existe une faible sensibilisation et connaissance de l'A4.0, avec une mise en œuvre limitée des technologies clés dans leurs opérations agricoles. Le plus souvent les participants ont rencontré des obstacles techniques et de connaissance, ces obstacles aient la plus forte puissance. Les obstacles gouvernementaux ont été considérés comme les moins puissants et le moins éprouvé.

Mots clés : Industrie 4.0 (I4.0), Agriculture 4.0 (A4.0), Technologies Numériques Avancées, Intelligence Artificielle (IA), Informatique en Nuage (CC), Analyse de Big Data (BDA), Internet des Objets (IdO), Agriculture Canadienne, Obstacles à la Mise en Œuvre.

Méthodes de recherche : Revue Systématique de la Littérature (RSL), Enquête en Ligne, Analyse Statistique Descriptive

Abstract

Global and Canadian agriculture is facing two main challenges: climate change and growing food demand. Agriculture 4.0 (A4.0), a subset of Industry 4.0 (I4.0), defined by the implementation of advanced digital technologies (ADTs), i.e., Artificial intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and the Internet of Things (IoT), has the potential to address the challenges of farmers in Canada—by supporting improved productivity and ecological sustainability. Despite the potential benefits for productivity and sustainability, A4.0 implementation faces significant barriers. There is still a significant gap in the literature in terms of understanding the concept and empirical research. The aim of this research is to gain insights on the state of A4.0 implementation within Canadian farms. Though a systematic literature review (SLR) a general understanding of the concept of A4.0 was developed by defining A4.0, identifying its core technologies, and Implementation barriers. Additionally, though a descriptive statistical analysis of data collected through an online survey of Canadian farmers it was determined that there is a low awareness and knowledge of A4.0 among participants, with limited implementation of core technologies with their farms' operations. Additionally, participants experienced technical barriers and knowledge barriers most, these barrier types also had the strongest capability to restrict the implementation of A4.0. Governmental barriers were deemed to have the least capacity to restrict the implementation of A4.0, additionally it is the least experienced barrier type.

Keywords: Industry 4.0 (I4.0), Agriculture 4.0 (A4.0), Advanced Digital Technologies (ADTs), Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), Internet of Things (IoT), Canadian Farming, Barriers to Implementation

Research methods: Systematic Literature Review (SLR), Online Survey, Descriptive Statistical Analytics

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List of Abbreviation and Acronyms

A4.0: Agriculture 4.0
ADTs: Advanced Digital Technologies
AI: Artificial Intelligence
AM: Additive Manufacturing
ANP: Advanced Network Processors
AR: Augmented Reality
BC: Blockchain
BDA: Big Data Analytics
CC: Cloud Computing
CPS: Cyber-Physical Systems
DL: Deep Learning
EC: Edge Computing
FC: Fog Computing
GIS: Geographic Information System
I4.0: Industry 4.0
IoT: Internet of Things
ISM: Information System Management
MFC: Mobile Fog Computing
ML: Machine Learning
PA: Precisions Agricultural
RQ: Research Question
RFID: Radio-Frequency Identification
SLR: Systematics Literature Review
UAVs: Unmanned Arial Vehicles
UR: Ubiquitous Reality
VR: Virtual Reality
WSN: Wireless Sensor Network

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Chapter 1
Introduction

Current and future, food production is threatened by the increasing number of natural hazards caused by climate change, which agriculture has undoubtedly contributed to through natural resource use, fertilizer use, pesticide use, and CO2 emissions. Agricultural activities account, for example, for 70% of freshwater use globally (United Nations Food and Agriculture Organization, 2020). On top of these current challenges, global food production will have to increase by 70% by 2050 to meet the needs of an increasing population, which is expected to reach 9.7 billion by 2050 (World Bank, 2022; United Nations, 2022). These challenges can be translated into two objectives: increased productivity and ecological sustainability.

As a result of their global nature, these challenges still arise in developed nations such as Canada. The Canadian Government acknowledges these challenges in several objectives, called "priority outcomes", within their Food Policy for Canada initiative. The "priority outcomes" include vibrant communities, increased connections within food systems, improved food-related health outcomes, strong indigenous food systems, sustainable food practices, and inclusive economic growth (Government of Canada, 2020).

Agriculture 4.0 (A4.0), a subset of Industry 4.0 (I4.0), defined by the implementation of advanced digital technologies (ADTs), i.e., Artificial intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and the Internet of Things (IoT), has the potential to address current and arising challenges of farmers in Canada and internationally—by supporting improved productivity and ecological sustainability. For example, A4.0 can help farmers make better use of resources by reducing the use of water, fertilizer, pesticides, and land.

However, the implementation of A4.0 within global and Canadian agriculture is not without its barriers. Such barriers hamper the potential of A4.0 to help agriculture reach its objectives, i.e., increased productivity and ecological sustainability. The field of A4.0 has been gaining popularity in the last decade, but there is still a significant gap in the literature regarding understanding the concept of A4.0 and empirical research on its use. No research has been conducted on the experience farmers have when implementing A4.0 within their farming operations—both on the global and Canadian stages.

Therefore, the main aim of this thesis is to explore the state of A4.0 implementation within Canadian farms. Since there is a lack of consensus on the concept of A4.0 within scientific literature, the first objective of this thesis is to develop an in-depth understanding of the current discourse around the concept of A4.0 to define A4.0, identify core technologies, and identify barriers to implementation. To achieve the first objective of this study, a systematic literature review (SLR) was conducted. Additionally, due to the lack of empirical research, the second objective is to develop an understanding of the current state of A4.0 implementation in Canadian farms. The main points examined are farmers' level of awareness and knowledge of A4.0, the level of implementation of core A4.0 technologies, and the propensity of barriers to the implementation of core A4.0 technologies.

The Chapter 2 provides an in-depth explanation of the employed methodologies during this thesis and the developed research questions. The results of the SLR will be presented in Chapter 3 to discuss RQ1, RQ2, and RQ3, research questions one, two, and three. Next, the results of the empirical study, i.e., the online survey, will be presented and discussed in Chapter 4 to discuss RQ4 and RQ5. Finally, the conclusion will be presented in Chapter 5, and presents this thesis' limitations and recommendations for future research.

Chapter 2
Methodology

1.0 Research Aim

The aim of this research is to gain insights on the state of A4.0 implementation within Canadian farms. The aim can be further dissected into two objectives. The first objective of this research is to provide an overview of the concept of A4.0, thus building a general understanding of the concept by defining A4.0, identifying its core technologies, and identifying implementation barriers. The second objective is to determine the level of awareness and knowledge of A4.0, the level of implementation of core technologies, and the propensity of barriers to this implementation within the Canadian agricultural setting.

2.0 Research Questions

The purpose of this section is to present the research questions (RQs) developed from the first objectives of this thesis, as stated in the previous section.

2.1 Research Queston 1 (RQ1): What are the main characteristics of Industry 4.0 and Agriculture 4.0 (A4.0) and what is the link between them?

The first aspect of the first objective is to better understand the concept of A4.0 by deriving a universally accepted definition. Despite the growing literature, no agreed-upon definition exists for A4.0 or I4.0. As I4.0 served as the basis for the formation of A4.0 after its coinage in 2011 in Germany it is important to develop an understanding of I4.0 to understand A4.0, among other 4.0 concepts (Bag et al., 2021; Chauhan et Singh, 2019). In fact, I4.0 can be seen as the overarching concept, and A4.0 as the term describing the application of I4.0 within agriculture. As such, the first research question of this study serves to create a singular definition for A4.0 and I4.0, individually, and to understand the links between the two concepts.

2.2 Research Question 2 (RQ2): What are the core Industry 4.0 technologies and the core Agriculture 4.0 technologies?

The second aspect of the first objective is to understand what technologies are considered I4.0 technologies and A4.0 technologies by current academic literature. More specifically, the goal is to determine which of these mentioned technologies are core to the implementation and, thus, the success of A4.0 and I4.0. Core technologies being defined as those that support the movement towards the adoption of A4.0 and I4.0. As such, the second research question serves to identify the core technologies of I4.0 and A4.0, define the core technologies, explain the links between these core technologies, and compare the list of technologies associated with A4.0 and I4.0.

2.3 Research Question 3 (RQ3): What are the common barriers to Agriculture 4.0 (A4.0) technology implementation within farming?

The third aspect to understanding the concept of A4.0 is to understand the barriers to the implementation of A4.0 technologies discussed within academic literature. It is important to identify the barriers to A4.0 technology implementation because such barriers prevent farmers from fully benefiting from the advantages that these technologies offer. A4.0 holds exciting potential for facilitating sustainable development within the context of Agri-Supply Chains, but barriers to implementation limit sustainable development across the agri-food supply chain and for farmers.

2.4 Research Question 4 (RQ4): What level of awareness and knowledge of Agriculture 4.0 (A4.0) do Canadian farmers have and what percentage of farmers have integrated core Agriculture 4.0 (A4.0) technologies?

In addition to the SLR, it is important to gain insights into the level of implementation of A4.0 and the level of awareness and knowledge farmers have on A4.0 within the Canadian context. One crucial piece of information needed to help understand the experience Canadian farmers have regarding the implementation of A4.0 is their level of awareness. Intricately linked is the number of Canadian farmers who have adopted A4.0. Such information would be valuable for business market research and policy development. To gain this understanding, the focus was placed on the core technologies of A4.0. These four technologies were identified through RQ2. The fourth research question aims to determine the percentage of Canadian farmers who have implemented AI, CC, BDA, and the IoT and what is the level of awareness and knowledge of A4.0 in Canada.

2.5 Research Question 5 (RQ5): Which barriers to Agriculture 4.0 (A4.0) technology implementation do Canadian farmers experience most?

Having insight into the level of awareness and knowledge of agriculture and the implementation level of core A4.0 technologies is not enough to understand the experience of Canadian farmers. To truly comprehend the level of implementation and the extent of awareness and knowledge, it is important to gain insights into the barriers to implementation Canadian farmers face. To provide empirical insights into the matter, farmers were asked about the barriers they faced. The list of barriers was developed through the SLR (RQ3). The fifth research question aims to provide insight into which barriers were prevalent for Canadian farmers when integrating A4.0 core technologies.

3.0 Data Collection, Sampling, and Analysis

The purpose of this section is to present the data collection process, sampling strategy and data analysis for the SLR conducted to answer RQ1, RQ2 and RQ3, in addition to the online survey that was administered to answer RQ4 and RQ5.

3.1 Systematic Literature Review: Understanding Agriculture 4.0 (A4.0) and Industry 4.0

An SLR was conducted to provide a high-level summary of A4.0 and I4.0 to understand the concept of I4.0 and A4.0. Through this SLR the key characteristics of I4.0 and A4.0 were identified to derive clear definitions. In addition, the SLR also served to identify the core technologies, and barriers to the implementation of A4.0. These core technologies and barriers were then used to build the online questionnaire.

First the appropriate keywords were selected for data searching in HEC Montreal's Library database. The main search keywords included "Industry 4.0," "Industrie 4.0," "Fourth Industrial Revolution,", "Smart Industry", "Agriculture 4.0," "Farming 4.0," "Digital Agriculture,", "Smart Farming", "Fourth Agricultural Revolution," and "Agriculture 4.0 Technology." These search terms were applied to keywords, titles, and abstracts. They were chosen as these terms are used interchangeably and refer to the same process.

Second, the articles included in the SLR were chosen. The scientific articles had to meet the following requirements: they had to be written in English, available through the HEC Montreal online database and Google Scholar, and peer reviewed.

Third, the process of analyzing the articles included in the SLR was conducted. For the definitions, i.e., RQ1, of I4.0 and A4.0, a list of mentioned characteristics was noted for each article. This list was then refined by regrouping characteristics based on similarity and relatedness. To determine the core technologies of both I4.0 and A4.0, i.e., RQ2, all mentioned technologies related to I4.0 and A4.0 were considered. Technologies from previous industrial and agricultural revolutions were omitted, and technologies that could be considered as subtypes were included in the final list as separate technologies. For the barriers to the implementation of A4.0 technologies, all challenges or barriers mentioned in the articles were included in the list of barriers. Some barriers were regrouped based on their high level of relatedness or similarity.

3.2 Online Survey: Agriculture 4.0 (A4.0) Technology Implementation in Canada

To obtain the essential primary data for statistical analysis aimed at understanding the experiences of Canadian farmers in implementing A4.0 technologies, a cross-sectional questionnaire was administered online. This means that the questionnaire was distributed to Canadian farmers at a specific moment in time, as described by Vomberg and Klarmann (2022). A Canadian lens was applied to the online survey.

The survey method was chosen due to its ability to use complex scales and filter questions, ease of distribution, low cost, impossibility of distortion of answers due to interaction between the participants and the interviewer, and the ability to reach and question large numbers of participants (Vomberg and Klarmann, 2022, and Glastonbury and MacKean, 1991).

The questionnaire was designed considering survey content, question content, question format, question wording, question sequence, survey layout, and the results of the pretest of the questionnaire (Vomberg and Klarmann, 2022). The wording of the questions was critical, as it was important for participants with little knowledge or understanding of A4.0 and its core technologies to grasp the concepts clearly. To view the questionnaire, please refer to Appendix A and Appendix B.

During data collection, a convenience sampling method was used due to the difficulty of obtaining random samples (Short et al., 2002). A convenience sampling method refers to the selection of samples based on accessibility (Vomberg and Klarmann, 2022). The participation requirements were that the farmers had to be located within the territorial boundaries of Canada and that they operate a commercial farm, i.e., they sell goods produced on their farms. Participants self-reported their answers.

As English and French are the official languages of Canada both an English and a French version of the questionnaire was made available. Online outreach was conducted through social media platforms to maximize convenience and reach. However, recognizing that participants reached through online channels might introduce bias into the data by favoring a younger and more technologically informed population, direct outreach to various agricultural cooperatives and social groups was undertaken. Targeting agricultural cooperatives and organizations aimed to increase the diversity of communities reached across Canada. Many cooperatives and organizations shared information and the questionnaire link with their members in their newsletters.

The primary data was analyzed using a descriptive statistical approach. The purpose of descriptive statistics is to create familiarity with the data and identify any unusual cases (Holt, 1991). This method was chosen due to the small sample size of the study, which is due to the low response rate. The aim is to identify current trends regarding the integration of A4.0 core technologies within Canadian farming.

Chapter 3
Results of the Systematic Literature Review

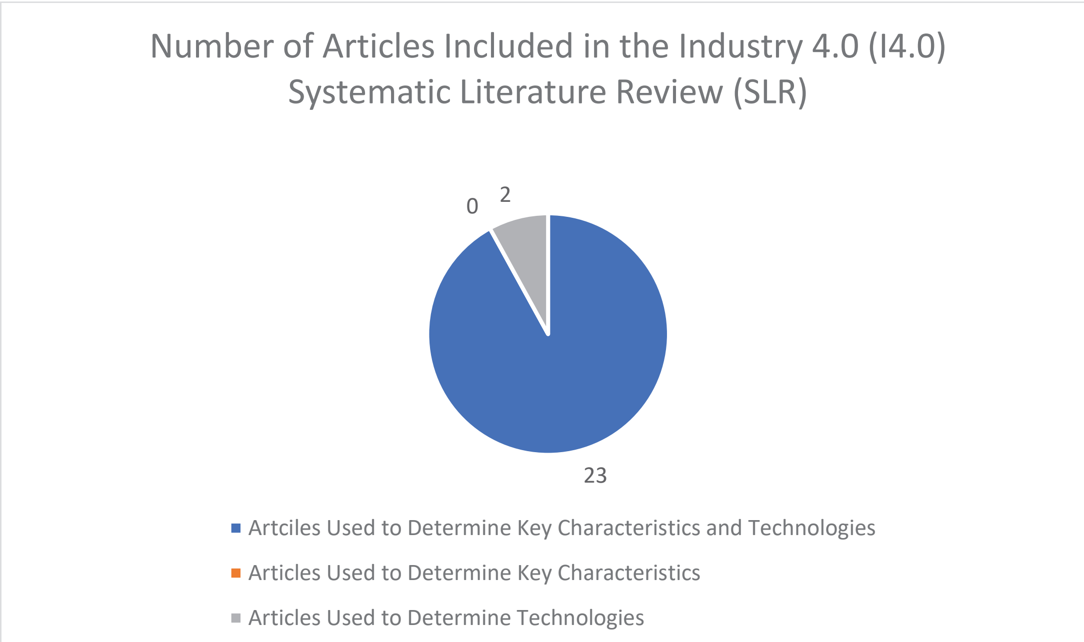
The purpose of this section is to present the findings of the systematics literature review conducted on A4.0 and I4.0 which included, the key characteristics and definitions of I.40 and A4.0, the determined core technologies of A4.0 and I4.0, and finally the categorized barriers to A4.0 technology implementation.

1.0 Defining Industry 4.0 (I4.0) and Agriculture 4.0 (A4.0): Similarities and Differences of Key Characteristics

The term "Industrie 4.0," coined in 2011, has grown in popularity in the last decade, as sustainability and increased productivity have become key challenges within supply chain management (Bag et al., 2021; Chauhan and Singh, 2019). However, despite its growth in popularity, there is a lack of a clear and general definition of the concept of I4.0—including its core technologies and principles. To develop such a definition and better understand the current discourse about I4.0, an SLR was conducted, examining 24 scientific articles on the topic of I4.0 published between 2013 and 2022. The purpose of this review is to extract the different characteristics and technologies of I4.0 mentioned in these scientific articles with the aim of identifying the key characteristics of I4.0. Many articles provide insights into the structure and definitions of A4.0 and I4.0, but very few provide insights into the links between both concepts. For example, De Silveira et al. examined the descriptions, technologies, advantages, and disadvantages of A4.0; however, they did not examine I4.0 or establish the important link between I4.0 and A4.0 (De Silveira et al., 2021).

Of the total of 25 scientific articles used during the literature review a subset of 23 articles was used to determine the characteristics of I4.0 as well as to identify I4.0 technologies (see Figure 1 and Appendix C), as discussed in Section 2.0. Overall, the number of articles published about I4.0 per year is increasing (see Appendix D). Two articles were used solely for the identification of technologies as they focused more on the technical application of I4.0.

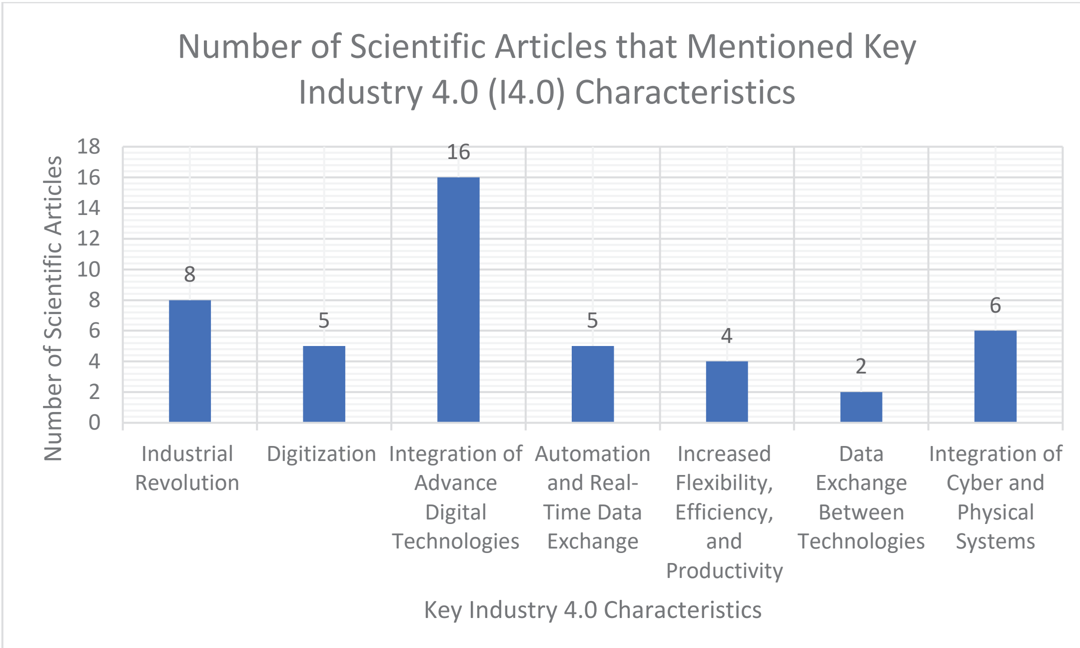
Figure 1: *Number of Articles Included in the Industry 4.0 (I4.0) Systematic Literature Review (SLR)*



As a result of this SLR, seven key characteristics were identified (see Figure 2 and Appendix E). First, I4.0 is an industrial revolution (33% of articles)—i.e., the fourth industrial revolution. This industrial revolution is based on the process of digitization (21% of articles), which refers to the process of integrating ADTs within industrial activities (67% of articles). These ADTs facilitate the exchange of data between technologies (8% of articles) in an automatic and real time manner (21% of articles), which permits the integration of cyber and physical systems (25% of articles), i.e., connecting machinery, people, and the internet through hardware and software. As a result, this digitization allows for increased flexibility, efficiency, and productivity (17%).

The most consistently mentioned characteristic in this context is the integration of ADTs, otherwise no temporal trend could be identified (see Appendix F).

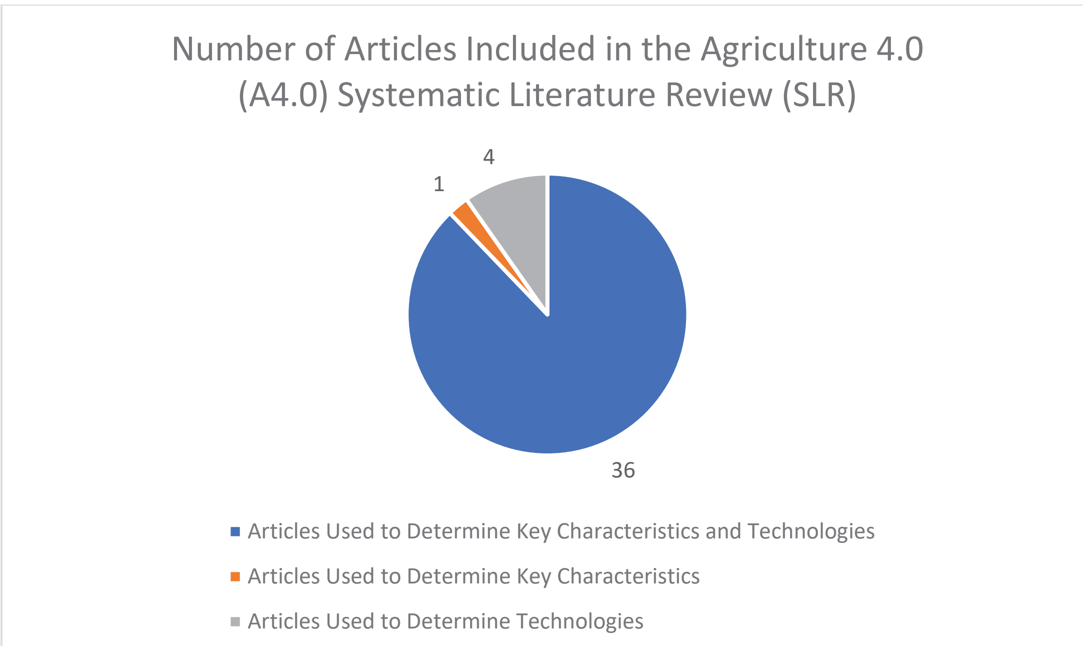
Figure 2: *Number of Scientific Articles that Mentioned Key Industry 4.0 (I4.0) Characteristics*



Finding application in many industrial settings, the concept of I4.0 has amongst others expanded into agriculture supply chains. The application of I4.0 in agriculture has been termed "A4.0" (Aceto et al., 2019). Similarly, to I4.0, A4.0 has gained in popularity over the last decade (Abbasi et al., 2022 and Araujo et al., 2021) yet lacks a generally agreed-upon definition. To develop such a definition and better understand the current discourse about A4.0, an SLR was conducted, examining 37 scientific articles on the topic of A4.0 published between 2017 and 2022. The purpose of this review is to extract the different characteristics and technologies of A4.0 mentioned in these scientific articles with the aim of identifying its key characteristics and technologies.

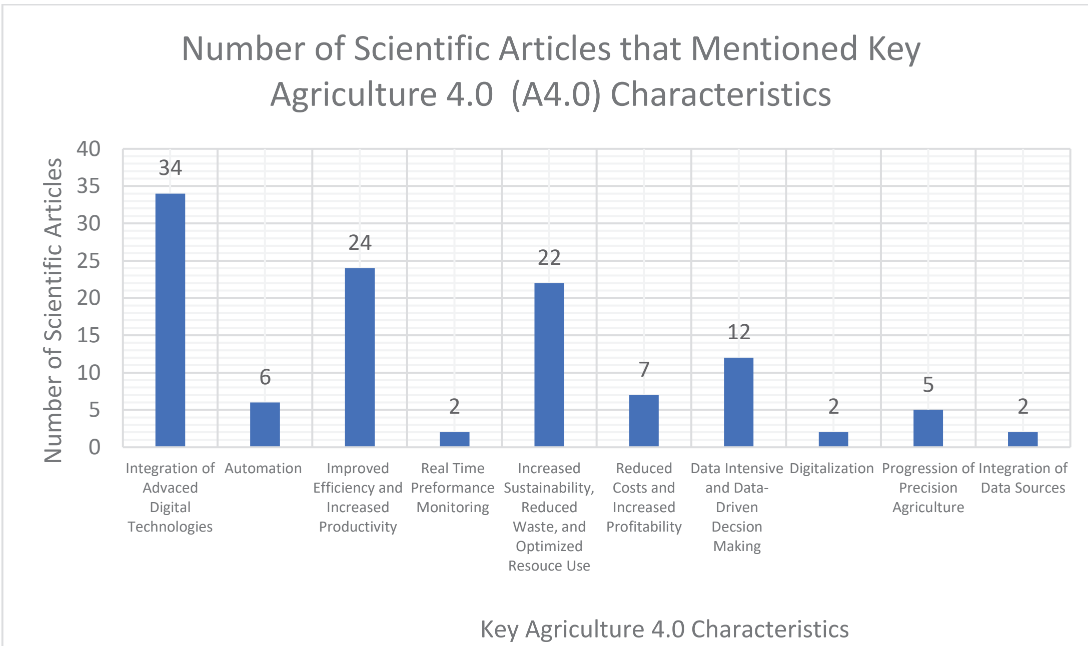
Of the total of 40 scientific articles used for this literature review a subset of 36 articles were used to both determine the characteristics of A4.0 and identify the key technologies (see Figure 3 and Appendix G). Some articles were used only for the identification of characteristics or technologies as some focused more on the structure and definition of A4.0 and others more on the technical side of A4.0. Overall, we see from this review that the number of articles published about A4.0 per year is increasing (see Appendix H).

Figure 3: *Number of Articles Included in the Agriculture 4.0 (A4.0) Systematic Literature Review (SLR)*



Moreover, through this SLR, ten key characteristics could be identified for A4.0 (see Figure 4 and Appendix I). The core of A4.0 is again the concept of digitization (5% of articles), which describes the process of implementing ADTs (ADT) within agricultural activities (92% of articles). This integration of ADTs leads to increased automation (16% of articles) which is tied to the progression of precision Agriculture—a pillar of Agriculture 3.0 (14% of articles). Integrating ADTs enables, moreover, an easier integration of data sources (5% of articles) which is crucial as decision-making within A4.0 is data driven (32% of articles). The joint integration of data and automation allows for real-time performance monitoring of crops and livestock (5% of articles) which helps improve efficiency and increases productivity (65% of articles), reducing cost and increasing profitability (19% of articles), as well as sustainability, by reducing waste, and optimizing resource use (59% of articles).

Figure 4: *Number of Scientific Articles that Mentioned Key Agriculture 4.0 (A4.0) Characteristics*



In short, A4.0 is best summarized by Sponchioni et al., defining A4.0 as:

> "the evolution of Precision Farming, realized through the automated collection, integration and analysis of previously separated data silos coming from the field, equipment sensors and other third-party sources, enabled by the use of smart and digital technologies of Industry 4.0, making in this way possible the generation of knowledge, to support the farmer in the decision-making process in the farm enterprise and when dealing with different players in the agricultural and food value chain, therefore breaking the boundaries of the single farm enterprise. The final aim is to enhance profitability and economic-environmental-social sustainability of agriculture. (Spronchioni, 2019, p.146)"

The key characteristics of A4.0 and I4.0 are, thus, vastly similar; however, the most important distinction between the concept of I4.0 and A4.0 is the inclusion of biological aspects within the supply chain, referring to animals and plants, which I4.0 does not (Debauche et al., 2022). The interactions between plants and animals with technology complexifies the use of these technologies.

Furthermore, some temporal trends were identified including that the characteristics of ‘integration of ADTs’, ‘improved efficiency and increased productivity,’ and ‘increased sustainability, reduced wasted and optimized resources use’ show a positive upward trend in terms of mentions over the years (see Appendix J). In addition, only the characteristics referring to the ‘integration of ADTs’ and ‘data intensive and data driven decisions’ are mentioned consistently, except for 2018 for which no relevant articles were included in the literature review. Otherwise, there is no notable temporal trend for the mention of A4.0 characteristics in the literature review.

In summary, A4.0 and I4.0 share the same key characteristics, in fact the main difference between these concepts is their sphere of application—with A4.0 including biological components within its operations and I4.0 not. The main aspect to take note of with these concepts is the attainment of more sustainable and productive supply chains through the implementation of ADTs. In fact, A4.0 can be seen as a subdivision of I4.0.

2.0 Determining Industry 4.0 and Agriculture 4.0 (A4.0) Core Technologies

As the integration of ADTs (ADTs) is a key pillar of both I4.0 and A4.0, SLRs were conducted for each respective concept to define a core set of I4.0 and A4.0 technologies, given the lack of consensus within the academic literature. During these SLRs, 22 technologies were identified for I4.0 (see Figure 5 and Appendix K), and 27 technologies were identified for A4.0 (see Figure 6 and Appendix L).

Figure 5: *Number of Scientific Articles that Mentioned Industry 4.0 (I4.0) Technologies*

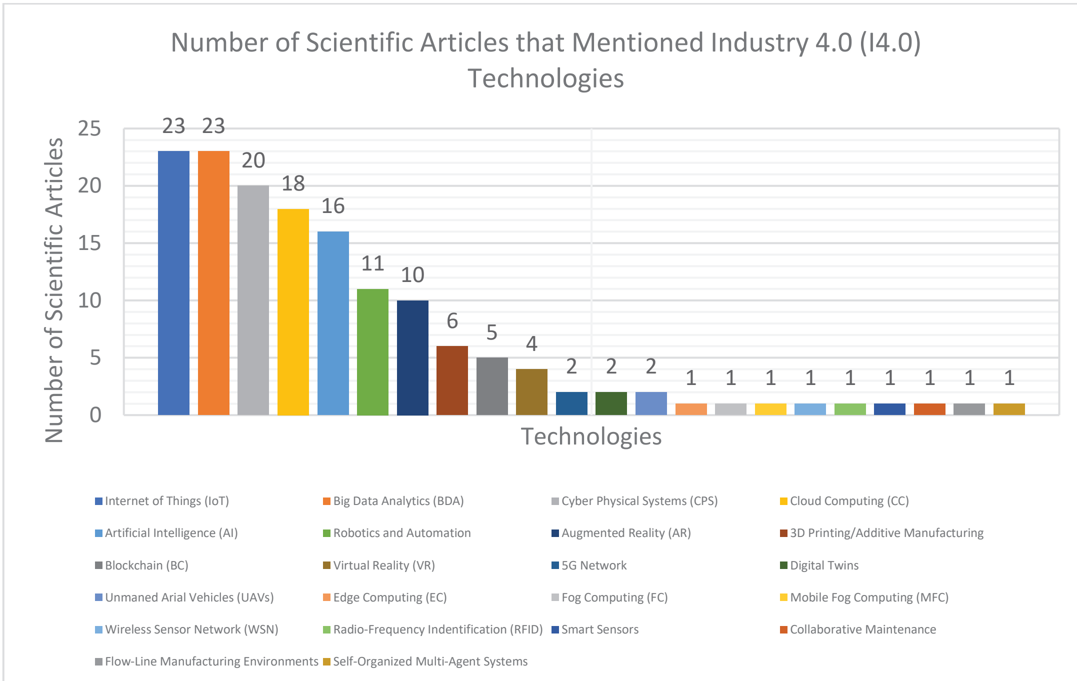
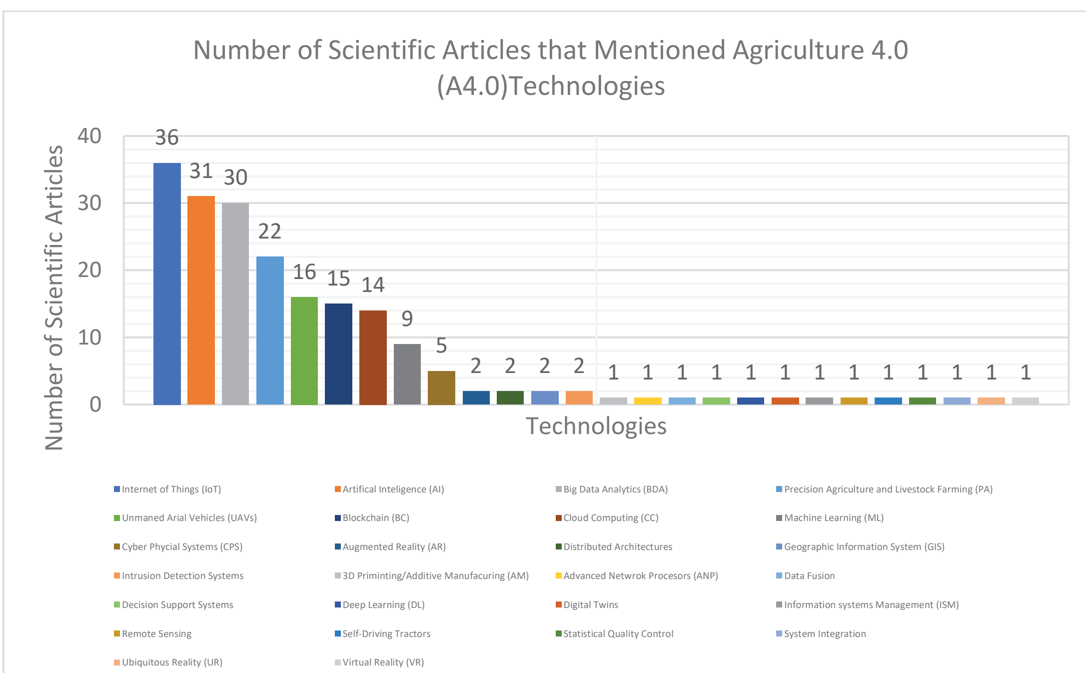
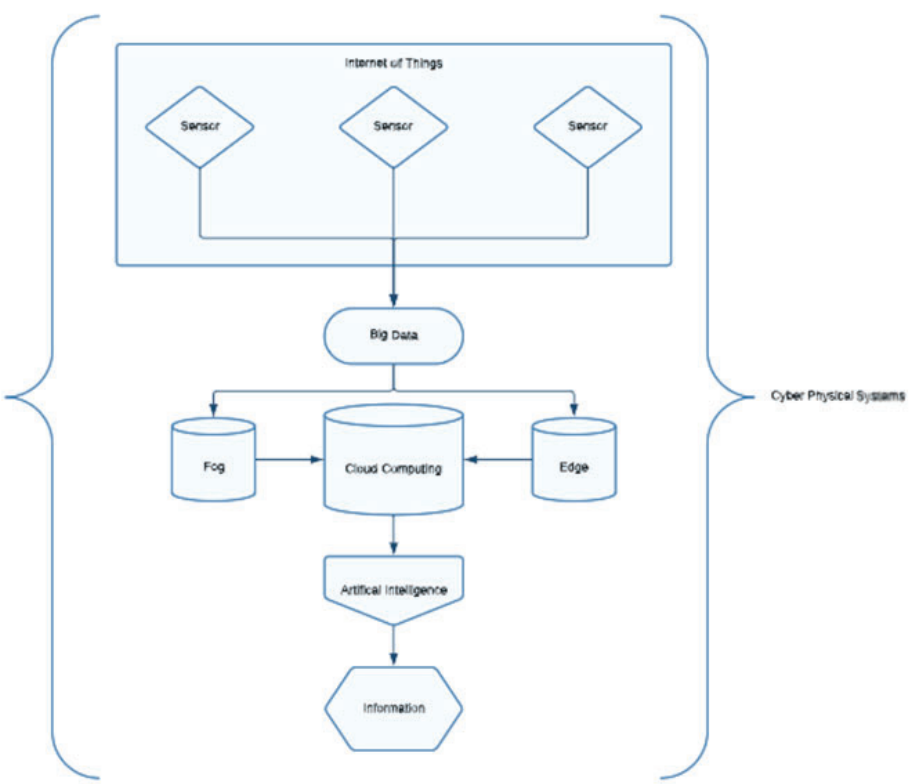


Figure 6: *Number of Scientific Articles that Mentioned Agriculture 4.0 (A4.0) Technologies*



For both I4.0 and A4.0, the core set of technologies established includes IoT, CC, BDA, and AI. A notable temporal component is that core technologies are consistently mentioned over the years while most other technologies are mentioned sporadically (see Appendix M and Appendix N). These technologies are the main components and enablers of cyber physical systems (as shown in Figure 7), known as Cyber-Physical Systems (CPS), which is why CPS is not considered a core technology. In CPS, IoT systems set up in fields allow for the collection of data through sensors, specifically big data. The data is then stored through CC. CC allows users to access the data remotely, i.e., from anywhere. BDA protocols are used to clean the data and to extract information useful for decision making. Due to the expansiveness of big data AI is used to complete the analysis of the data collected. Information extracted from this process does not only create a digital twin of farms and the physical environment but also allow people to gain a better understanding of their operations to make better, more informed decisions. This is in fact a decision support system (Araujo et al., 2021).

Figure 7: *Agriculture 4.0 (A4.0) Core Technologies*



In the following subsections the definitions of previously mentioned core technologies are provided.

2.1 Internet of Things (IoT)

Internet of things (IoT) can be defined as a network of physical devices, vehicles, home appliances, buildings, and other items embedded with electronics, software, sensors, and network connectivity. It enables these objects to connect and exchange data with servers, centralized systems, other connected devices, and the Internet itself (De Franco, 2021; Elazhary, 2019; Rose, Eldridge, and Chapin, 2015; Khanna and Kaur, 2019; Pillai and Sivathanu, 2020; Srivastava and Das, 2020; Li and Niu, 2020; Feng, Yan, and Liu, 2019; and Murtaza and Ali, 2021). This connectivity between the physical environment and the internet allows for the collection of vast amounts of data that once analyzed enable better decision making. IoT is key to the attainment of Cyber-physical systems as its is the data collected through IoT systems that allows for the creation of digital twins.

2.2 Cloud Computing (CC)

Cloud computing (CC) is a model that enables convenient, on-demand access to a shared pool of computing resources over the internet. It allows users to store, access, and process data on remote servers rather than local machines. This approach offers scalability, rapid provisioning, and minimal management effort. CC operates as a utility, providing organizations with faster innovation, flexible resource utilization, and cost efficiencies. (Al-Asaly, Hassan, and Alsanad, 2019; Hung, 2019; Jukan et al., 2019; Mthunzi et al., 2020; Wang et al., 2015; Uddin et al., 2021; Kalyani and Collier, 2021; Rajarama, 2014; Sharma et al., 2016; Ruparelia, 2016; and Trovati et al., 2015)

2.3 Big Data Analytics (BDA)

Big data analytics (BDA) is the process of examining extensive and diverse data sets to uncover valuable information and patterns that inform organizations' decision-making (White, Amrine, and Larson, 2018; Ryan, 2020; and Coble et al., 2018). It involves using advanced techniques and tools to process and analyze large, complex data sets, extracting insights for informed decision-making from big data. Big data is characterized by the volume of data gathered, the velocity in which the data is generated, processed, and collected, the variety of sources from which the data originates, the veracity of data (i.e., quality, reliability, accuracy, and potential), and the value of the data regarding finding useful knowledge to make decisions (Abbasi et al, 2022).

2.4 Artificial Intelligence (AI)

Artificial Intelligence (AI) refers to the development of computer systems that can perform tasks requiring human-like intelligence (Kutyauripo et al., 2023). It encompasses technologies and algorithms that simulate human intelligence, such as learning, reasoning, and perception (Liu, 2020). AI enables machines to learn, solve problems, and make decisions like humans (Zha, 2020). It aims to create intelligent machines capable of tasks like perception, reasoning, learning, problem-solving, decision-making, and natural language processing (Bahoo et al., 2023). AI involves the development of computer systems that simulate human intelligence and perform tasks typically requiring human intelligence (Confalonieri et al., 2021; and Mithas and Saldanha, 2022).

2.5 Other Industry 4.0 (I4.0) and Agriculture 4.0 (A4.0) Technologies

Some highly mentioned technologies are not considered core technologies due to various factors. For instance, Precision Agriculture (PA) was mentioned numerous times in the context of A4.0; however, it is considered a pillar of Agriculture 3.0 and a predecessor to A4.0 (Vincenzo et al., 2022). In fact, Precision Agriculture (PA), precision livestock farming, robotics, and automation are enhanced by CC, IoT, AI, and BDA. Unmanned aerial vehicles (UAVs), which are also frequently mentioned, along with smart sensors, wireless sensor networks (WSN), geographic information systems (GIS), advanced network processors (ANP), radio-frequency identification (RFID), and 5G networks enable IoT and big data collection in both contexts (Araujo et al. 2021 and Vincenzo et al. 2022).

Blockchain (BC) is not considered a core technology because it doesn't facilitate data-driven autonomous decision-making, which is key to both I4.0 and A4.0. Instead, BC primarily serves as a security tool for transactions between supply chain actors (Aceto et al. 2019). Finally, some authors mentioned multiple technologies that are often grouped under one umbrella technology by other authors. For example, under CC, there are subtypes such as edge computing (EC), fog computing (FC), and mobile fog computing (Debauche et al., 2022). Similarly, under AI, subtypes like machine learning (ML) and deep learning (DL) were mentioned (Abbasi et al., 2022).

In summary, A4.0 and I4.0 have been found to have the same core technologies. The way these technologies are implemented varies between I4.0 and A4.0, due to the inclusion of non-human biological factors like plants and livestock. The need of a manufacturer is different from farmers as these biological components produce differing challenges and barriers to implementation when aiming for higher sustainability and productivity.

3.0 Barriers and enablers of Core Agriculture 4.0 (A4.0) Technologies Implementation

Even though the popularity of A4.0 and the utilization of A4.0 technologies have grown over the last decade, the implementation of core technologies has been hindered by barriers, resulting in lower sustainability and productivity due to the lower performance of core technologies. To identify the barriers that are currently being discussed within the academic literature, a SLR was completed, including 36 scientific articles published between 2017 and 2022, 34 of these articles were used in the SLR on A4.0 while two were included in the reviewed articles on I4.0. From these articles, a total of 19 barriers were identified (see Figure 8, Figure 9, and Appendix O) and categorized into five barrier types: economic, governmental, knowledge, social, and technical (see Figure 8 and Figure 10). The knowledge barriers were the most mentioned with technical barriers being the second most mentioned (see Figure 10). Governmental barriers were the least mentioned barrier type within the SLR (see

Figure 10). There is no temporal component to the presence of barriers to A4.0 technology implementation (see Appendix P).

Figure 8: *Barriers to Core Agriculture 4.0 (A4.0) Technology Implementation*

Economic Barriers	High cost of aquiring, implementing, transitioning, and maintaining technology
	Financial support and funding opportunities
Governmental Barriers	Government policies, incentitives, and financial that support the integration of A4.0
	Legal and regulatory concerns
Knowledge Barriers	Knowledge and skill gap of farmers and labour force
	Increasing comeplexity of technology and data management (quality, cleanliness, granularity, and source integration)
	Concerns of social and environmnetal impacts of technologies
	Research, open knwoledge sources, and training oportunities
	Limited understanding of benefits and ROI from A4.0 implementation
Social Barriers	Trust and colloboration among stakeholder (researchers, farmers, technology providers, and governement)
	Resistance to change
	Unequal distribution of benefits and risks among stakeholders
Technical Barriers	Interoperability, standarization, reliability, cutsomization, and scability of technologies, data, and infrastructure (internet, Power, telecomunications, etc.)
	Data security, privacy, and ownership concerns
	Unequal access to infrastructure and technology between urban and rural areas
	Lack of industry standards and protocols
	Access to human-cenetred technology
	Subpar preformance of technologies
	Harsh field environments and climate conditions

Economic barriers (mentioned in 83% of articles) relate to the financial aspects of implementing technologies. A4.0 technologies can cost farms significant capital to acquiring said technologies, implementing them into farm operations, transitioning between the old technologies and new technologies, as well as maintaining the hardware and software (78% of articles). Implementing such technologies on a large scale can be very costly (Araujo et al. 2021). In addition, to keep the accuracy of technologies they must be constantly updated which can be hard to do in a cost-effective way (Arvanitis et al., 2020). These high costs make it difficult for small and medium farmers to adopt the core technologies (Diego et al., 2022). Many authors noted that there was a lack of financial support and funding opportunities from non-governmental organizations e.g., banks, which would help reduce the financial burden of implementing technologies (25%of articles). In fact, private investments, thus, play an important role to promote the growth of A4.0 technologies (Nadezhda and Dmitry, 2022).

Figure 9: *Number of Scientific Articles that Mentioned Individual Barriers to Core Agriculture 4.0 (A4.0) Technology Implementation*

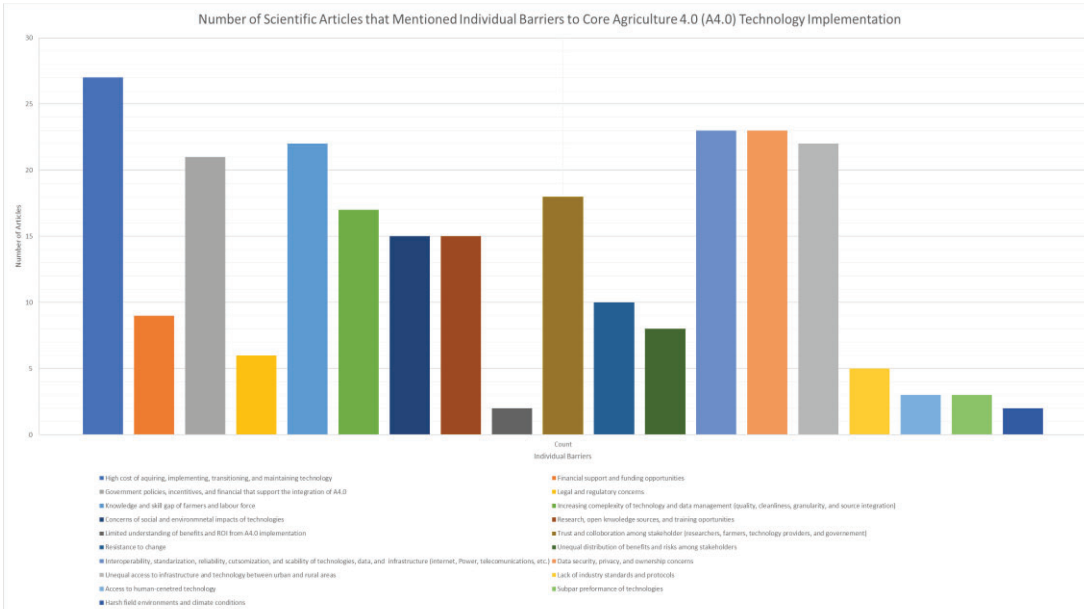
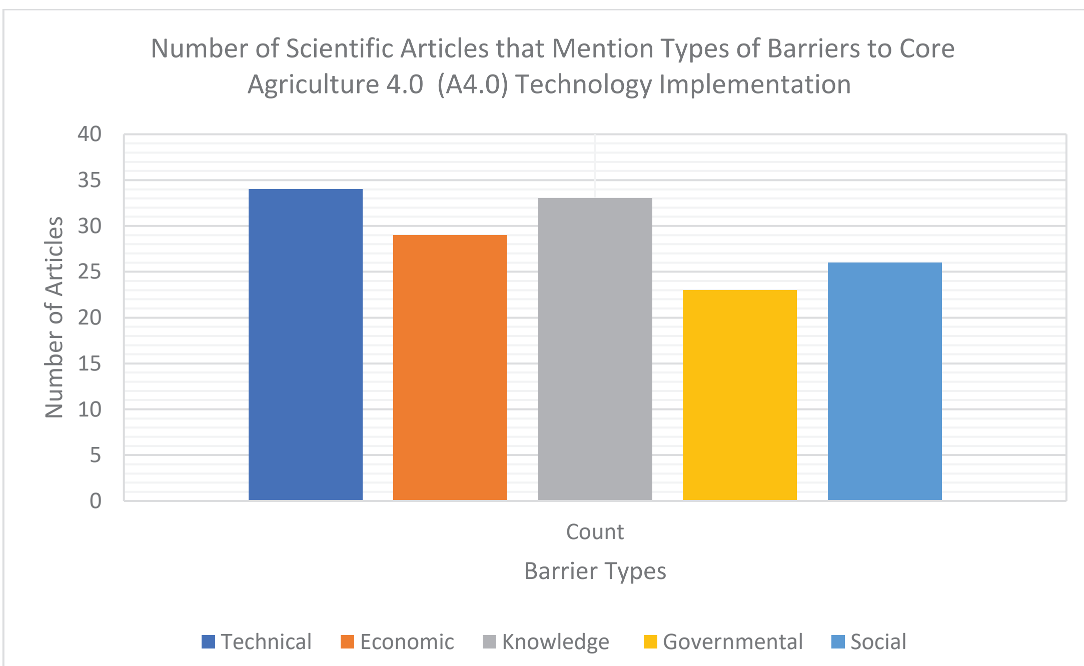


Figure 10: *Number of Articles That Mention Types of Barriers to Core Agriculture 4.0 (A4.0) Technology Implementation*



Governmental barriers (66% of articles) relate directly to government activities in the agricultural sector. It is noted that there is a lack of government policies, incentives, and financial programs that support the implementation of A4.0 technologies within agriculture (58% of articles). Without the proper support and incentives, the motivation to implement A4.0 technologies is relatively low. There are also concerns regarding laws and regulations about A4.0 technologies that establish guidelines for the use of A4.0 technologies, e.g., regarding data ownership and privacy, arial right regarding UAVs, and applications of AI. (19% of articles).

Knowledge based barriers (94% of articles) relate to the existing knowledge and skill gap of farmers and their labour force towards the use of A4.0 technologies (64% of articles). Meaning that users are not properly trained or skilled to operate A4.0 technologies properly. Another barrier is the increasing complexity of technology and data management tasks (quality, cleanliness, granularity, and source integration) (50% of articles). The complexity of technologies and data management make the use of technologies daunting to use and implement. Another barrier is the concerns that farmers have towards the impact that A4.0 technologies have on society and the environment (42% of articles). These concerns are well described by Diego et al., who note that "we do not know the ramifications that digital agriculture may have in the future (Diego et al., 2022, p. 11)". One prime example is the inequality of food distribution, were there is fear that A4.0 technologies will increase food security for some and decrease food security for others. Another example is the unknown ramifications advanced technologies will have on the nature of agricultural work and employment (Rose et al. 2021). Additionally, the lack of access to academic research, open knowledge sources, and training opportunities that farmers have is another knowledge-based barrier (42% of articles). The final knowledge-based barrier is the farmers' limited understanding of the benefits and return on investment that can come from implementing A4.0 technologies on their farms (8% of articles). Often it is hard for farmers to determine the period it will take to recover the capital cost, but they also lack understanding on how A4.0 technologies can benefit them (Abbasi et al., 2022).

Social barriers (72% of articles) relate to a lack of trust and collaboration among stakeholder (researchers, farmers, technology providers, and government) (53% of articles). They relate to the existing resistance to change that farmers and consumers harbor, i.e., transitioning from older technologies to A4.0 technologies (31% of articles). As well as the unequal distribution of benefits and risks among stakeholders (22% of articles), where farmers take on the most risk and typically enjoy the least number of benefits.

Technical barriers (86% of articles) relate to issues around the lack of interoperability, standardization, reliability, customization, and scalability of technologies, data, and infrastructure (internet, Power, telecommunications, etc.) (67% of articles). This main technical barrier looks at the lack of standardization of software and hardware offered by agricultural technology companies. The lack of standardization reduces the ability of farmers to seamlessly connect older and new technologies, as well as technology coming from different suppliers. In addition, not all technology is reliable in terms of technical aspects related to hardware and software, i.e., the length of battery life. Moreover, there is also a lack of customization which limits farmers' ability to fit the technology to their specific operation, goals, and needs. These issues related to reliability, customization, standardization, and interoperability make it more complex to increase the scale of the technology use. Technical barriers also include data security, privacy, and ownership concerns held by farmers (67% of articles). For many farmers this concern looks like losing control over data due to their lack of trust in infrastructure providers, e.g., being locked out of their CC infrastructure (Aceto et al., 2019). In this case farmers would lose access to their valuable data that allows them to make better data driven decisions and have their data leaked or accessed by nonauthorized parties. Additionally, the unequal access to infrastructure and technology between urban and rural areas is a huge barrier for farmers (61% of articles). Rural and isolated areas have less developed infrastructure in terms of internet than more developed areas (Mohd et al., 2022). Meaning farmers in those areas do not have access to the infrastructure enabling them to use ADTs. The barrier also includes a lack of industry standards and protocols (17% of articles). Such standards and protocols act as guidelines for technology providers and users (Aceto et al., 2019). Such standards allow for better interoperability and performance of technologies (Mohd et al. 2022). The lack of access to human centered technology is another technical barrier (8% of articles). Human centered technologies consider human needs when designing the hardware and software. They are typically easier to use, especially for users who have limited knowledge or experience using ADTs, which makes implementation less daunting for new users. The subpar performance of technologies also limits implementation of A4.0 technologies (8% of articles). This barrier mostly refers to the ability of technologies to perform with as little human interference as possible (Araujo et al., 2021). The harsh field environments and climate conditions where the technology is used (8% of articles) affects the ability of technologies to function properly as not all hardware can withstand to changing weather and climate conditions (Abbassi et al., 2022). Even wildlife can harm devices and disrupt their functionality (Araujo et al., 2021).

It's important to note that these barriers pertain to the implementation of A4.0 technologies, and they do not consider each core technology individually. This assumption is based on the idea that farmers face similar barriers to the implementation of all ADTs. Additionally, the barrier to adoption and implementation was not considered separately for these technologies because the independent adoption and implementation of certain technologies do not yield benefits for farmers. In fact, whether in the context of I4.0 or A4.0, AI, IoT, BDA, and CC should be implemented simultaneously for productivity and sustainability benefits to be experienced. AI, IoT, CC, and BDA function simultaneously to create cyber-physical systems or digital twins that enable autonomous data-driven decisions. Primarily, IoT systems collect data that is stored within CC systems, where BDA is applied via AI models to extract information vital for decision-making and the automation of machinery.

Chapter 4
Results of the Empirical Research

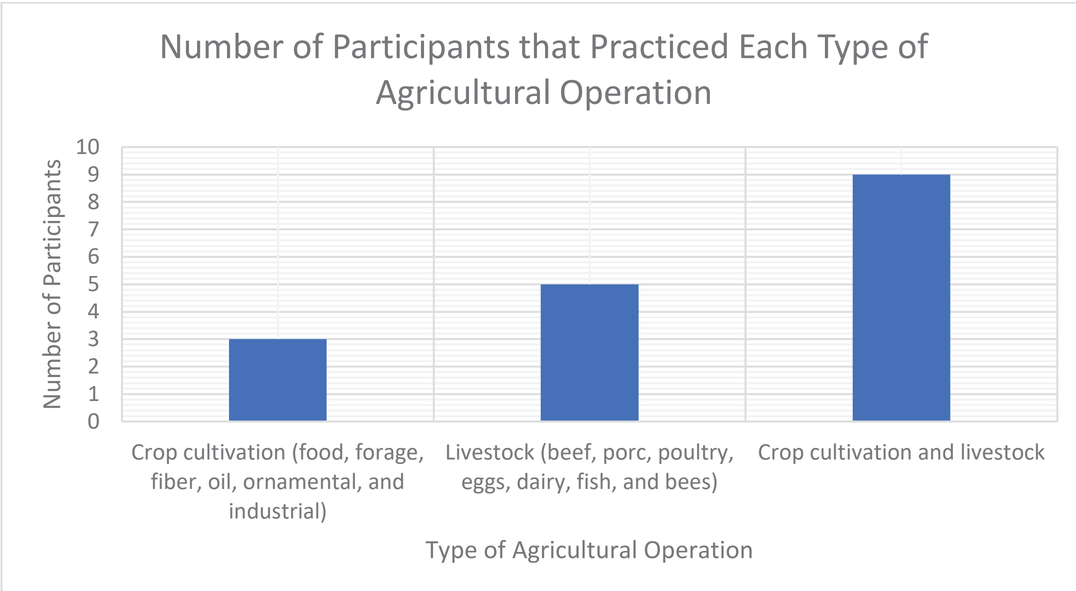
The SLR provided insights into the current discourse around A4.0—key characteristics, core technologies, and barriers to integration. Although the SLR provided useful insights on A4.0, there is a significant lack of empirical research on the experience of farmers implementing A4.0, especially regarding the prevalence of barriers. Research has focused on the technical and theoretical aspects of A4.0 and not the practical application. There is valuable information to be gained about the process of implementing A4.0 directly from farmers. Thus, the purpose of this section is to present the results of the analysis of the primary data gathered via the online survey.

1.0 Description of Sample: Type of Agricultural Operation, Location, and Education Level

The online survey focused on the Canadian context, as little research has been conducted on the use of A4.0 within the North American context. The agri-food system and agriculture are significant aspects of the Canadian economy, employing 2.3 million people and generating 7% of Canada's GDP (Government of Canada, 2023). It is important to gain insight into the experience of Canadian farmers as they are at the heart of implementing A4.0. Their decisions directly affect the health of agriculture in Canada, which represents a significant part of the Canadian economy.

The survey, as previously mentioned in the methodology section of this thesis, was administered online, and outreach was done through social media and agricultural organizations. Due to the low response rate to the query for participants, the sample size of the survey is n=17. The individual response rate for each question varied between 12% and 100%, with an average response rate of 60% (see Appendix Q).

Figure 11: *Number of Participants that Practiced Each Type of Agricultural Operation*



One main characteristic of the farmers surveyed was the type of agricultural operation they practiced. Most farmers surveyed indicated that they both manage livestock and cultivate crops (52.94%) (see Figure 11). The least numerous groups were composed of farmers solely cultivating crops (17.65%) (see Figure 11).

A second characteristic was the geographic dispersion of the participants. The number of participants from Ontario and New Brunswick both amounted to 35.29% of the participants, followed by Quebec with 23.53%, and Saskatchewan amounting to 5.88% (see Figure 12).

Another characteristic of the participants that was of interest is the level of education of the participants and their employees. Most farmers who participated in the survey hold a bachelor's degree (58.82%) (see Figure 13). The second most numerous groups were farmers with a vocational school degree (17.65%) (see Figure 13). The education level of participants, the geographical location of participants' farms, and the type of agricultural operation of participants' farms were used in the analysis for RQ4, RQ5, and RQ6 to gain further insights into the varying experiences of Canadian farmers regarding the implementation of A4.0 technologies.

Figure 12: Number of Participants per Province

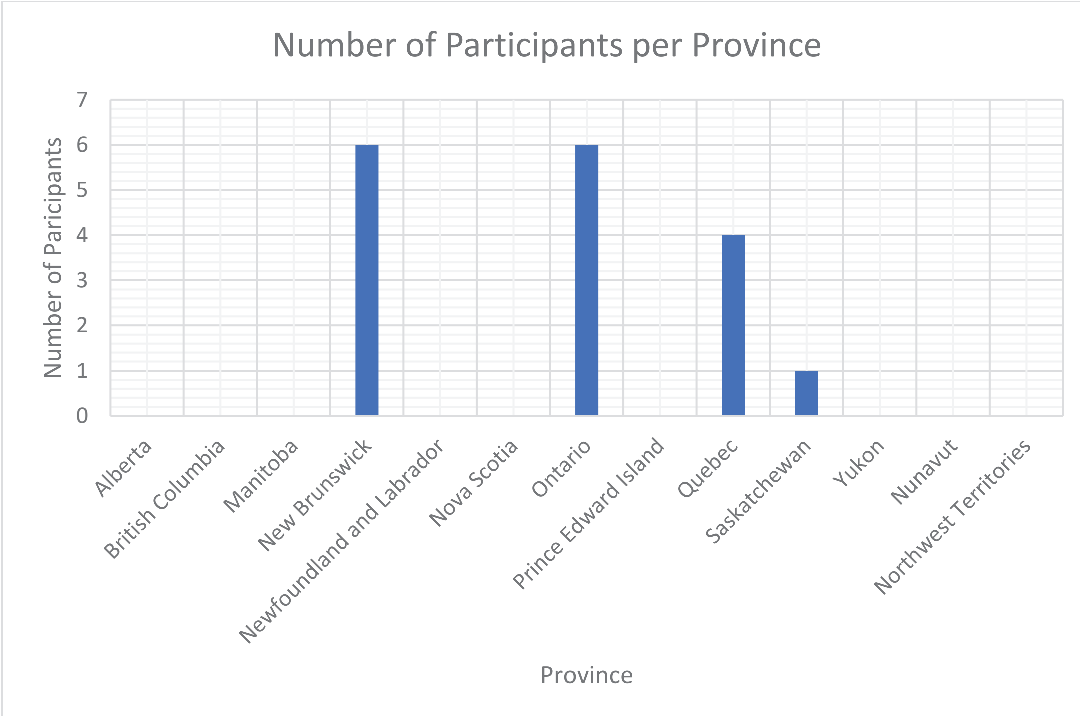
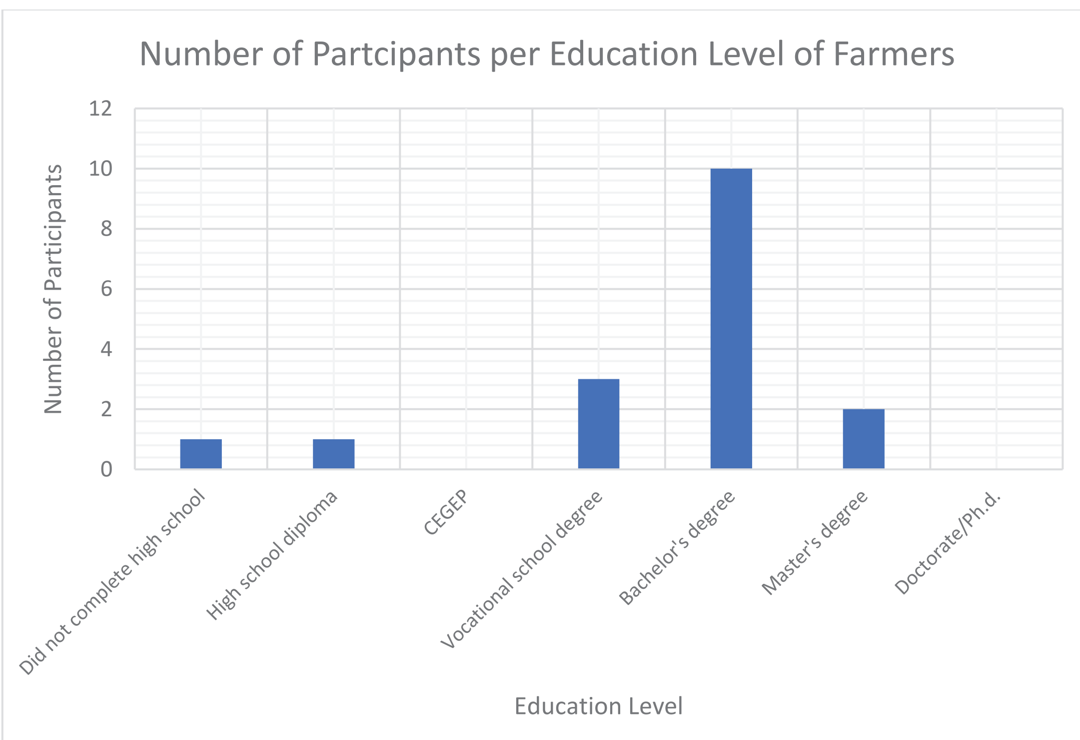


Figure 13: *Number of Participants per Education Level for Farmers and Employees*



2.0 Canadian Farmer's Awareness of Agriculture 4.0 (A4.0) and Implementation Level of Core Agriculture 4.0 (A4.0)

A key element in understanding the experience of implementing A4.0 within Canadian farms is the level of awareness and knowledge that farmers have of the concept of A4.0. It is also crucial to gain an understanding of the level of integration of A4.0 core technologies—AI, CC, BDA, and IoT. To gain these insights, participants were asked about their awareness or knowledge of A4.0 and whether they had implemented AI, CC, BDA, and IoT within their operations. The response rate to the questions was 100%.

Through empirical research, it was identified that most participants (70.59%) are not aware of or knowledgeable about A4.0 (see Figure 14). Additionally, most farmers have not implemented core A4.0 technologies, with CC having an implementation rate of 41.17%, AI of 23.53%, IoT of 25.53%, and BDA of 17.65% (see Figure 15). These insights indicate that the Canadian farming community is neither well-informed aboutA4.0 nor implementing core technologies. These findings are not surprising. Firstly, due to the high prevalence of technical and knowledge barriers within the SLR. Secondly, the low level of awareness and knowledge can be explained by A4.0

Figure 14: *Number of Participants per Awareness and Knowledge Level of Agriculture*

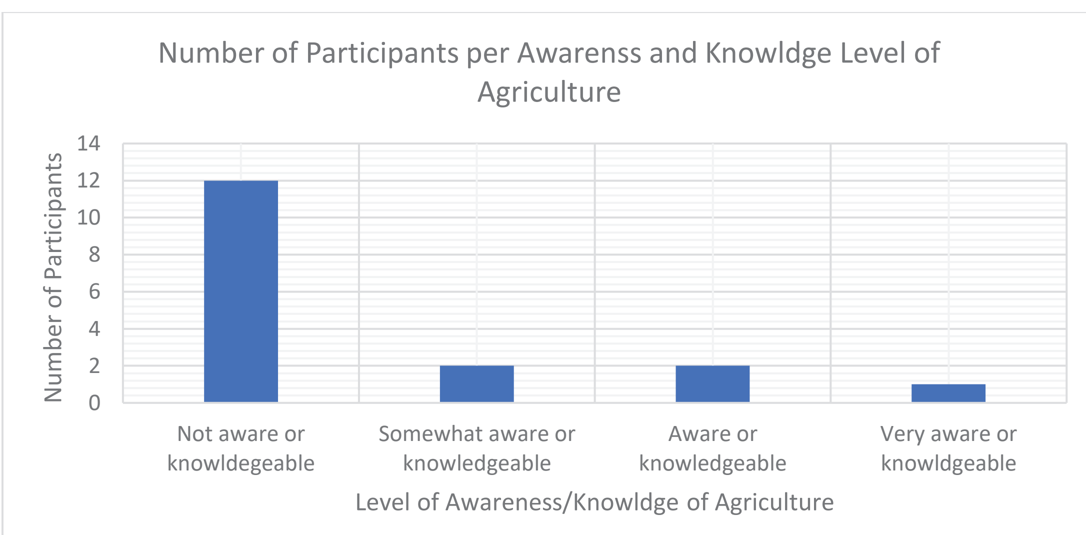
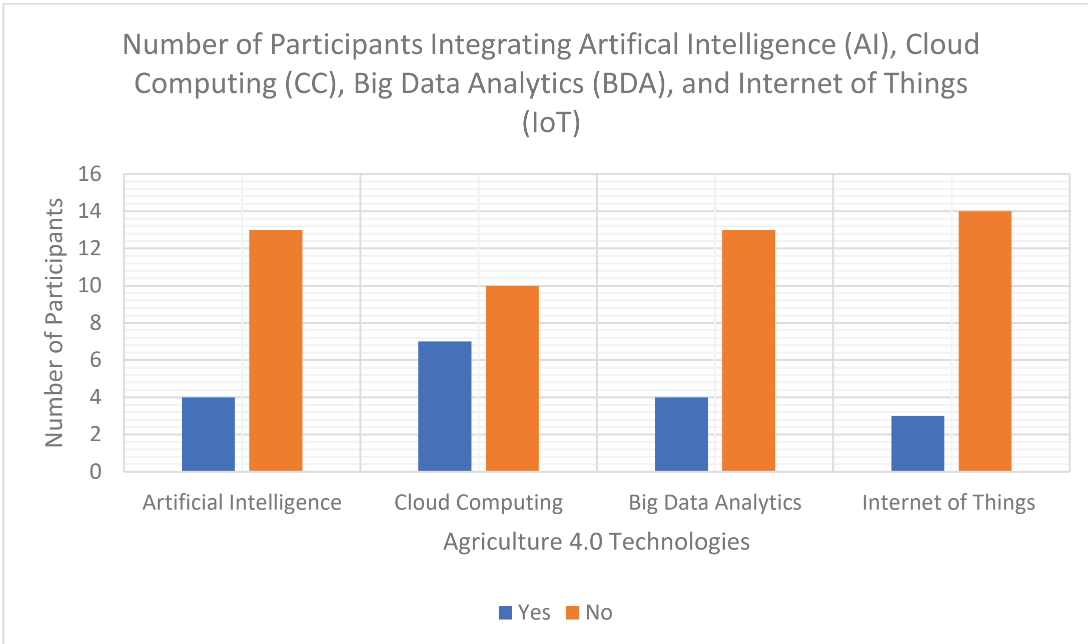


Figure 15: *Number of Participants that Integrated Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*



recent emergence within academic literature and grey literature and how a lack of awareness and knowledge is a hindrance to the implementation of core technologies. This hindrance is evident due to how the implementation of the core A4.0 technologies follows the same trend as the awareness and knowledge farmers have about A4.0. This shows a link between both descriptive findings of the Canadian agricultural community.

Furthermore, the link between awareness and knowledge of A4.0 and technology implementation are not surprising when considering how entangled technical barriers and knowledge barriers are. The low implementation rate also shows that the high technicality of core technologies does not ease implementation, as presented in the SLR, and neither does the lack of awareness or knowledge of A4.0.

The lack of awareness and knowledge of A4.0 and the low implementation rate of core A4.0 technologies persist regardless of whether the data are analyzed considering the location of farms (province), education level of farmers, or type of agricultural practice. Farmers belonging to any subgroup consistently show unawareness or lack of knowledge about A4.0 and low implementation of core technologies within their operations. The one instance in which the implementation rate of CC reaches the majority is for participants who manage livestock and cultivate crops (see Appendix T).

Some groups have slightly more awareness or knowledge about A4.0 or have a slightly higher implementation rate of core technologies. Farmers managing livestock indicate a higher level of awareness (see Appendix R) and a higher rate of implementation for all four core technologies (see Appendixes S, T, U, and V). This considers farmers who solely manage livestock as well as farmers who manage livestock alongside cultivating crops.

Additionally, farmers from Quebec and Ontario show slightly higher levels of awareness and knowledge of A4.0 than farmers from other provinces (see Appendix W). However, no provincial group of participants shows to have the highest implementation rate for all core technologies (see Appendices X, Y, Z, and AA). However, Quebec is the only province to have participants implement all four technologies.

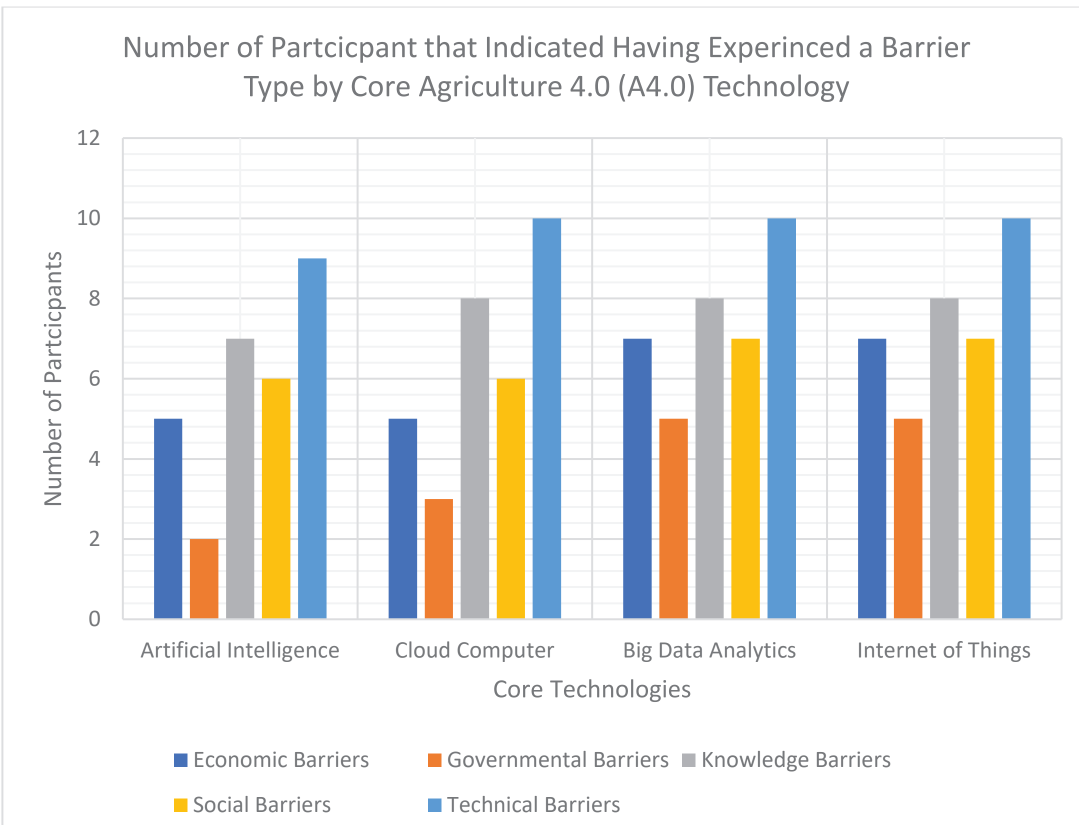
Finally, farmers with higher levels of education indicate being more aware or knowledgeable about A4.0 (see Appendix AB), as well as implementing core A4.0 Technologies at a higher rate than participants with a lower level of education (see Appendices AC, AD, AE, and AF). This is not surprising considering the higher level of access to research that those with bachelor's degrees and master's degrees have compared to those without university degrees.

These observations made through the lens of geographic dispersion, education level, and type of agricultural practices solidify the link between awareness and knowledge of A4.0 and the implementation rate—one that is positive.

3.0 Canadian Farmer's Experience with Barriers to Agriculture 4.0 (A4.0) Technology Implementation

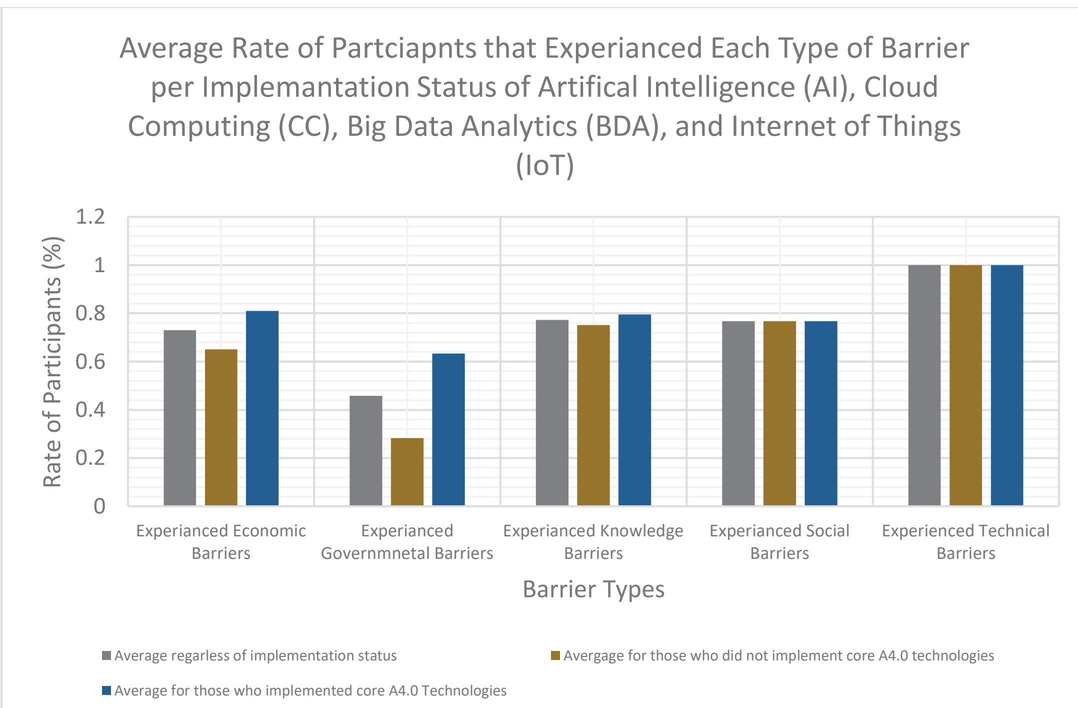
With the insight that most participants are neither knowledgeable nor aware of A4.0 and have not implemented core A4.0 technologies, it is important to understand what barriers they experience, such as technical barriers and knowledge barriers previously mentioned. Using the list of barriers established in Section 3.0 of Chapter 3, participants were asked which of the individual barriers they experience while implementing each core A4.0 technology (AI, CC, BDA, and IoT).

Figure 16: *Number of Participants that Indicated Having Experienced a Barrier Type by Core Agriculture 4.0 (A4.0) Technology*



Overall, participants indicated that they experience each barrier type rather consistently across all four technologies (see Figure 16), with governmental barriers having the highest variance and technical barriers had the lowest variance. The variance was measuring the difference between the average number of participants indicating having experienced the barrier type and the dispersion of the number of participants indicating experiencing each barrier type. A low variance indicating a more equal rate of participants experiencing a barrier across core technologies. This low variance of technical barriers is also supported by the equal rate of participants experiencing technical barriers regardless of implementation status (see Figure 17, Appendix AG, and AH).

Figure 17: *Average Rate of Participants that Experienced Each Type of Barrier per Implementation Status of Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*



Furthermore, technical barriers have no difference between the participants who implemented core technologies and those who did not (see Figure 17, Appendix AG, and AH). Knowledge barriers and social barriers also had little variance between the rates of participants that implemented core technologies and those who did not (see figure 17). There is however a significant difference present for governmental barriers, where those who did not implement core technologies indicated having experienced governmental barriers at a higher rate (63.39%) than the overall average (46.85%) and those did implement core technologies (28.33). This indicates that largely there is little difference between the experience of participants who implemented core technologies and those who did not implemented core technologies when facing barrier types.

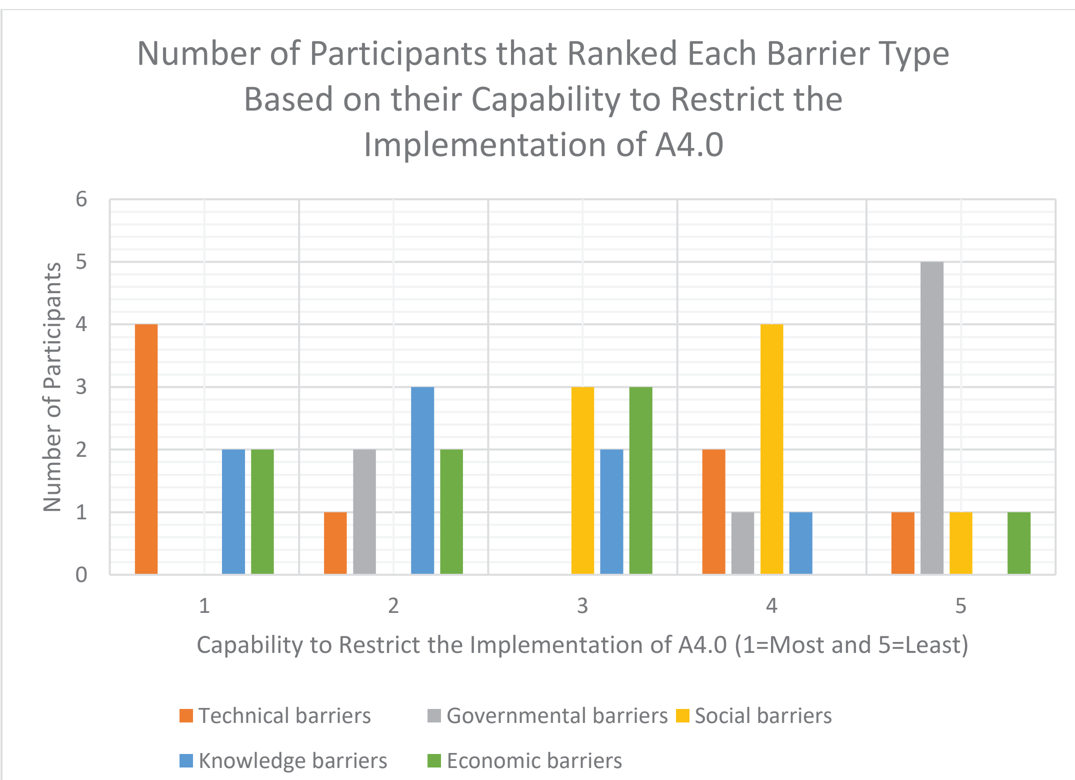
Additionally, participants indicated that they experience the following barriers in the following decreasing order: technical barriers, knowledge barriers, social barriers, economic barriers, and governmental barriers. Technical barriers are the most prevalent barrier type. This prevalence stands even when taking into account weather or not participants implemented AI, CC, BDA, or IoT, as previously mentioned, all participants regardless of the implementation status of Core A4.0 technology experienced technical barriers. This follows the trend of technical barrier being the most prevalent barrier within the SLR.

Knowledge barriers are seen to be the second most prevalent barrier in the SLR and empirical study. Knowledge barriers (79.51%) are also highly experienced by participants who implemented core A4.0 technologies, only slightly less than economic barriers (80.95%). In addition, knowledge barriers (75.12%) are also highly experienced participants who did not implemented core A4.0 technologies, only slightly less than social barriers (76.78%). These differences are insignificant, meaning these insights further supports the prevalence of knowledge barrier as the second most prevalent barrier type. These insights are not surprising considering how often technical and knowledge barriers were mentioned in the SLR.

To gain further insights into the capability to restrict the implementation of A4.0 of the barrier types, participants were asked to rank barrier types based on how restricting they were to implement A4.0 technologies. Unsurprisingly, participants indicated that, on average, governmental barriers restricted the implementation of core A4.0 the least (see Figure 18), as most participants noted that governmental barriers were not applicable, or they had not encountered governmental barriers (see Appendix AH). Knowledge and technical barriers were indicated to be the most restrictive of the barriers. This means that, in addition to being noted to as most experienced types of barriers, technical and knowledge barriers are barriers that impact the level of implementation of core technologies the most.

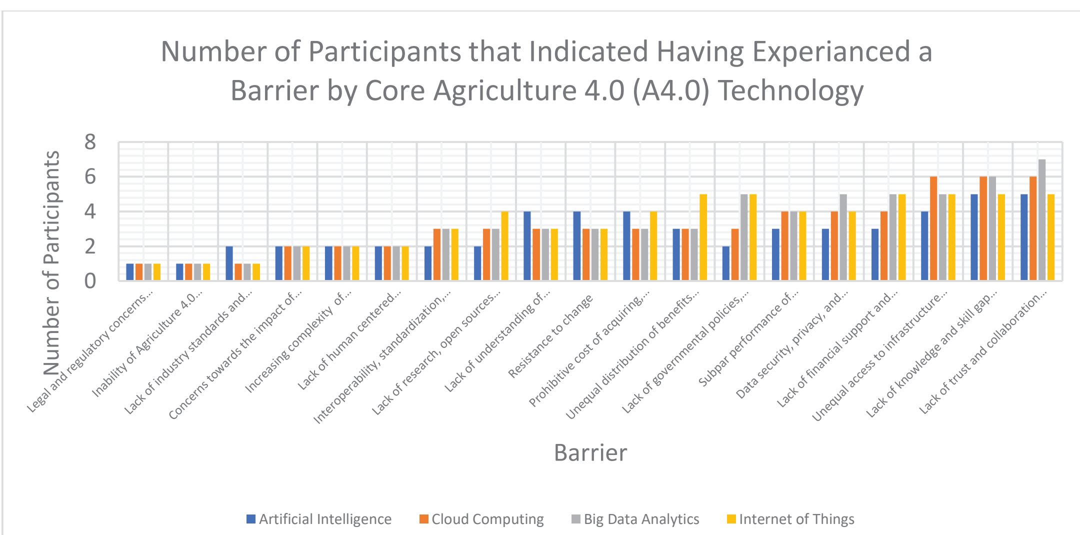
Although governmental barriers have a weak capability in restricting A4.0 implementation they still impact the strength of knowledge and technical barriers' capability in restricting implementation. Government lead training programs impact the overall knowledge farmers and farm employees have regarding A4.0 technologies. Recently the federal government has funded a micro-credential program offering free courses on IoT, data analysis, drones, smart technology for agriculture and agri-food professionals was promoted and funded by the government of Canada (QuickTrain Canada, 2023). These types of training are lacking, however. When asked what measure they believed need to be implemented to support A4.0 implementation participants noted that more training on A4.0 technologies should be offered and advertised.

Figure 18: *Number of Participants that Ranked Each Barrier Type Based on their Capability to Restrict the Implementation of A4.0*



In addition to knowing which barrier types are experienced the most and which barrier has the most capability to restrict the implementation of A4.0, it is important to understand which individual barriers are experienced the most overall and by the type of barrier. Overall, the participants indicated experiencing the lack of trust and collaboration between stakeholders (social barrier), the lack of knowledge and skill (knowledge barrier), and unequal access to infrastructure and technology between urban and rural areas (technical barrier) the most of all the individual barriers (Figure 19). The most prominent economic barrier was the lack of financial support and funding opportunities (non-governmental) (see Appendix AG). The most prominent governmental barrier was the lack of governmental policies, incentives, financial support for the integration of A4.0 (see Appendix AH). The most prominent knowledge barrier was the lack of knowledge of A4.0 and skill gap of both farmers and their labor force (see Appendix AI). The most prominent social barrier is the lack of trust and collaboration between stakeholders (see Appendix AJ). The most prominent technical barrier is the unequal access to infrastructure and technology between urban and rural areas (see Appendix AK). This was also mentioned by two participants when asked what measures or incentives would help overcome barriers to implementation.

Figure 19: *Number of Participants that Indicated Having Experienced a Barrier by Core Agriculture 4.0 (A4.0) Technology*



To further gain insights into their experience implementing A4.0 core technologies participants were asked what measure or incentives would help overcome barrier to implementation. Most participants noted incentives and measures that aligned closely with some individual barriers identified in the SLR. One participant noted a measure that had not be discussed in the SLR. This is the lack of younger generations taking over farms.

This demographic challenge was not noted in any of the analyzed articles included in the SLR. This raises the question what challenges age, gender, etc. affect A4.0 implementation. Such demographic challenges would be classified as social barriers to implementation.

Overall, technical and knowledge barriers have been observed to being the most experienced barrier types but have the weakest capability to restrict the implementation of A4.0. The governmental barrier type was deemed to have the strongest capability to restrict the implementation of A4.0 by participants, while most participants noted that they were not experienced or applicable to their experience implementing A4.0 core technologies.

Chapter 5
Conclusion

1.0 research Aim, Results, and Theoretical Implications

With agriculture facing the challenging objectives of achieving greater sustainability and increased productivity, A4.0 presents itself as a potential means of facilitating the attainment of these objectives. However, the implementation of A4.0 is not as straightforward as it could be due to a lack of understanding of the concept itself, as well as its technologies and the barriers that hinder the implementation of such technologies.

As such, the main aim of this thesis was to develop an overview of A4.0, including its definition, core technologies, and barriers to implementation. A literature review was completed to construct this overview and gain an understanding of the status of academic research on the topic. Seven key characteristics of I4.0's structure was identified, and 10 key characteristics of A4.0's structure were recognized from the literature. Spronchioni et al. definition of A4.0 effectively summarized these key characteristics, serving as a reference point for both industry and academia in discussions about A4.0 (Spronchioni et al., 2019). Furthermore, AI, CC, BDA, and the IoT were determined to be the core technologies of both I4.0 and A4.0. These core technologies are central to A4.0 and Industry, underscoring the importance of monitoring the implementation of these technologies for the success of I4.0 and A4.0. From the literature, 19 individual barriers to their implementation were identified, categorized into economic barriers, governmental barriers, knowledge barriers, social barriers, and finally, technical barriers.

From the SLR, it was evident that little empirical research had been conducted on the experiences of farms implementing A4.0 technologies within their operations. Consequently, the second aim of this thesis was to gain insight into the implementation level of A4.0 technologies and identify the most recurring barriers.

This aim was applied to the Canadian context due to the lack of information on A4.0 within Canadian farming. It was determined that most participating farmers had no awareness or knowledge of the concept of A4.0, which is not a surprising finding due to the high mention of knowledge being a barrier to implementation. A finding that is also not surprising and aligned with the previous finding is that most participants had not implemented AI, CC, BDA, or IoT within their operations. These results indicate that A4.0 in Canada is little known about or utilized.

A key insight is that the level of awareness and knowledge of A4.0 plus the implementation rate of core technologies increased as participants' level of education increased, i.e., vocational school degrees, bachelor's degrees, and master's degrees. Another insight noted was that farmers managing livestock and cultivating crops are more aware and knowledgeable about A4.0 and have higher implementation rates for the core technologies, i.e., AI, CC, BDA, and IoT.

Regarding the barriers to implementation, farmers that participated in the study experienced barriers to implementation quite evenly among the four core technologies. Technical barriers and knowledge barriers were the most experienced barrier types. Of which the most indicated individual barriers were the lack of knowledge and skill (knowledge barrier) and lack of access to infrastructure within rural areas (technical barrier), which is where most farms are located regardless of the farm type (Statistics Canada, 2023). Technical barriers were also deemed to have the strongest capability of restricting A4.0 implementation within farms. Participants indicated governmental barriers to be the least restrictive to A4.0 core technology implementation but also the least experienced barrier type.

2.0 Limitations

2.1 Limitations of the Systematics Literature Review

Despite meticulous care in selecting and structuring a SLR (SLR), certain limitations inevitably emerge. Firstly, there is a challenge related to publication bias, where articles with statistically significant or positive results are more likely to be published and consequently included in the SLR. To address this, the SLR incorporated both conference papers and traditional scientific articles from various journals. Another critique pertains to the quality of the included articles; to counter this, only peer-reviewed articles and conference papers were considered.

A limitation in the choice of articles emerged from the decision to include only those published in English. This choice, driven by language barriers, however, excludes research and insights from a vast body of scientific literature published in other languages. Additionally, the exclusion of grey literature, resulting from the focus on paper quality through the selection of peer-reviewed literature, may have omitted valuable insights and perspectives.

Another limitation stems from the inherent subjectivity in conducting an SLR; a certain degree of subjectivity is unavoidable in the review process. Finally, the evolution of the field poses a limiting factor for the SLR. The definition of I4.0 and A4.0, the core technologies of I4.0 and A4.0, and the barriers to A4.0 technologies may undergo changes over time as the field matures, especially given the nascent stage at which I4.0 and A4.0 research currently find themselves.

2.2 Limitations of the Online Questionnaire

Despite putting significant effort into distributing the online questionnaire, the response rate was low, yielding only 17 responses. This limitation severely constrained the scope of statistical analyses that could be undertaken, such as correlational statistical analysis or determining statistical significance. The descriptive statistical analysis conducted was also limited by the low response rate (see appendix Q). An analysis considering organic certification and fair-trade certification could not be conducted due to the low response rate. Nor could an analysis be done on the participants satisfaction of core A4.0 technologies. A drawback of online questionnaires lies in the response rate, not only to the questionnaire itself but also to individual questions. Participants may have been reluctant to share certain information about their farming practices. Compliance with regulations from the HEC Research

Ethics Board resulted in optional questions, potentially introducing non-response bias, and affecting the reliability and validity of the study (Vomberg and Klarmann, 2022).

The inability to conduct more in-depth statistical analyses beyond descriptive ones prevented the establishment of relationships between participants' characteristics and the implementation of core technologies, participants' characteristics, and barriers to implementation, as well as the level of implementation of core technologies and barriers to implementation.

Another limitation of questionnaires lies in the limited depth and context of information gathered due to the absence of opportunities for detailed explanations. To address this, open-ended questions were included, allowing participants to provide more nuanced responses. However, interviews, if feasible in terms of time and resources, might have offered additional insights beyond what the online survey could provide.

The choice of convenience sampling presents an additional limitation, potentially resulting in underrepresentation of the population (Vomberg and Klarmann, 2022). This decision was made due to limited accessibility to a random sample, with the understanding that a random sample might have been more representative of the targeted population.

Lastly, adopting a Canadian lens in the empirical research introduces a limitation, as the study may not be fully representative of farmers in significantly different geopolitical contexts. Factors such as climate, specific to Canada, may not align with the experiences of farmers in other parts of the world, especially those in tropical locations. Nonetheless, the results can serve as a foundational framework for similar research in diverse countries.

3.0 Future Research and Recommendations

From the conducted SLR, as previously mentioned, it is evident that more empirical research is essential to gain a better understanding of the current implementation of not only A4.0 but also I4.0. Given the limitation of this study concerning the sample size, it is crucial for similar research to be undertaken. This research should extend not only to the national level, i.e., countries, but also to regional levels, considering factors such as trade agreements, climate, and other relevant elements to gain insights specific to such contexts.

Additionally, due to the limitations of the online survey, establishing statistical significance, as well as correlational and causal relationships between barriers and the implementation level of core technologies, was not feasible. Future research endeavors should strive to determine the effects of each barrier on the implementation level of A4.0 and its core technologies. Moreover, no correlation or causal relationship could be established between the characteristics of farmers (e.g., education) or farm characteristics (e.g., size, type of agricultural practice, and location—rural vs. urban) and the implementation level or the capability of barriers to restrict the implementation of A4.0.

It is crucial to comprehend how effectively A4.0 is implemented and precisely how barriers are impacting implementation. Such insights and knowledge are pivotal for developing policies not only to encourage A4.0 but also for future agricultural revolutions, such as Agriculture 5.0, and their core technologies.

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1. Quel type d'agriculture pratiquez-vous ?

    a. Cultures (alimentaires, fourragères, fibres, huiles, ornementales et industrielles)

    b. Élevage (bovins, volaille, porcs, œufs, produits laitiers et poissons)

    c. Cultures et élevage

2. Dans quelle province ou territoire votre ferme est-elle située?

    a. Alberta

    b. Colombie Britannique

    c. Ile-de-Prince-Edouard

    d. Manitoba

    e. Nouveaux Brunswick

    f. Nouvelle-Ecosse

    g. Ontario

    h. Québec

    i. Saskatchewan

    j. Terre-Neuve-et-Labrador

    k. Territoires du Nord-Ouest

    l. Nunavut

    m. Yukon

3. Votre exploitation agricole est-elle certifiée biologique ?

    a. Oui

    b. Non

4. Si vous avez répondu oui à la question précédente, veuillez indiquer les certifications dont bénéficie votre exploitation agricole.

5. Votre ferme est-elle certifiée comme commerce équitable ?

    a. Oui

    b. Non

6. Quel type d'élevage pratiquez-vous ?

    a. Bovins : Viande

b. Bovins : Produits laitiers

c. Volailles (poules, canards, cailles, faisans, oies, cygnes, dindes, autruches) : Viande

d. Volailles (poules, canards, cailles, faisans, oies, cygnes, dindes, autruches) : Œufs

e. Porc : Viande

f. Poisson : Viande

g. Abeilles : Cire et Miel

h. Autres

7. Si vous avez sélectionné Autre à la question précédente, veuillez indiquer quels autres types de bétail vous possédez ?

8. Quelle est la taille de votre exploitation agricole ? Veuillez indiquer le nombre d'individus par type d'élevage.

9. Quels types de récoltes pratiquez-vous principalement ?

   a. (Fruits, légumes, céréales)

   b. Fibres (coton, chanvre, coco, jute, lin)

   c. Fourragères (herbes, légumineuses, ensilage)

   d. Huiles (olive, soja, palme, colza, tournesol)

   e. Ornementales (fleurs, arbustes, arbres non fruitiers)

   f. Biocarburants (maïs, colza, canne à sucre, palme, jatropha, soja, herbe à switch)

10. Si vous produisez des cultures vivrières, veuillez indiquer le type spécifique ?

11. Comment cultivez-vous vos produits ?

    a. Vignoble

    b. Champ

    c. Serre

    d. Hydroponie

    e. Autre

12. Quelle est la taille de votre ferme ? Veuillez indiquer la superficie de terres cultivées pour les cultures (en acres).

13. Quel est votre plus haut diplôme obtenu ?

a. N'a pas terminé l'école secondaire.

b. Diplôme d'études secondaires.

c. CEGEP.

d. Diplôme d'école professionnelle.

e. Licence (baccalauréat).

f. Maîtrise

g. Doctorat/PhD.

14. Quel est le diplôme habituel obtenu par vos employés?

a. N'ont pas terminé l'école secondaire.

b. Diplôme d'études secondaires.

c. CEGEP.

d. Diplôme d'école professionnelle.

e. Licence (baccalauréat).

f. Maîtrise

g. Doctorat/PhD.

15. À quel point êtes-vous conscient ou informé de l'A4.0 ?

a. Très conscient ou informé

b. Conscient ou informé

c. Quelque peu conscient ou informé

d. Pas conscient ou informé

16. Avez-vous mis en place des technologies d'intelligence artificielle (IA) dans votre exploitation agricole ?

L'IA (Intelligence Artificielle) est le développement de systèmes informatiques qui imitent l'intelligence humaine, permettant aux machines d'apprendre, de résoudre des problèmes et de prendre des décisions comme le feraient les humains. Cela implique la création de machines intelligentes capables d'accomplir des tâches nécessitant des capacités similaires à celles des humains.

a. Oui

b. Non

17. Si oui, veuillez préciser à quelle étape de la culture vous utilisez l'IA ?

a. Avant la récolte

b. Pendant la récolte

c. Après la récolte

18. Avez-vous mis en place des technologies de CC (CC) dans votre exploitation agricole ? L'informatique en nuage (ou CC) permet l'accès basé sur Internet à des ressources de calcul, offrant ainsi une évolutivité, une provision rapide et des économies de coûts. Elle fonctionne comme une utilité, permettant aux utilisateurs de stocker, d'accéder et de traiter des données sur des serveurs distants.

    a. Oui

    b. Non

19. Si oui, veuillez préciser à quelle étape de la culture vous utilisez l'CC ?

    a. Avant la récolte.

    b. Pendant la récolte.

    c. Après la récolte.

20. Avez-vous mis en place des technologies d'analyse de Big Data (BDA) dans votre exploitation agricole ?

    L'analyse des mégadonnées (BDA) consiste à analyser des ensembles de données vastes et diversifiés afin de découvrir des informations précieuses et des schémas qui éclairent la prise de décision organisationnelle. Des techniques et outils avancés sont utilisés pour traiter et analyser de grands ensembles de données complexes, en extrayant des informations exploitables pour une prise de décision éclairée.

    a. Oui

    b. Non

21. Si oui, veuillez préciser à quelle étape de la culture vous utilisez l'analyse des mégadonnées (BDA) :

    a. Avant la récolte.

    b. Pendant la récolte.

    c. Après la récolte.

22. Si oui, veuillez préciser le type de technologies d'analyse des mégadonnées (BDA) que vous avez mises en œuvre :

    a. Descriptif : déterminer ce qui s'est passé.

    b. Diagnostique : déterminer pourquoi quelque chose s'est produit.

    c. Prédictif : déterminer ce qui se passera ensuite (prévision).

d. Préscriptif : déterminer quoi faire ensuite (prise de décision).

23. Avez-vous mis en œuvre des technologies de l'Internet des objets (IoT) dans votre exploitation agricole ?

    L'Internet des objets (IoT) est un réseau d'objets physiques, de dispositifs, de véhicules et de bâtiments intégrant des composants électroniques, des logiciels, des capteurs et une connectivité. Il permet à ces objets de collecter et d'échanger des données, favorisant une connectivité omniprésente et une interaction avec l'environnement grâce à Internet et aux services basés sur le cloud.

    a. Oui

    b. Non

24. Si oui, veuillez préciser à quelle étape de la culture vous utilisez l'IoT :

    a. Avant la récolte

    b. Pendant la récolte

    c. Après la récolte

25. Si vous avez mis en œuvre des technologies de l'A4.0, comment classeriez-vous le niveau d'intégration des technologies de l'A4.0 dans vos opérations agricoles ?

	Phase d'adoption initiale : Les individus au sein de l'organisation commencent à apprendre à utiliser la technologie de l'A4.0 dans leurs opérations. Il n'existe pas de procédures développées concernant l'utilisation de la technologie de l'A4.0.	Phase d'adoption de projet : Les technologies sont adoptées dans des projets actifs ou nouveaux au sein de l'organisation. Certaines procédures concernant l'utilisation de la technologie de l'A4.0 sont en train d'être établies pour chaque projet.	Phase d'adoption organisationnelle : Les technologies de l'A4.0 sont adoptées dans toute l'organisation. Des procédures concernant l'utilisation des technologies de l'A4.0 sont en train d'être établies.	Phase de gestion quantitative : Les procédures concernant l'utilisation des technologies de l'A4.0 sont bien établies au niveau de l'organisation, permettant ainsi de mesurer et de surveiller les performances technologiques et les résultats.	Phase d'optimisation continue : Les procédures concernant l'utilisation de l'A4.0 sont bien établies au niveau de l'organisation. L'accent est mis sur l'utilisation des mesures de performance pour comprendre les domaines d'amélioration et mettre en œuvre des solutions pour améliorer les procédures.
Intelligence Artificielles					
CC					

Analyse des mégadonnées					
Internet des chose					

26. Comment évalueriez-vous votre niveau de satisfaction global quant aux performances de l'A4.0 dans vos opérations agricoles ?

	Extrêmement satisfait.	Satisfait	Légèrement satisfait.	Neutre	Légèrement insatisfait.	Insatisfait	Extrêmement insatisfait
Intelligence Artificielles							
CC							
Analyse des mégadonnée s							
Internet des chose							

27. Quels obstacles économiques avez-vous rencontrés dans la mise en œuvre de l'A4.0?

	Coût élevé de l'acquisition, de la mise en œuvre, de la transition et de la maintenance de l'A4.0.	Manque de soutien financier et d'opportunités de financement (non gouvernementales).	Autre.	Non applicable ou aucun obstacle rencontré.
Intelligence Artificielles				
CC				
Analyse des mégadonnées				
Internet des chose				

28. Quels obstacles gouvernementaux avez-vous rencontrés dans la mise en œuvre de l'A4.0?

	Absence de politiques gouvernementales, d'incitations et de soutien financier pour l'intégration de l'A4.0.	Préoccupations juridiques et réglementaires concernant l'utilisation de l'A4.0.	Autre.	Non applicable ou aucun obstacle rencontré.
Intelligence Artificielles				

CC				
Analyse des mégadonnées				
Internet des chose				

29. Quels obstacles liés aux connaissances avez-vous rencontrés dans la mise en œuvre de l'A4.0?

	Manque de recherche, de sources de connaissances ouvertes et d'opportunités de formation.	Manque de connaissances et d'écart de compétences chez les agriculteurs et la main-d'œuvre.	Préoccupations concernant l'impact de l'A4.0 sur la société et l'environnement.	Manque de compréhension des avantages et du retour sur investissement de la mise en œuvre de l'A4.0.	Complexité croissante de l'A4.0 et de la gestion des données.	Autre.	Non applicable ou aucun obstacle rencontré.
Intelligence Artificielles							
CC							
Analyse des mégadonnées							
Internet des chose							

30. Quels obstacles sociaux avez-vous rencontrés dans la mise en œuvre de l'A4.0?

	Distribution inégale des avantages et des risques entre les parties prenantes (agriculteurs, chercheurs, fournisseurs de technologie et gouvernement).	Manque de confiance et de collaboration entre les parties prenantes (agriculteurs, chercheurs, fournisseurs de technologie et gouvernement).	Résistance au changement.	Autre.	Non applicable ou aucun obstacle rencontré.
Intelligence Artificielles					
CC					
Analyse des mégadonnées					
Internet des chose					

31. Quels obstacles techniques avez-vous rencontrés dans la mise en œuvre de l'A4.0?

	Interopérabilité, normalisation, fiabilité, personnalisation et évolutivité des technologies, des données et de l'infrastructure	Préoccupations concernant la sécurité des données, la confidentialité et la propriété.	Accès inégal à l'infrastructure et à la technologie entre les zones urbaines et rurales.	Manque de normes et de protocoles de l'industrie.	Manque d'IoT centré sur l'humain	Performance insuffisante de l'IoT.	Incapacité de l'IoT à résister aux conditions environnementales et climatiques difficiles.	Autre.	Non applicable ou aucun obstacle rencontré.
Intelligence Artificielles									
CC									
Analyse des mégadonnées									
Internet des chose									

32. Si vous avez sélectionné "Autre", veuillez indiquer tout obstacle à la mise en œuvre de l'Internet des objets ***auquel*** vous avez été confronté et qui n'a pas été mentionné précédemment.

33. Veuillez classer les types de barrières suivants en fonction de l'ampleur de leur impact sur la restriction de l'adoption des technologies de l'A4.0 au sein de votre organisation. L'échelle va de 1 = plus important à 5 = moins important.

    a. Obstacles techniques

    b. Obstacles gouvernementaux

    c. Obstacles sociaux

    d. Obstacles lies aux connaissances

    e. Obstacles économiques

34. Offrez-vous une formation technique à vos employés ? Sélectionnez les technologies incluses.

    a. Intelligence artificielle

    b. CC (informatique en nuage)

c. Analyse de données volumineuses (BDA)

d. Internet des objets (IoT)

e. Aucune des options ci-dessus

35. Quels avantages environnementaux voyez-vous dans la mise en œuvre des technologies de l'A4.0 dans vos activités agricoles ?

a. Réduction de l'utilisation de pesticides.

b. Réduction de l'utilisation d'engrais.

c. Réduction de l'utilisation d'eau.

d. Réduction du gaspillage alimentaire.

e. Réduction de la consommation d'énergie.

f. Réduction des terres en jachère.

g. Autre.

h. Non applicable ou aucun avantage observé.

36. Quels avantages économiques voyez-vous dans la mise en œuvre des technologies de l'A4.0 dans vos activités agricoles ?

a. Coûts de production fixes réduits.

b. Coûts de production variables réduits.

c. Prix de vente plus élevé (en fonction du marché).

d. Meilleure qualité des produits.

e. Plus grande quantité de produits.

f. Autre.

g. Non applicable ou aucun avantage observé.

37. Quels sont les avantages sociaux que vous observez en mettant en œuvre des technologies de l'A4.0 dans vos opérations agricoles ?

a. Réduction des accidents liés au travail.

b. Compensation pour la perte ou le manque de main-d'œuvre.

c. Meilleur équilibre entre vie professionnelle et vie personnelle.

d. Augmentation de la sécurité alimentaire.

e. Meilleur bien-être animal.

f. Plus de transparence au sein de la chaîne d'approvisionnement agricole.

g. Facilitation de la prise de décision.

h. Augmentation de l'égalité des salaires.

i. Autre.

j. Non applicable ou aucun avantage observé.

38. Si vous avez sélectionné "Autre", veuillez indiquer quels avantages vous avez observés grâce à la mise en œuvre de l'A4.0 qui n'ont pas été mentionnés dans la question précédente.

39. Selon vous, quelles mesures ou incitations pourraient contribuer à surmonter les obstacles à la mise en œuvre des technologies de l'A4.0 ?

HEC MONTRĒAL

Retrait d'une ou des pages pouvant contenir des renseignements personnels

   a. Crop cultivation (food, forage, fibber, oil, ornamental, and industrial)
   b. Livestock (beef, poultry, proc, eggs, dairy, and fish)
   c. Crop cultivation and livestock

2. In which province is your farm located?
   a. Alberta
   b. British Columbia
   c. Prince Edward Island
   d. Manitoba
   e. New Brunswick
   f. Nova Scotia
   g. Ontario
   h. Quebec
   i. Saskatchewan
   j. Newfoundland and Labrador
   k. Northwest Territories
   l. Nunavut
   m. Yukon

3. Is your farm certified organic?
   a. Yes
   b. No

4. If you answered yes to the question above, please write down which certifications your farm has?

5. Is your farm certified fair trade?
   a. Yes
   b. No

6. Which type of livestock do you keep?
   a. Cattle: Meat
   b. Cattle: Dairy

    c. Poultry (chickens, ducks, quail, pheasants, geese, swans, turkeys, ostriches): Meat
    d. Poultry (chickens, ducks, quail, pheasants, geese, swans, turkeys, ostriches): Eggs
    e. Pork: Meat
    f. Fish: Meat
    g. Bees: honey and Wax
    h. Other

7. If you selected Other to the question above, please indicate what other types of livestock you keep?
8. What is the size of your farm? Please indicate the number of individuals (heads) you have per type of livestock.
9. What types of crops do you primarily cultivate?
    a. Food (fruits, vegetables, grain)
    b. Fiber (Cotton, hemp, coir, jute, flax)
    c. Forage/feed (grasses, legumes, silage)
    d. Oil (olive, soybean, palm, rape, sunflower)
    e. Ornamental (flowers, shrubs, non-fruit trees)
    f. Industrial/Biofuel (corn, rapeseed, sugarcane, palm, jatropha, soybean, switchgrass)
10. If you cultivate food crops, please indicate which specific type?
11. How do you grow your crops?
    a. Orchard
    b. Vineyard
    c. Field
    d. Greenhouse
    e. Hydroponics
    f. Other
12. What is the size of your farm? Please indicate the area of land cultivated for crops (acres).
13. What is your highest degree earned?
    a. Did not complete high school.
    b. High school diploma

c. CEGEP

d. Vocational school degree

e. Bachelor's degree

f. Master's degree

g. Doctorate/Ph.D.

14. What is the usual degree earned among your employees?

    a. Did not complete high school.

    b. High school diploma

    c. CEGEP

    d. Vocational school degree

    e. Bachelor's degree

    f. Master's degree

    g. Doctorate/Ph.D.

15. How aware or knowledgeable are you of A4.0?

    a. Very aware or knowledgeable

    b. Aware or knowledgeable

    c. Somewhat aware or knowledgeable

    d. Not aware or knowledge

16. Have you implemented any Artificial Intelligence (AI) technologies on your farm?

    AI is the development of computer systems that imitate human intelligence, enabling machines to learn, solve problems, and make decisions like humans. It involves creating intelligent machines that can perform tasks requiring human-like abilities.

    a. Yes

    b. No

17. If yes, please specify during which stage of cultivation do you use AI?

    a. Pre-harvesting

    b. Harvesting

    c. Post-harvesting

18. Have you implemented any CC (CC) technologies on your farm?

CC enables internet-based access to compute resources, offering scalability, quick provisioning, and cost savings. It operates as a utility, allowing users to store, access, and process data on remote servers.

a. Yes

b. No

19. If yes, please specify during which stage of cultivation do you use CC?

a. Pre-harvesting

b. Harvesting

c. Post-harvesting

20. Have you implemented any BDA (BDA) technologies on your farm?

BDA involves analyzing extensive and diverse data sets to uncover valuable insights and patterns that inform organizational decision-making. Advanced techniques and tools are used to process and analyze large, complex data sets, extracting actionable information for informed decision-making.

a. Yes

b. No

21. If yes, please specify during which stage of cultivation do you use BDA?

a. Pre-harvesting

b. Harvesting

c. Post-harvesting

22. If yes, please specify the type of BDA technologies you have implemented.

a. Descriptive: determine what happened.

b. Diagnostic: determine why something happened.

c. Predictive: determine what will happen next (forecasting)

d. Prescriptive: Determine what to do next (decision making).

23. Have you implemented any IoT (IoT) technologies on your farm?

The IoT (IoT) is a network of physical objects, devices, vehicles, and buildings embedded with electronics, software, sensors, and connectivity. It enables these objects to collect and exchange data, fostering pervasive connectivity and interaction with the environment through the Internet and cloud-based services.

a. Yes

b. No

24. If yes, please specify during which stage of cultivation do you use IoT?

    a. Pre-harvesting

    b. Harvesting

    c. Post-harvesting

25. If you have implemented A4.0 technologies, how would you classify the level of integration of A4.0 technologies in you farming operations?

	Initial adoption phase: Individuals within the organization are beginning to learn how to use A4.0 technology within their operations. There are no developed procedures regarding the use of A4.0 technology.	Project adoption phase: Technologies are being adopted within active or new projects within the organization. Some procedures regarding the use of A4.0 technology are being established for each project.	Organizational adoption phase: A4.0 technologies are being adopted throughout the organization. Procedures regarding the use of A4.0 technologies are being established.	Quantitatively managed phase: Procedures regarding the use of A4.0 technologies are well established at the organizational level, thus allowing for the performance of technology and results to be measured and monitored.	Continuous optimization phase: Procedures regarding the use of A4.0 are well established at the organizational level. The focus is directed at using performance measures to understand areas of improvement and implementing solutions to improve procedures.
AI					
CC					
BDA					
IoT					

26. How would you rate your overall level of satisfaction with the performance of A4.0 technologies within your farming operations?

	Extremely satisfied.	Satisfied	Slightly satisfied.	Neutral	Slightly dissatisfied.	Dissatisfied	Extremely dissatisfied
AI							
CC							
BDA							
IoT							

27. What economic barriers have you faced towards the implementation of A4.0 technologies?

	Prohibitive cost of acquiring, implementing, transitioning, and maintaining A4.0 technologies	Lack of financial support and funding opportunities (non-governmental)	Other	Not applicable or no barrier encountered.
AI				
CC				
BDA				

IoT				

28. What governmental barriers have you faced towards the implementation of A4.0 technologies?

	Lack of government policies, incentives, financial support for the integration of A4.0 technologies	Legal and regulatory concerns towards the use of A4.0 technologies	Other	Not applicable or no barrier encountered.
AI				
CC				
BDA				
IoT				

29. What knowledge barriers have you faced towards the implementation of A4.0 technologies?

	Lack of research, open sources of knowledge, and training opportunities	Lack of knowledge and skill gap of farmers and labor force	Concerns towards the impact of A4.0 technologies on society and the environment	Lack of understanding of benefits and ROI of A4.0 technologies implementation	Increasing complexity of A4.0 technologies and data management	Other	Not applicable or no barrier encountered.
AI							
CC							
BDA							
IoT							

30. What social barriers have you faced towards the implementation of A4.0 technologies?

	Unequal distribution of benefits and risks among stakeholders (Farmers, researchers, technology providers, and government)	Lack of trust and collaboration between stakeholders (farmers, researchers, technology providers, and government)	Resistance to change.	Other	Not applicable or no barrier encountered
AI					
CC					
BDA					
IoT					

31. What technical barriers have you faced towards the implementation of A4.0 technologies?

	Interoperability, standardization, reliability, customization, and scalability of technologie	Data security, privacy, and ownership concerns	Unequal access to infrastructure and technology between urban and rural areas	Lack of industry standards and protocols	Lack of human centered A4.0 technologies	Subpar performance of A4.0 technologies	Inability of A4.0 technologies to endure harsh field environment and climate	Other	Not applicable or no barrier encountered.

	s Data, and infrastructure						conditions.		
AI									
CC									
BDA									
IoT									

32. If you selected other for question 27, 28, 29, 30, and/or 31, please indicate any barriers to the implementation of A4.0 technologies you have faced that was not priorly listed.

33. Please rank the following types of barriers based on the extent to which they have restricted the adoption of A4.0 technologies within your organization. The scale ranging from 1 = most important and 5 = least important.

    a. Technical barriers

    b. Governmental barriers

    c. Social barriers

    d. Knowledge barriers

    e. Economic Barriers

34. Do you offer technical training to your employees? Select which technologies are included.

    a. Artificial Intelligence

    b. CC

    c. BDA

    d. IoT

    e. None of the above

35. What environmental benefits do you see from implementing A4.0 technologies into your farming operations?

    a. Reduced use of pesticides

    b. Reduced use of fertilizer

    c. Reduced use of water

    d. Reduced (food) waste.

    e. Reduced energy use

    f. Reduced fallow land.

    g. Other

h. Not applicable or no observed benefits

36. What economic benefits do you see from implementing A4.0 technologies into your farming operations? (Multiple options can be selected)

    a. Lower fixed production costs

    b. Lower variable production cost

    c. Higher selling price (market reflected)

    d. Higher quality of products

    e. Higher yield per acre

    f. Other

    g. Not applicable or no observed benefits

37. What social benefits do you see from implementing A4.0 technologies into your farming operations? (Multiple options can be selected)

    a. Reduced work-related injuries.

    b. Compensation for lost/lack of labour.

    c. Better work life balance

    d. Increased food security.

    e. Better animal welfare

    f. More transparency within Agricultural Supply Chain

    g. Eased decision making.

    h. Increased equality of wages

    i. Other

    j. Not applicable or no observed benefits

38. If you selected other for questions 35, 36 and/or 37 please indicate which benefits you have observed from implementing A4.0 not mentioned in the previous questions. (Open ended, to be answered only be participants that select "i" for question 35, "g" for question 36, "i" question 37)

39. In your opinion, what measures or incentives could help over come barriers to implementing A4.0 technologies at your farm? (Open ended)

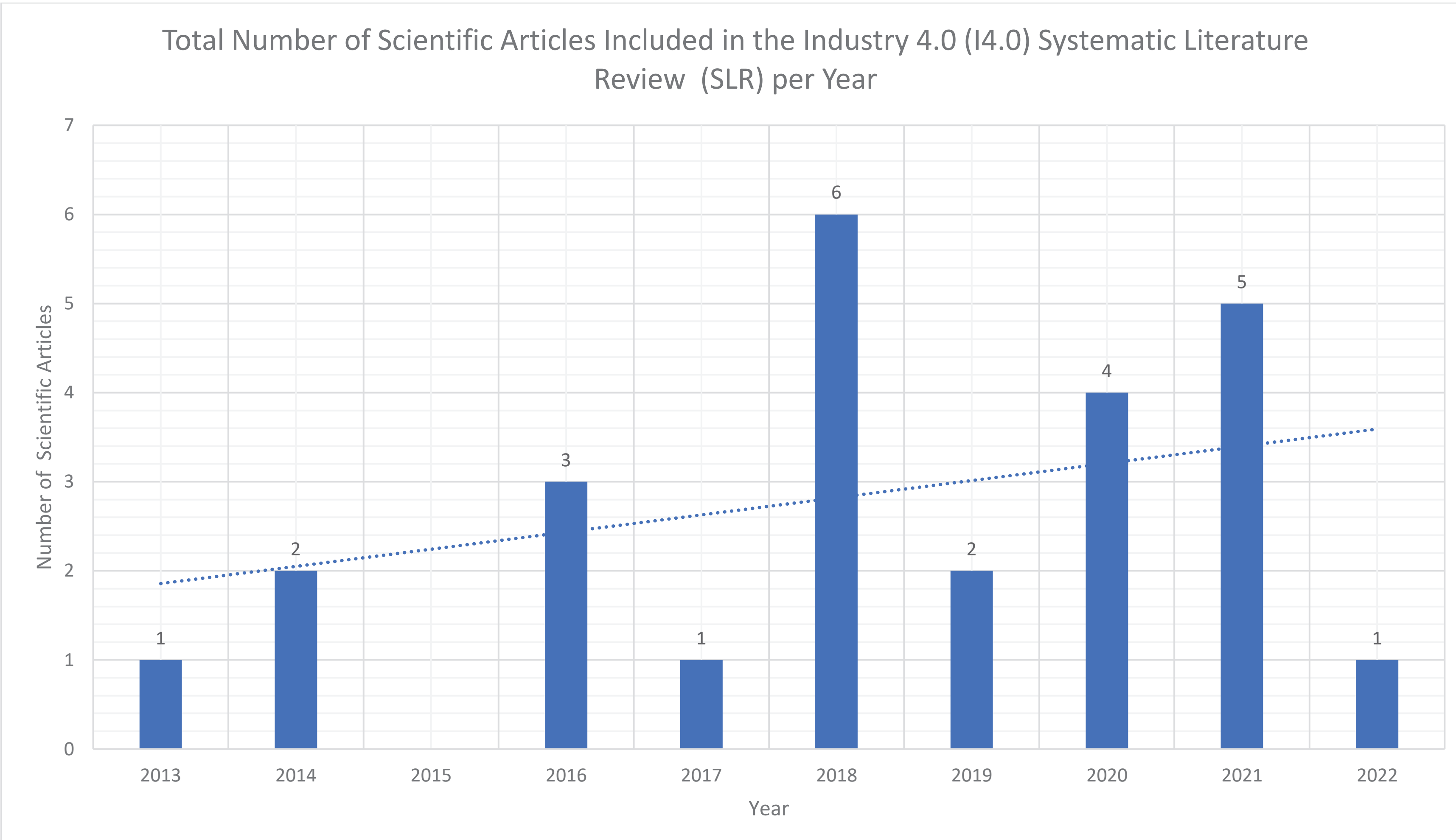
Appendix C

Table 1: *Industry 4.0 (I4.0) Systematic Literature Reviews (SLRs) Author Comparison*

Authors	Key Characteristics Systematic Literature Review	Technology Systematic Literature Review
(Abdirad and Krishnan, 2021)	x	x
(Aceto et al., 2019)	x	x
(Ali et al., 2021)	x	x
(Bag et al., 2018)	x	x
(Bar et al., 2018)	x	x
(Bauer, 2018)	x	x
(Belinski et al., 2020)	x	x
(Chauhan and Singh, 2019).	x	x
(Culot et al., 2020)	x	x
(Dalenogare et al., 2018)	x	x
(Drath and Horch, 2014)	x	x
(Dombrowski and Richter, 2017).	x	x
(Ghadge et al., 2020)	x	x
(Javaid et al., 2022)	x	x
(Kagermann, Wahlster and Helbig, 2013)	x	x
(Lasi et al.,2014).	x	x
(Latino et al. 2021)		x
(Liu et al. 2021)		x
(Murugaiyan and Ramasamy, 2021)	x	x
(Oesterreich and Teuteberg, 2016)	x	x
(Ortt e.g., al., 2020)	x	x
(Oztemel et Gursev, 2018)	x	x
(Piccarozzi, Aquilani, and Gatti, 2018)	x	x
(Sipsas et al., 2016)	x	x
(Wang et al., 2016)	x	x

Appendix D

Figure 20: *Total Number of Scientific Articles Included in the Industry 4.0 (I4.0) Systematic Literature Review (SLR) per Year*



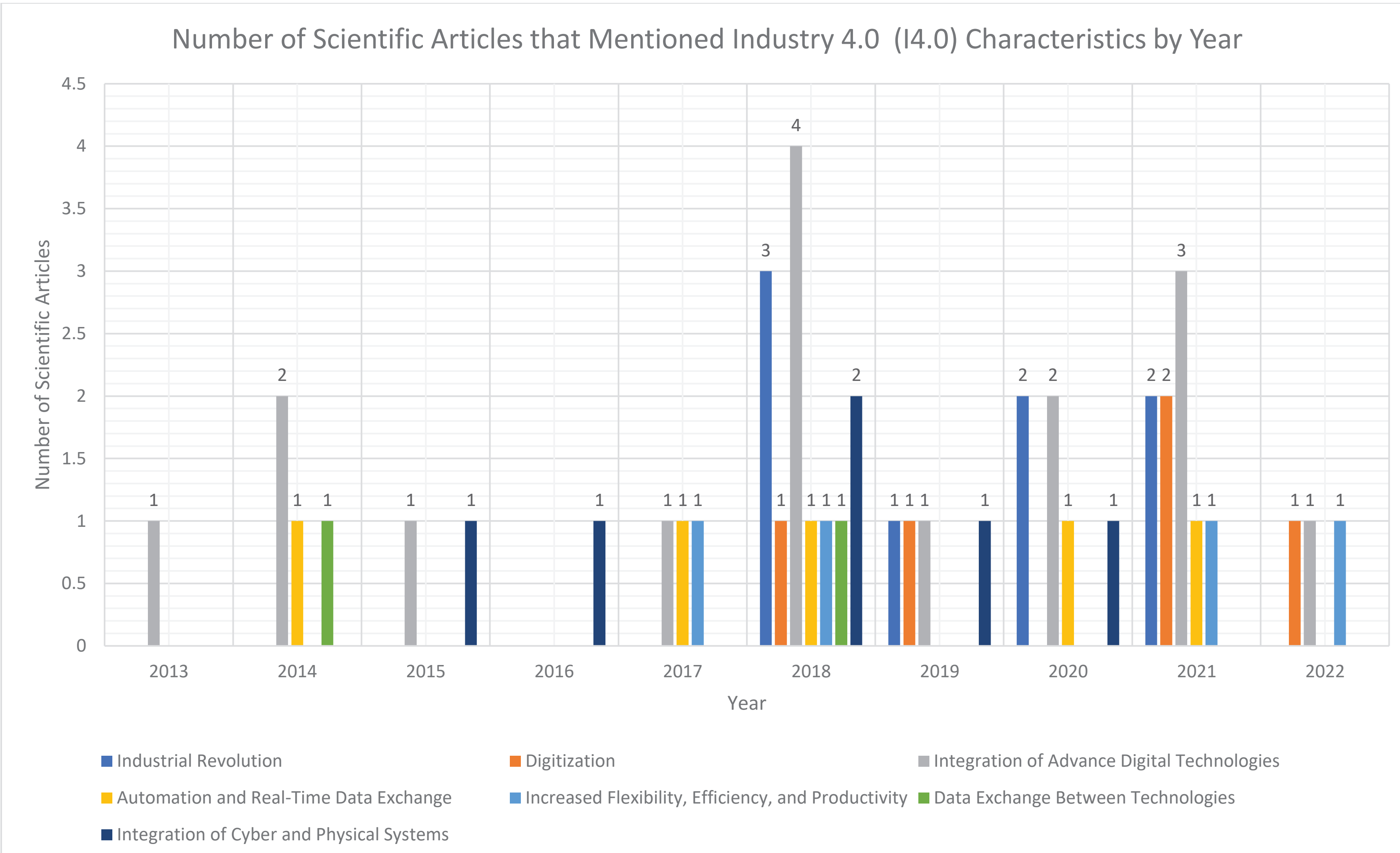
Appendix E

Table 2: *Systematic Literature Review (SLR) of Key Characteristics of Industry 4.0 (I4.0)*

Authors	Industrial Revolution	Digitization	Integration of Advance Digital Technologies	Automation and Real-Time Data Exchange	Increased Flexibility, Efficiency, and Productivity	Data Exchange Between Technologies	Integration of Cyber and Physical Systems
(Abdirad and Krishnan, 2021)	x	x	x				
(Aceto et al., 2019)		x	x				
(Ali et al., 2021)	x	x					
(Bag et al., 2018)	x		x				
(Bar et al., 2018)			x	x		x	
(Bauer, 2018)		x	x		x		
(Belinski et al., 2020)							x
(Chauhan and Singh, 2019).	x						x
(Culot et al., 2020)			x	x			
(Dalenogare et al., 2018)	x		x				
(Drath and Horch, 2014)			x				
(Dombrowski and Richter, 2017).			x	x	x		
(Ghadge et al., 2020)	x		x				
(Javaid et al., 2022)		x	x		x		
(Kagermann, Wahlster and Helbig, 2013)			x				
(Lasi et al.,2014).			x	x		x	
(Liu et al., 2021)			x		x		
(Murugaiyan and Ramasamy, 2021)			x	x			
(Oesterreich and Teuteberg, 2016)							x
(Ortt e.g., al., 2020)	x						
(Oztemel et Gursev, 2018)	x						x
(Piccarozzi, Aquilani, and Gatti, 2018)							x
(Sipsas et al., 2016)			x				
(Wang et al., 2016)							x

Appendix F

Figure 21: *Number of Scientific Articles that Mentioned Industry 4.0 (I4.0) Characteristics by Year*



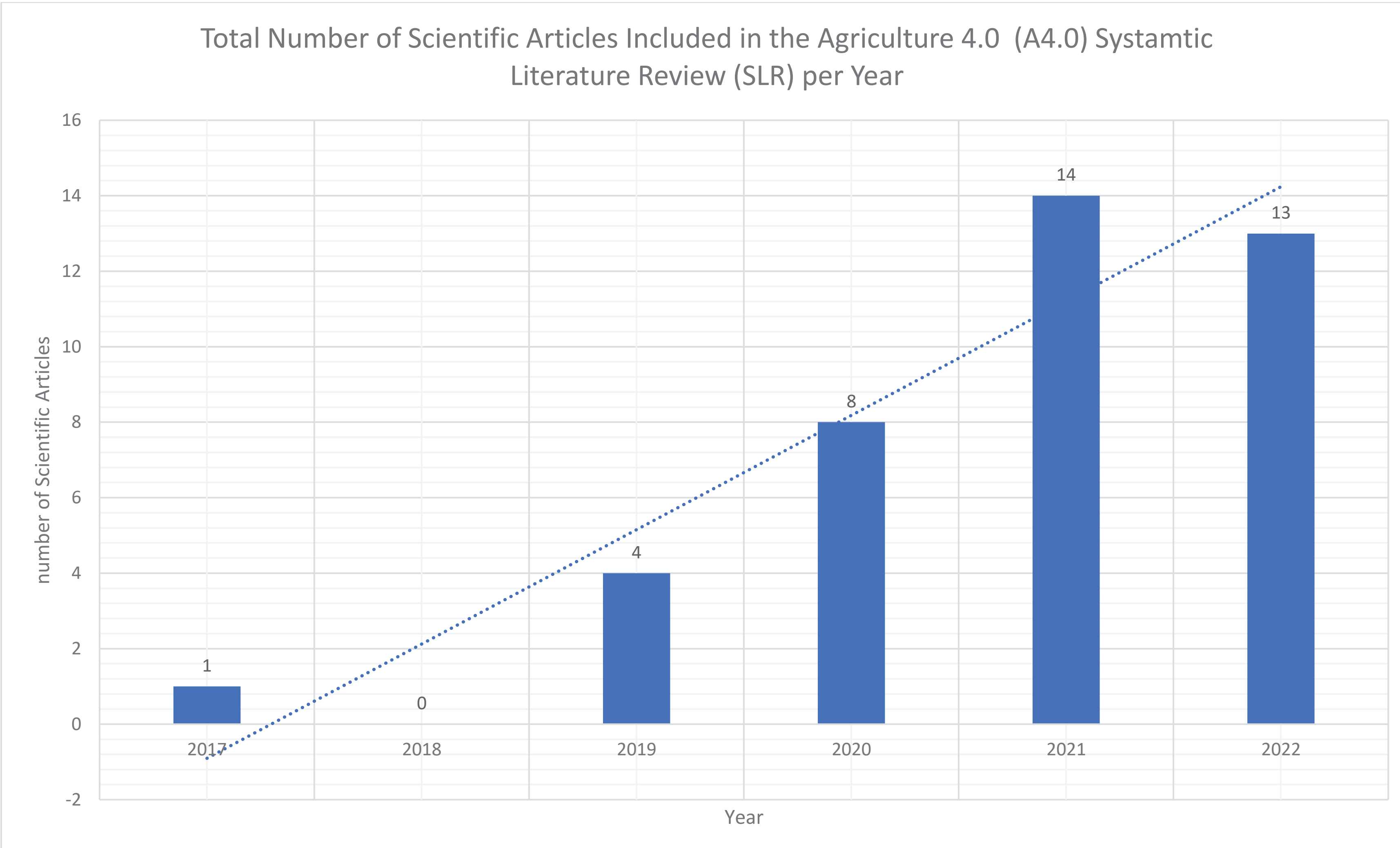
Appendix G

Table 3: *A4.0 Systematic Literature Reviews (SLRs) Author Comparison*

Authors	Key Characteristics Literature Review	Technology Literature Review
(Abbasi et al., 2022)	x	x
(Aceto et al., 2019)	x	x
(Albiero et al., 2020)	x	x
(Amaral et al., 2020)	x	x
(Araujo et al., 2021)	x	x
(Arvanitis and Symeonaki,2020)	x	x
(Bešić et al., 2021)	x	x
(Debauche et al., 2022)	x	x
(Diego and Leticia, 2022)	x	x
(Eastwood et al., 2021)	x	x
(Erdogan, 2022)	x	x
(Fedotova et al., 2021)	x	x
(Ferrag et al., 2022)	x	x
(Gonzalez-Salazar, 2020)	x	x
(Heinz et al., 2021)		x
(Ilaria et al. 2019)	x	
(Ilham et al., 2022)	x	x
(Ismael et al., 2022)	x	x
(Klerkx et al. 2019)	x	x
(Kumar et al., 2021)	x	x
(Lezoche et al., 2020)		x
(Lioutas and Charatsari, 2022)	x	x
(Liu et al., 2021)		x
(Martinho et al., 2022)	x	x
(Michele et al., 2022)	x	x
(Mohamed et al., 2021)	x	x
(Mohd et al., 2022)	x	x
(Monteleone et al., 2020)	x	x
(Nadezhda and Dmitry, 2022)	x	x
(Nugun et al., 2021)	x	x
(Ozdogan et al., 2017)	x	x
(Polyakov, 2021)	x	x
(Rose et al., 2021)	x	x
(Samson et al., 2021)	x	x
(Silva et al., 2020)	x	x
(Solodovnik et al., 2021)	x	x
(Sponchioni et al., 2019)	x	x
(Vincenzo et al., 2022)	x	x
(Widiyanti et al., 2022)	x	x
(Zhai et al., 2020)	x	x

Appendix H

Figure 22: *Total Number of Scientific Articles Included in the Agriculture (A4.0) Systematic Literature Review (SLR) per Year*



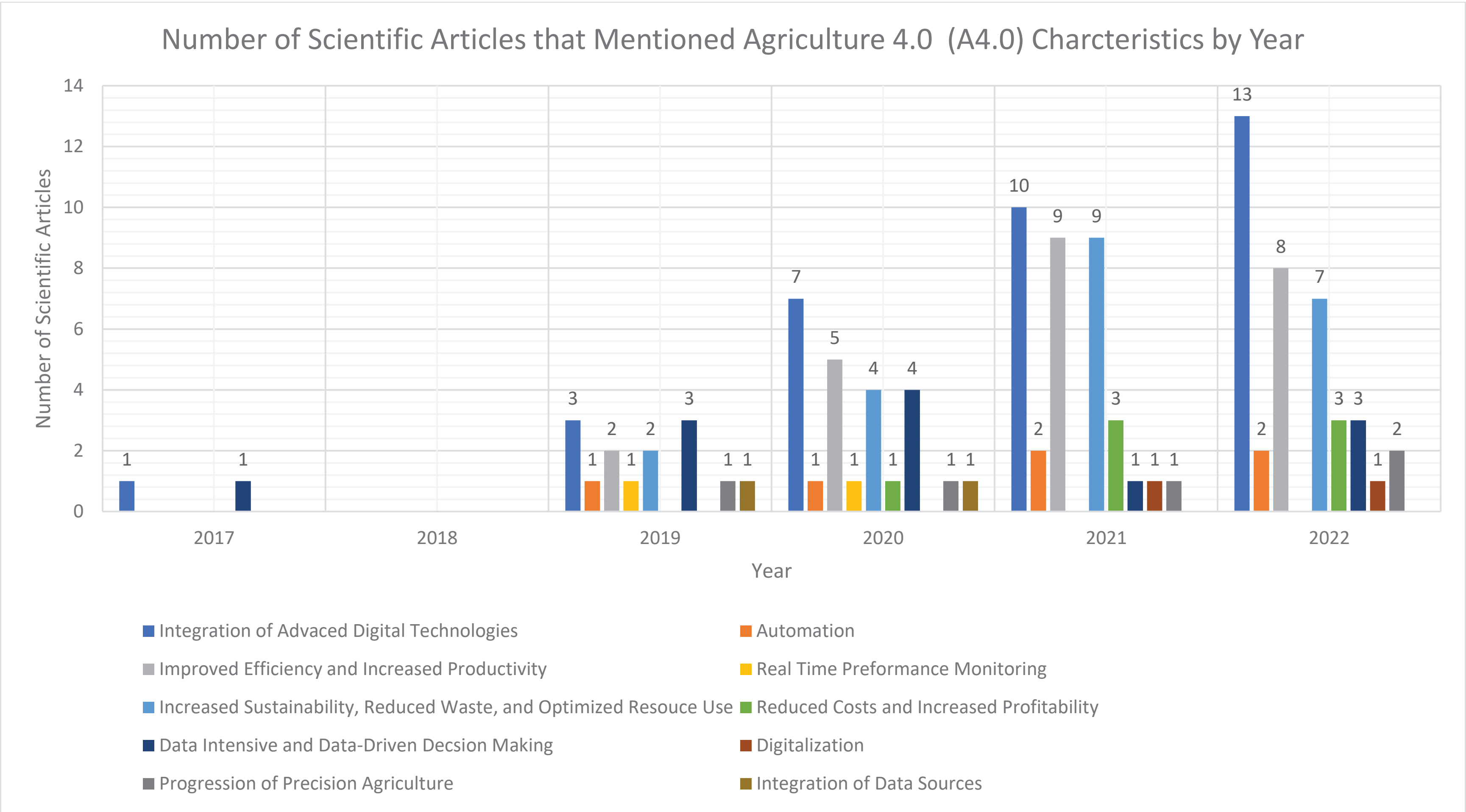
Appendix I

Table 4: *Systematic Literature Review (SLR) of Key Characteristics of Agriculture 4.0 (A4.0)*

Authors	Integration of Advanced Digital Technologies (ADTs)	Automation	Improved Efficiency and Increased Productivity	Real Time Performance Monitoring	Increased Sustainability, Reduced Waste, and Optimized Resource Use	Reduced Costs and Increased Profitability	Data Intensive and Data-Driven Decision Making	Digitalization	Progression of Precision Agriculture	Integration of Data Sources
(Abbasi et al., 2022)	x	x	x							
(Aceto et al., 2019)			x	x	x					
(Albiero et al., 2020)	x		x		x					
(Amaral et al., 2020)	x		x		x	x				
(Araujo et al., 2021)	x	x	x		x					
(Arvanitis and Symeonaki, 2020)	x	x	x		x		x			
(Bešić et al., 2021)	x		x							
(Debauche et al., 2022)	x		x		x					
(Diego and Leticia, 2022)	x		x		x	x				
(Eastwood et al., 2021)	x		x		x	x	x			
(Erdogan, 2022)	x		x		x	x				
(Fedotova et al., 2021)	x		x		x	x		x		
(Ferrag et al., 2022)	x		x		x					
(Gonzalez-Salazar, 2020)	x						x		x	x
(Ilaria et al. 2019)	x		x		x		x			
(Illham et al., 2022)	x		x		x	x			x	
(Ismael et al., 2022)	x						x			
(Klerkx et al. 2019)	x						x			
(Kumar et al., 2021)	x				x					
(Lioutas and Charatsari, 2021)					x					
(Martinho et al., 2022)	x									
(Michele et al., 2022)	x									
(Mohamed et al., 2021)	x		x							
(Mohd et al., 2022)	x						x			
(Monteleone et al., 2020)	x						x			
(Nadezhda and Dmitry, 2022)	x						x		x	
(Nugun et al., 2021)			x		x				x	
(Ozdogan et al., 2017)	x						x			
(Polyakov, 2021)	x	x								
(Rose et al., 2021)	x		x		x					
(Samson et al., 2021)	x		x		x	x				
(Silva et al., 2020)	x		x	x			x			
(Solodovnik et al., 2021)	x		x		x					
(Sponchioni et al., 2019)	x	x					x		x	x
(Vincenzo et al., 2022)	x	x	x		x			x		
(Widiyanti et al., 2022)	x		x		x					
(Zhai et al., 2020)	x		x		x					

Appendix J

Figure 23: *Number of Scientific Articles that Mentioned Agriculture 4.0 (A4.0) Characteristics by Year*



Appendix K

Table 5: *Systematic Literature Review (SLR) of Industry 4.0 (I4.0) Technologies*

Authors	Internet of Things (IoT)	Big Data Analytics (BDA)	Cloud Computing (CC)	Cyber Physical Systems (CPS)	Artificial Intelligence (AI)	Augmented Reality (AR)	Blockchain (BC)	Edge Computing (EC)	Fog Computing (FC)	Mobile Fog Computing (MFC)	Wireless Sensor Network (WSN)	Radio-Frequency Identification (RFID)	5G Network	Robotics and Automation	3D Printing/Additive Manufacturing (AM)	Digital Twins	Smart Sensors	Unmanned Arial Vehicles (UAVs)	Collaborative Maintenance	Flow-Line Manufacturing Environments	Self-Organized Multi-Agent Systems	Virtual Reality (VR)
(Abdirad and Krishnan, 2021)	x	x	x	x	x	x	x															
(Aceto et al., 2019)	x	x	x	x	x	x	x	x	x	x	x	x	x									x
(Ali et al., 2021)	x	x	x	x	x		x															
(Bag et al., 2018)	x	x	x	x	x		x															
(Bar et al., 2018)	x	x	x	x	x	x																
(Bauer, 2018)	x	x	x	x		x																
(Belinski et al., 2020)	x	x			x	x																x
(Chauhan and Singh, 2019).	x	x	x	x	x	x																
(Culot et al., 2020)	x	x	x	x	x									x	x							
(Dalenogare et al., 2018)	x	x	x		x									x								
(Drath and Horch, 2014)	x	x	x	x																		
(Dombrowski and Richter, 2017).	x	x	x	x		x								x	x	x						
(Ghadge et al., 2020)	x	x		x	x																	
(Javaid et al., 2022)	x	x	x	x	x	x								x	x	x						x
(Kagermann, Wahlster and Helbig, 2013)	x	x	x	x										x	x		x					
(Lasi et al.,2014).	x	x	x	x											x							
(Latino et al. 2021)	x	x												x				x				
(Liu et al. 2021)	x	x	x	x	x								x	x				x				
(Murugaiyan and Ramasamy, 2021)	x	x	x	x	x																	
(Oesterreich and Teuteberg, 2016)	x		x	x		x								x								x
(Ortt et al., 2020)	x	x		x	x									x								
(Oztemel et Gursev, 2018)	x	x	x	x	x									x	x							
(Piccarozzi, Aquilani, and Gatti, 2018)	x	x		x	x	x	x							x								
(Sipsas et al., 2016)																			x	x		
(Wang et al., 2016)		x																			x	

Appendix L

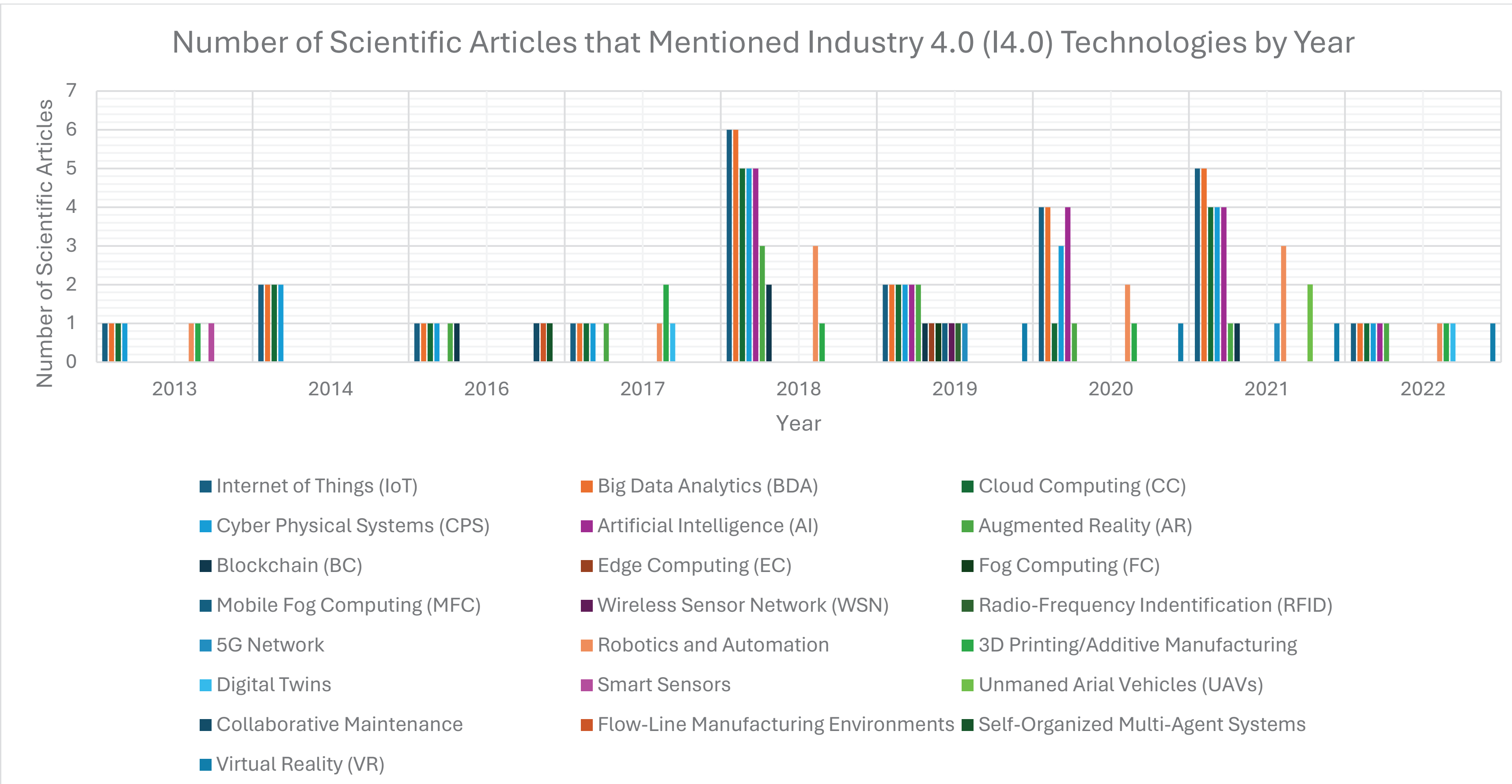
Table 6: *Systematic Literature Review (SLR) of Agriculture 4.0 (A4.0) Technologies*

Technology	Internet of Things (IoT)	Artificial Intelligence (AI)	Big Data Analytics (BDA)	Robotics and Automation (R&A)	Precision Agriculture and Livestock Farming (PA)	Unmanned Arial Vehicles (UAVs)	Blockchain (BC)	Cloud Computing (CC)	Machine Learning (ML)	Cyber Physical Systems (CPS)	Augmented Reality (AR)	Distributed Architectures	Geographic Information System (GIS)	Intrusion Detection Systems	3D Printing/ Additive Manufacturing (AM)	Advanced Network Processors (ANP)	Data Fusion	Decision Support Systems	Deep Learning (DL)	Digital Twins	Information systems Management (ISM)	Remote Sensing	Self-Driving Tractors	Statistical Quality Control	System Integration	Ubiquitous Reality (UR)	Virtual Reality (VR)
(Abbasi et al., 2022)	x	x	x	x	x		x	x																			
(Aceto et al., 2019)	x	x	x				x	x		x	x																x
(Albiero et al., 2020)	x	x	x	x	x	x				x																	
(Amaral et al., 2020)	x		x		x	x							x														
(Araujo et al., 2021)	x	x	x	x	x	x	x			x																	
(Arvanitis and Symeonaki,2020)	x	x	x	x	x					x																	
(Bešić et al., 2021)	x	x	x	x	x		x	x		x																	
(Debauche et al., 2022)	x	x	x					x	x			x															
(Diego and Leticia, 2022)	x	x	x	x	x	x	x																				
(Eastwood et al., 2021)	x	x	x	x	x		x	x	x			x															
(Erdogan, 2022)	x	x	x	x		x																					
(Fedotova et al., 2021)	x	x	x	x	x	x	x	x																			
(Ferrag et al., 2022)	x		x	x		x		x	x					x													
(Gonzalez-Salazar, 2020)	x	x	x	x	x	x																					
(Heinz et al., 2021)	x	x	x	x																							
(Illham et al., 2022)	x	x	x	x	x	x	x	x																			
(Ismael et al., 2022)	x																										
(Klerkx et al. 2019)	x	x	x	x			x		x		x				x					x					x	x	
(Kumar et al., 2021)																x					x						
(Lezoche et al., 2020)	x	x	x	x			l	x																			
(Lioutas and Charatsari, 2021)	x	x			x		x																				
(Liu et al., 2021)	x		x					x																			
(Martinho et al., 2022)	x	x			x				x				x														
(Michele et al., 2022)	x	x			x		x																				
(Mohamed et al., 2021)									x					x					x								
(Mohd et al., 2022)	x	x	x	x																							

(Monteleone et al., 2020)	x	x	x	x	x				x																		
(Nadezhda and Dmitry, 2022)	x	x	x																								
(Nugun et al., 2021)	x	x	x		x																						
(Ozdogan et al., 2017)	x		x			x		x																			
(Polyakov, 2021)	x	x	x	x	x				x																		
(Rose et al., 2021)	x	x	x	x	x	x	x																				
(Samson et al., 2021)	x	x		x	x		x																				
(Silva et al., 2020)	x	x	x	x	x	x		x																x			
(Solodovnik et al., 2021)	x	x	x	x	x	x		x																			
(Sponchioni et al., 2019)	x	x		x																							
(Vincenzo et al., 2022)						x											x					x	x				
(Widiyanti et al., 2022)	x	x	x	x	x	x																					
(Zhai et al., 2020)	x	x	x	x		x	x	x	x									x									

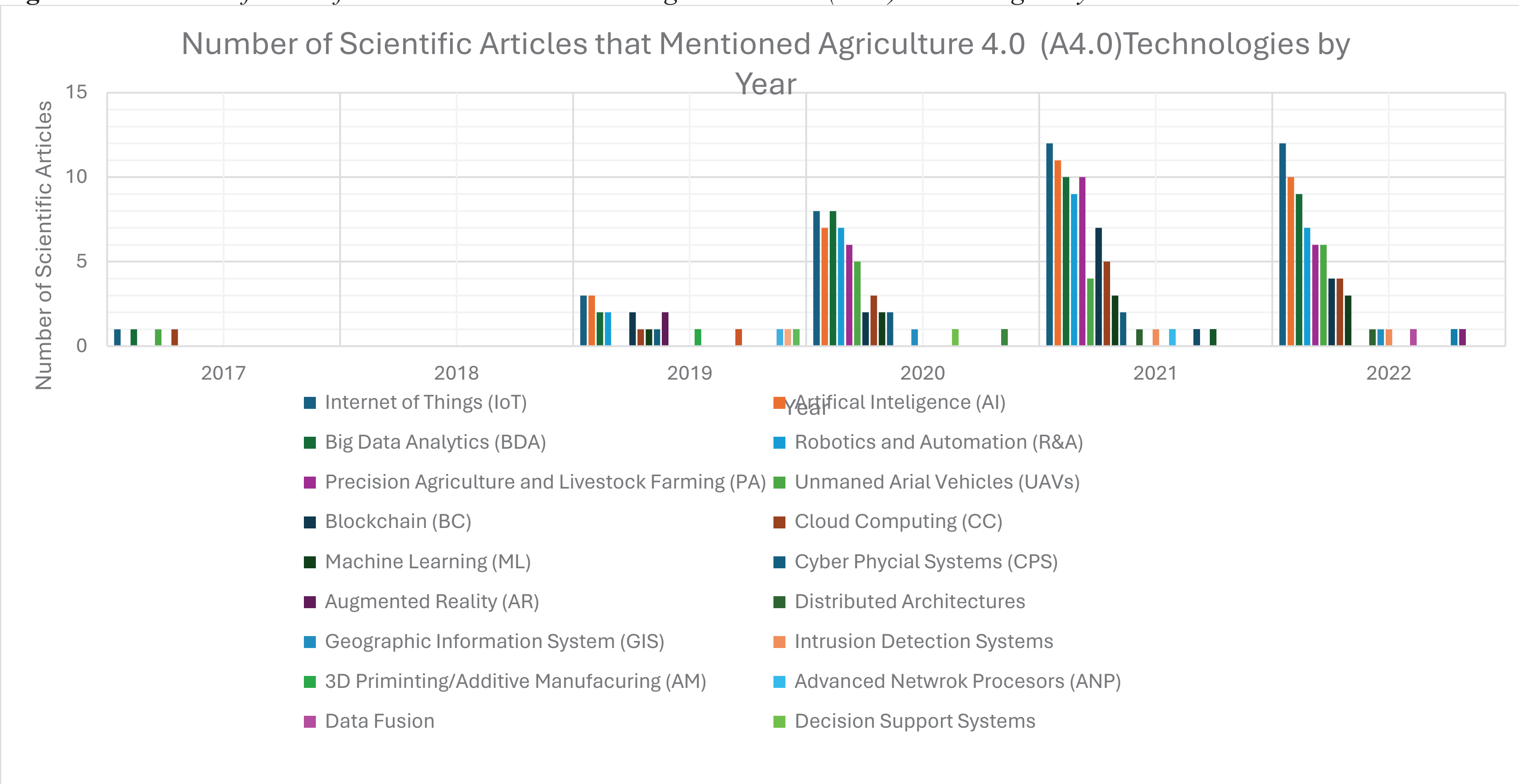
Appendix M

Figure 24: *Number of Scientific Articles that Mentioned Industry 4.0 (I4.0) Technologies by Year*



Appendix N

Figure 25: *Number of Scientific Articles that Mentioned Agriculture 4.0 (A4.0) Technologies by Year*



Appendix O

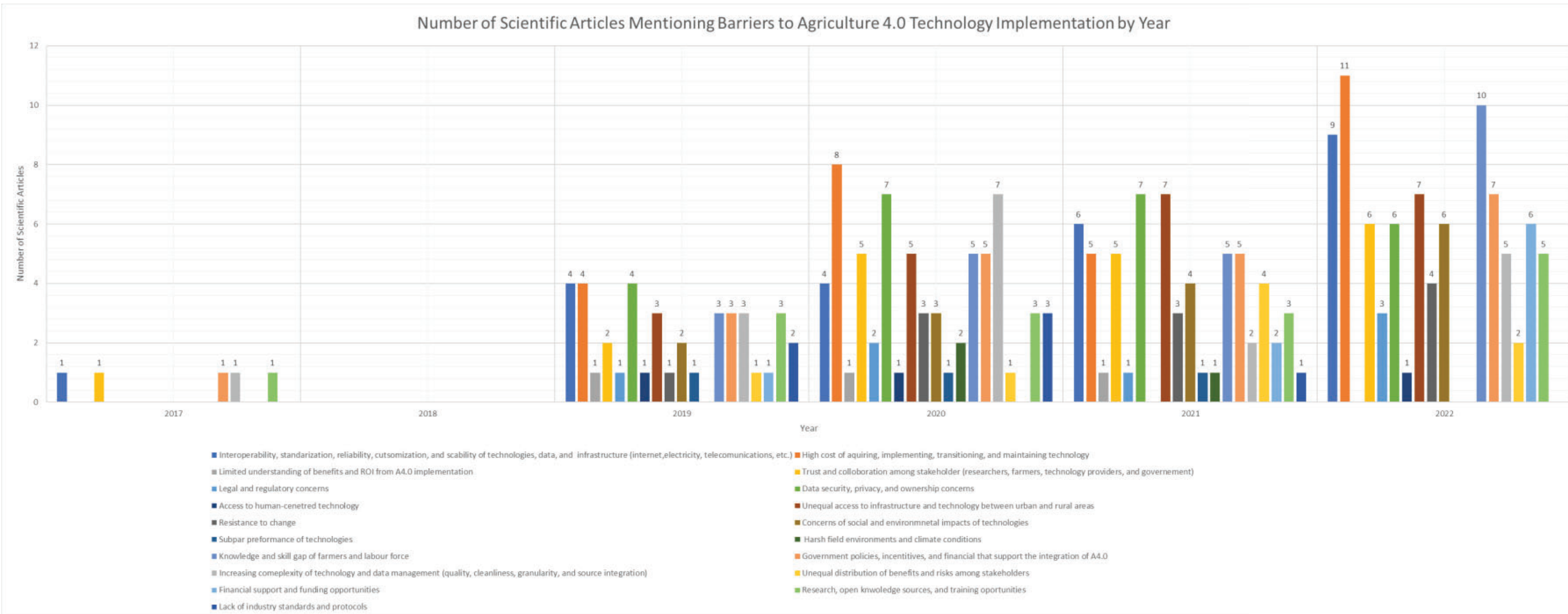
Table 7: *Systematic Literature Review (SLR) of the Barrier to Agriculture 4.0 (A4.0) Core Technology Implementation*

Author	Interoperability, standardization, reliability, customization, and scalability of technologies, data, and infrastructure (internet, electricity, telecommunications, etc.)	High cost of acquiring, implementing, transitioning, and maintaining technology	Limited understanding of benefits and ROI from A4.0 implementation	Trust and collaboration among stakeholder (researchers, farmers, technology providers, and government)	Legal and regulatory concerns	Data security, privacy, and ownership concerns	Access to human-centred technology	Unequal access to infrastructure and technology between urban and rural areas	Resistance to change	Concerns of social and environmental impacts of technologies	Subpar performance of technologies	Harsh field environments and climate conditions	Knowledge and skill gap of farmers and labour force	Government policies, incentives, and financial that support the integration of A4.0	Increasing complexity of technology and data management (quality, cleanliness, granularity, and source integration)	Unequal distribution of benefits and risks among stakeholders	Financial support and funding opportunities	Research, open knowledge sources, and training opportunities	Lack of industry standards and protocols
(Abbasi et al., 2022)	x	x		x			x		x				x	x	x			x	
(Aceto et al., 2019)	x	x		x	x	x	x	x			x				x			x	x
(Albiero et al., 2020)		x				x		x	x	x			x						
(Amaral et al., 2020)		x				x					x								x
(Araujo et al., 2021)	x	x				x					x	x			x				
(Arvanitis and Symeonaki,2020)	x	x										x		x	x				
(Bešić et al., 2021)		x	x													x		x	
(Debauche et al., 2022)	x	x		x		x												x	
(Diego and Leticia, 2022)	x	x								x			x					x	
(Eastwood et al., 2021)	x	x		x		x		x		x			x	x	x	x			
(Erdogan, 2022)		x						x					x					x	
(Fedotova et al., 2021)								x											
(Ferrag et al., 2022)		x				x							x		x				
(Ghadge et al., 2020)	x	x		x	x	x			x					x	x			x	
(Gonzalez-Salazar, 2020)								x					x		x			x	
(Ilaria et al. 2019)	x	x	x			x		x	x	x			x	x			x	x	
(Illham et al., 2022)	x	x			x			x		x			x	x			x	x	
(Ismael et al., 2022)	x	x			x			x	x	x			x				x		
(Klerkx et al. 2019)	x	x		x		x				x			x	x	x			x	
(Kumar et al., 2021)								x	x				x	x					x

(Liu et al., 2021)	x		x		x				x							
(Martinho et al., 2022)	x	x	x							x	x	x		x		
(Mohd et al., 2022)	x	x	x		x		x		x	x	x	x	x	x		
(Monteleone et al., 2020)		x	x		x	x	x		x	x	x	x	x			
(Nadezhda and Dmitry, 2022)	x		x		x		x	x	x	x	x		x	x		
(Nugun et al., 2021)			x		x		x	x		x	x		x	x	x	
(Ozdogan et al., 2017)	x		x								x	x			x	
(Polyakov, 2021)	x	x	x	x	x		x		x		x			x		
(Samson et al., 2021)	x		x		x		x	x		x					x	
(Silva et al., 2020)	x	x	x		x		x				x	x				
(Solodovnik et al., 2021)	x	x			x		x		x	x	x		x			
(Sponchioni et al., 2019)	x	x			x		x			x	x	x	x			x
(Vincenzo et al., 2022)	x	x		x	x		x	x		x	x			x		
(Widiyanti et al., 2022)		x	x		x		x		x		x	x				
(Zhai et al., 2020)		x	x		x		x		x	x	x	x			x	x

Appendix P

Figure 26: *Number of Scientific Articles that Mentioned Barriers to Agriculture 4.0 (A4.0) Technology Implementation by Year*



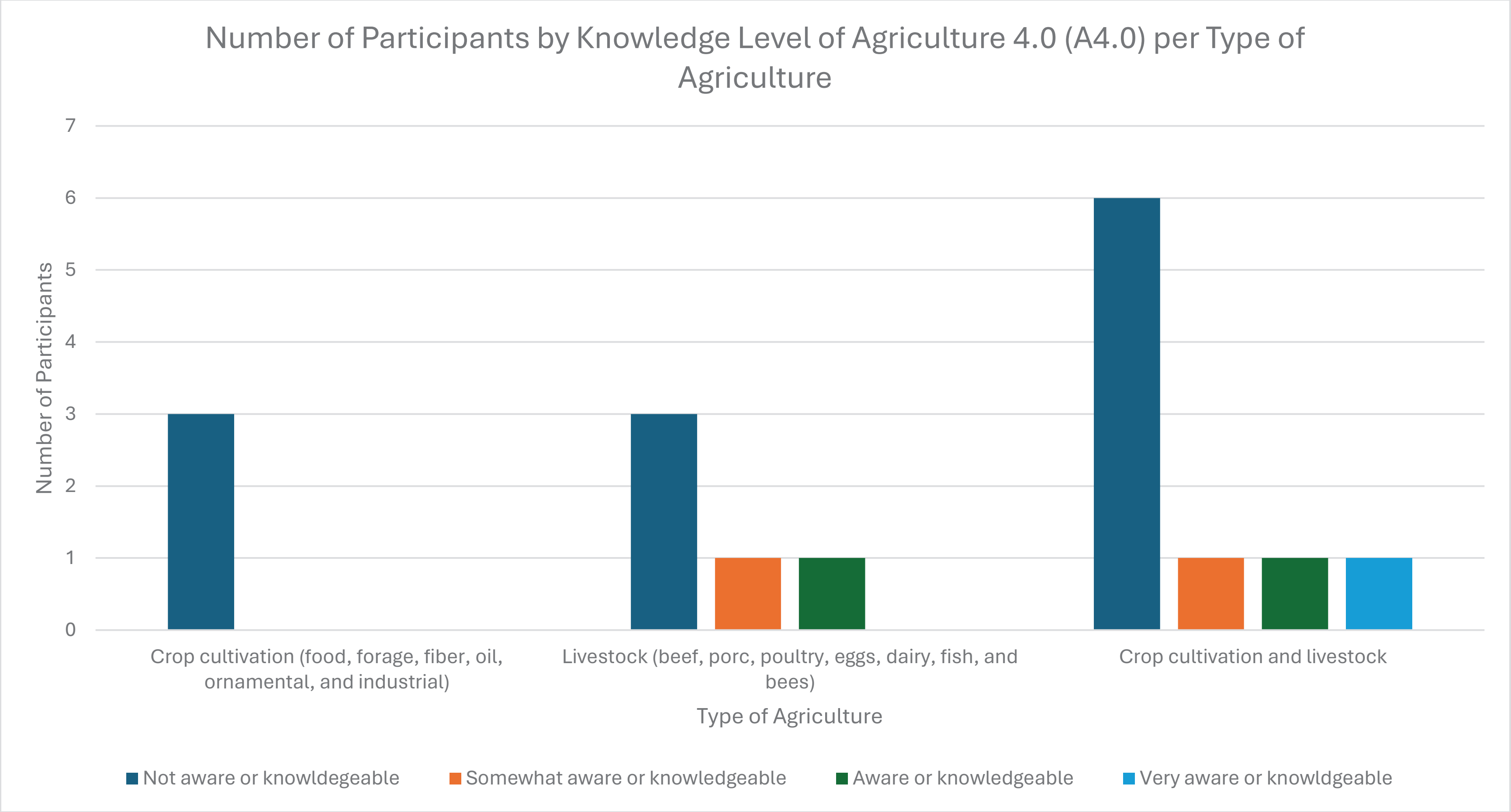
Appendix Q

Figure 27: *Response Rate per Question of Online Survey*

Question	Core Technology	Response Rate	Question	Core Technology	Response Rate
1		100%	27	AI	53%
2		100%	27	CC	53%
3		24%	27	BDA	53%
4		12%	27	IoT	59%
5		24%	28	AI	47%
6		88%	28	CC	53%
7		29%	28	BDA	59%
8		76%	28	IoT	65%
9		88%	29	AI	59%
10		29%	29	CC	65%
11		71%	29	BDA	65%
12		76%	29	IoT	71%
13		100%	30	AI	59%
14		100%	30	CC	65%
15		100%	30	BDA	65%
16		100%	30	IoT	71%
17		71%	31	AI	53%
18		100%	31	CC	59%
19		71%	31	BDA	59%
20		100%	31	IoT	59%
21		71%	32		18%
22		47%	33		82%
23		100%	33	AI	65%
24		71%	33	CC	65%
25	AI	29%	33	BDA	71%
25	CC	29%	33	IoT	65%
25	BDA	53%	34		88%
25	IoT	35%	35		100%
26	AI	35%	36		100%
26	CC	41%	37		94%
26	BDA	41%	38		18%
26	IoT	35%	39		59%

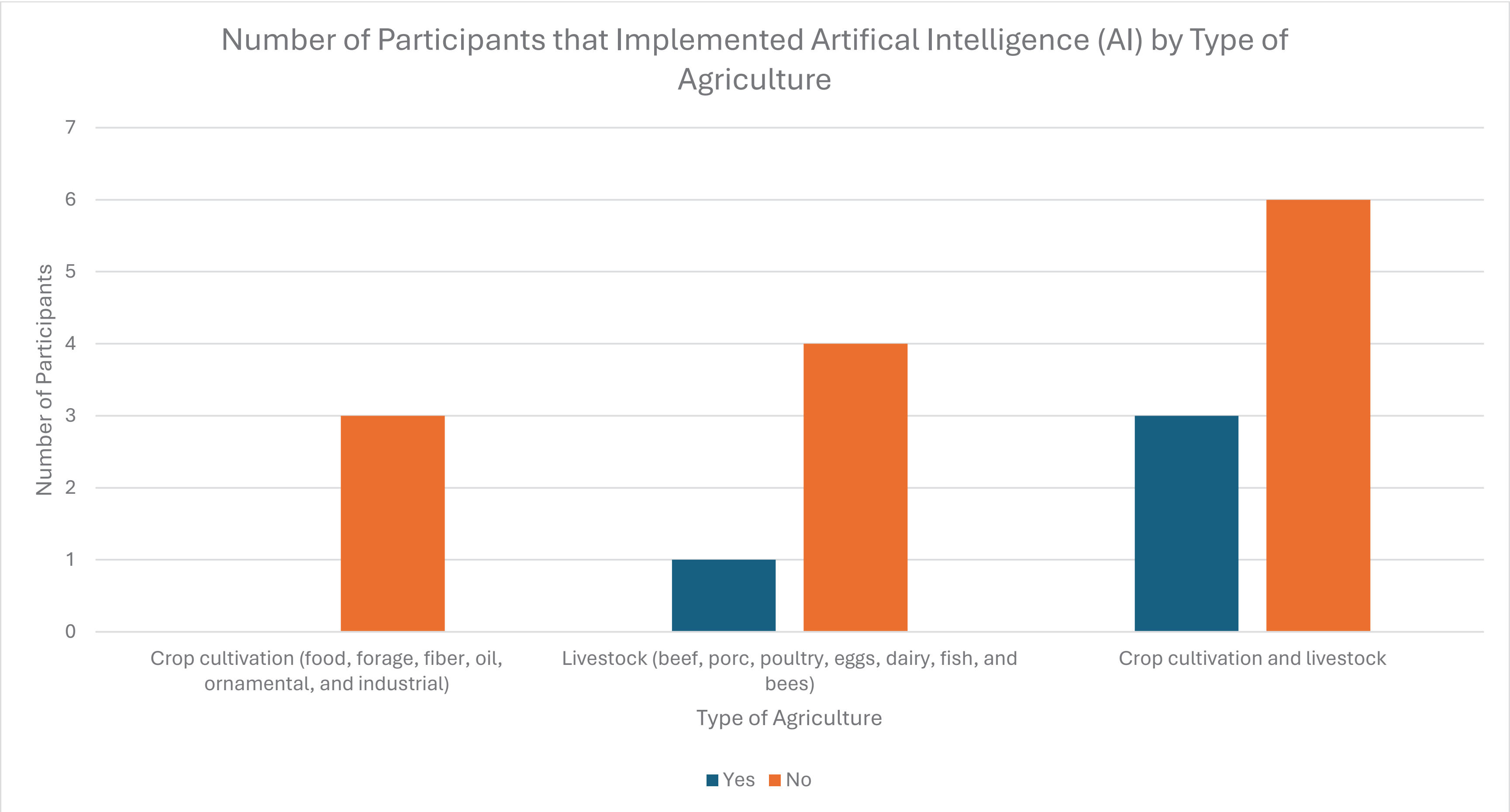
Appendix R

Figure 28: *Number of Participants by Knowledge Level of Agriculture 4.0 (A4.0) per Type of Agriculture*



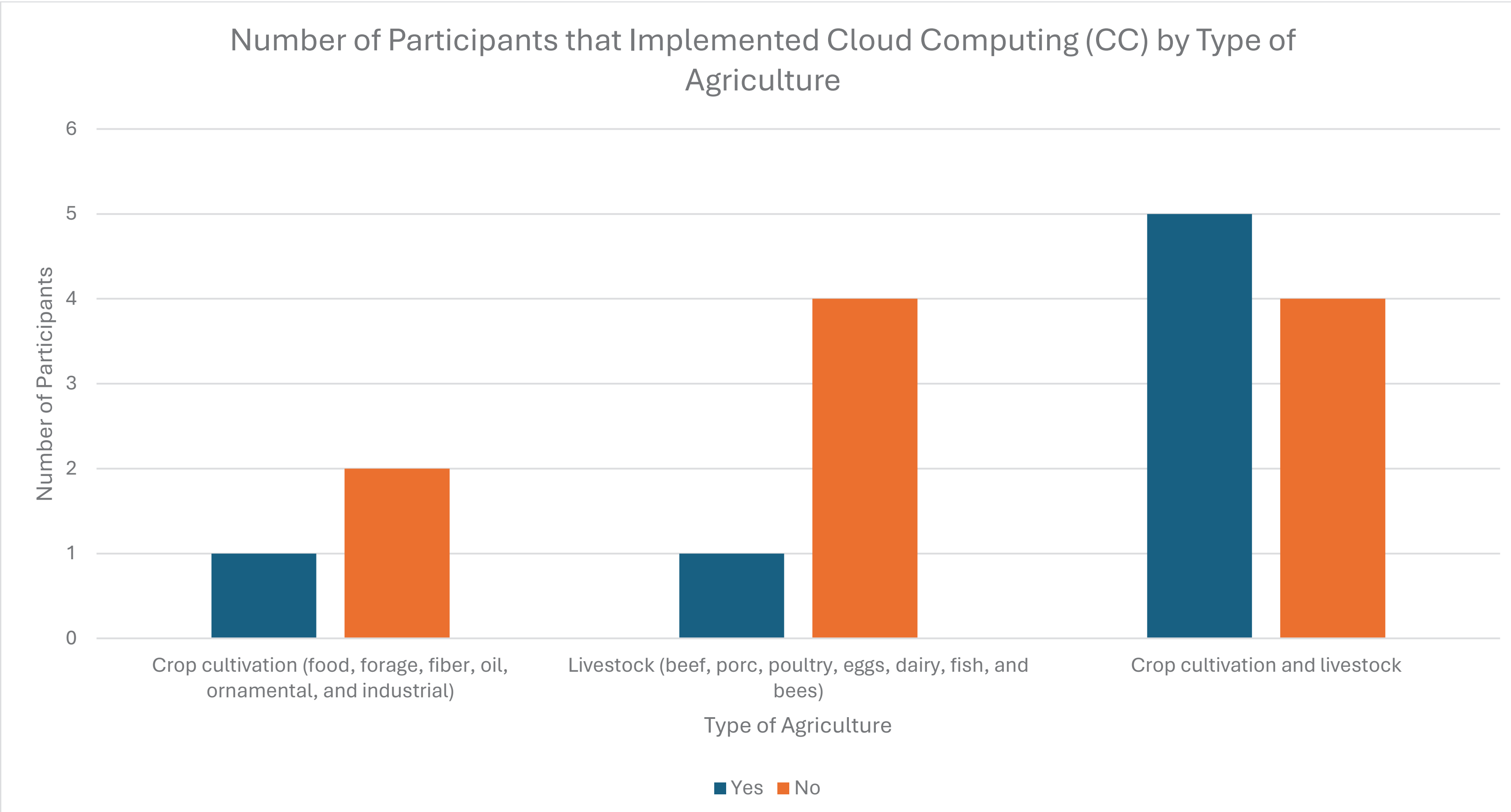
Appendix S

Figure 29: *Number of Participants that Implemented Artificial Intelligence (AI) by Type of Agriculture*



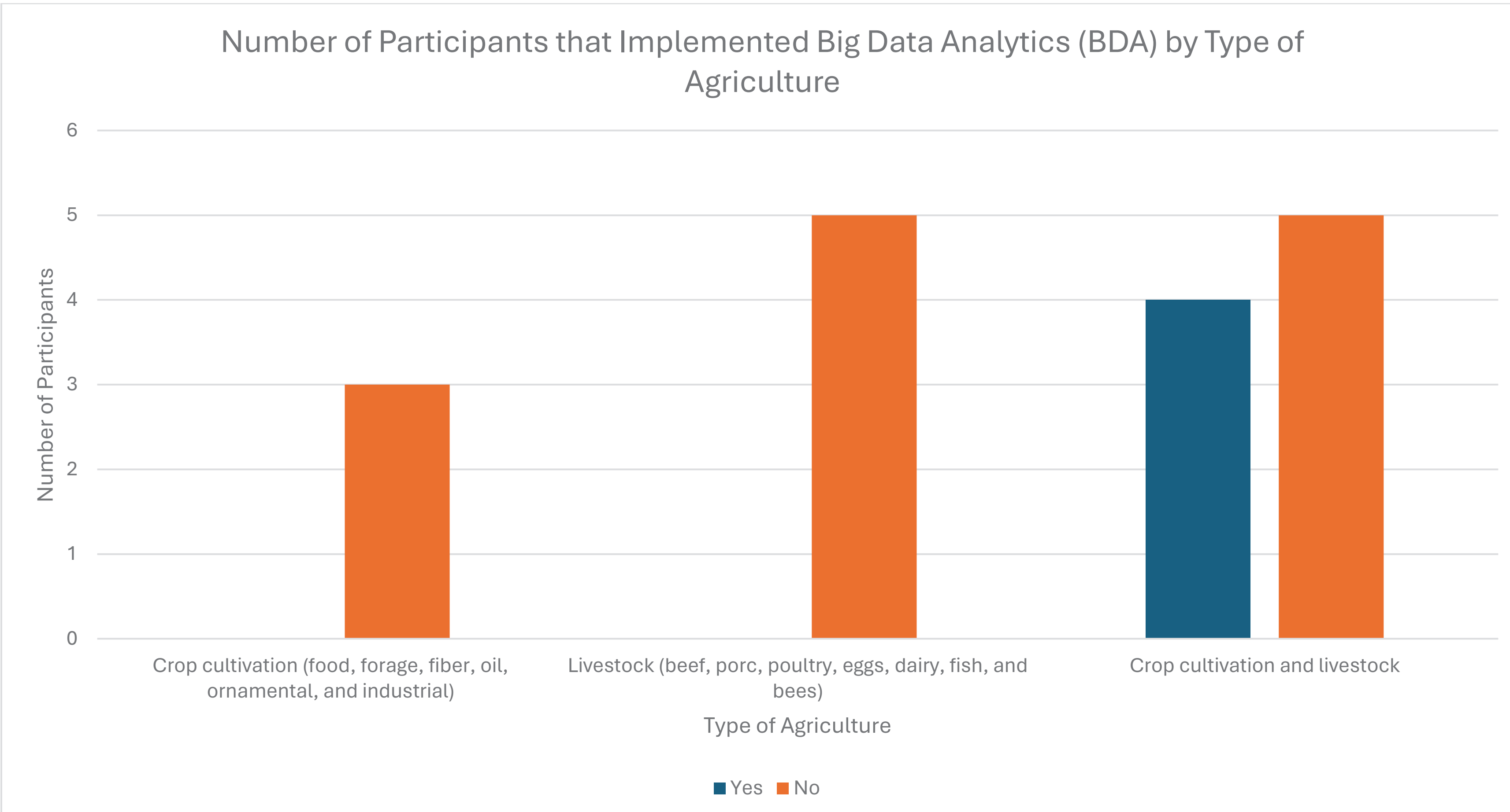
Appendix T

Figure 30: *Number of Participants that Implemented Cloud computing (CC) by Type of Agriculture*



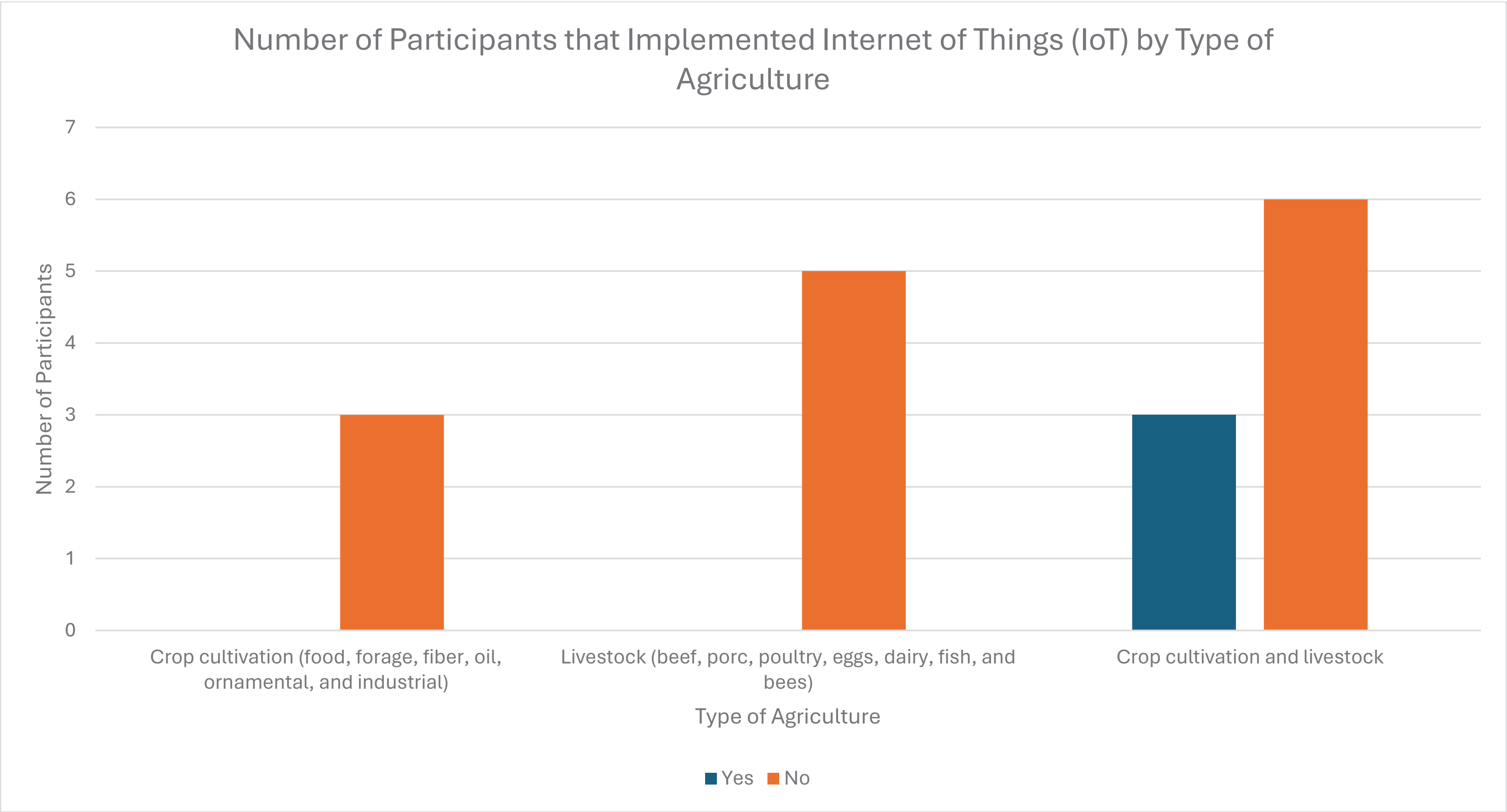
Appendix U

Figure 31: *Number of Participants that Implemented Big Data Analytics (BDA) by Type of Agriculture*



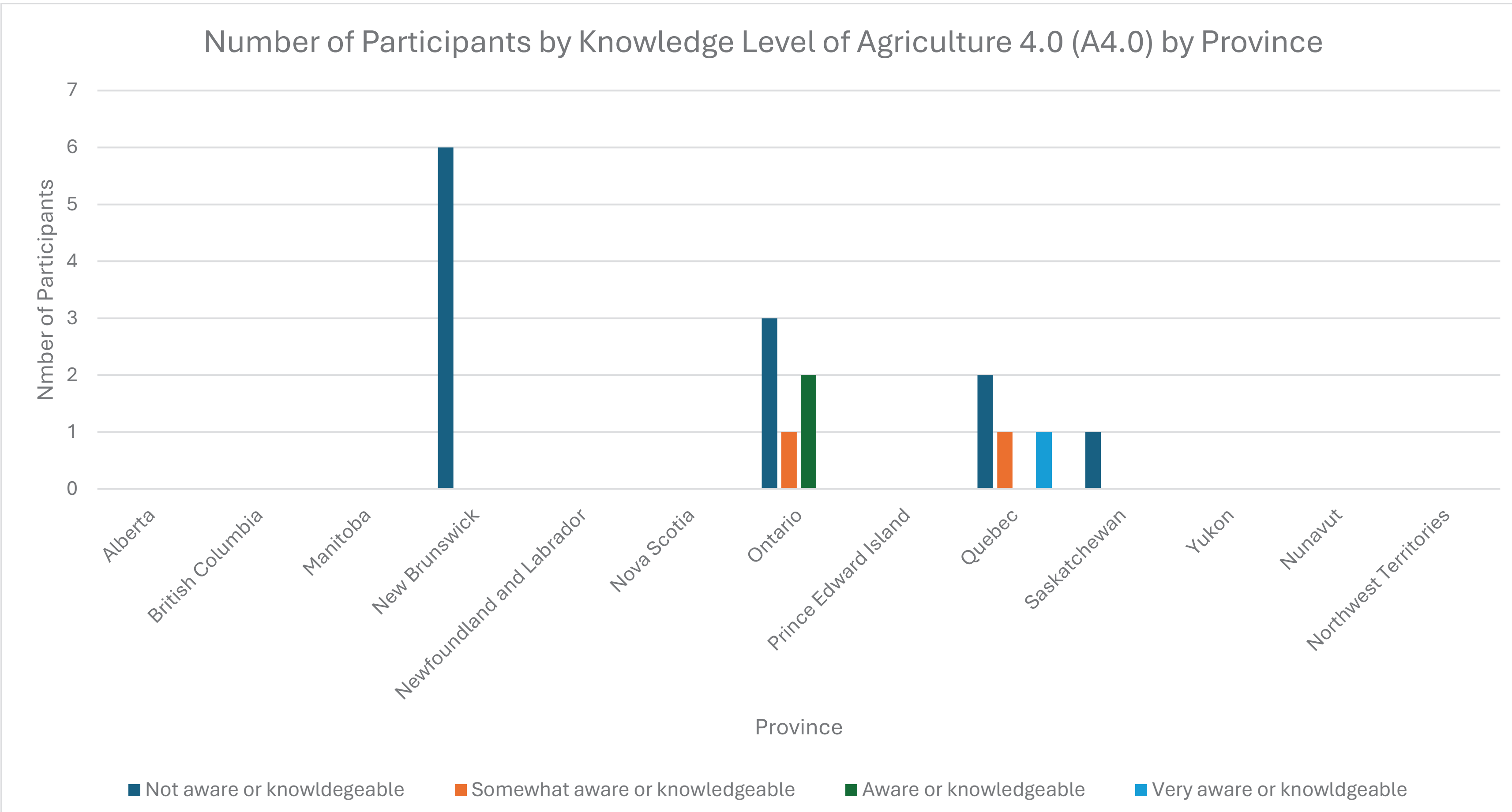
Appendix V

Figure 32: *Number of Participants that Implemented Internet of Things (IoT) by Type of Agriculture*



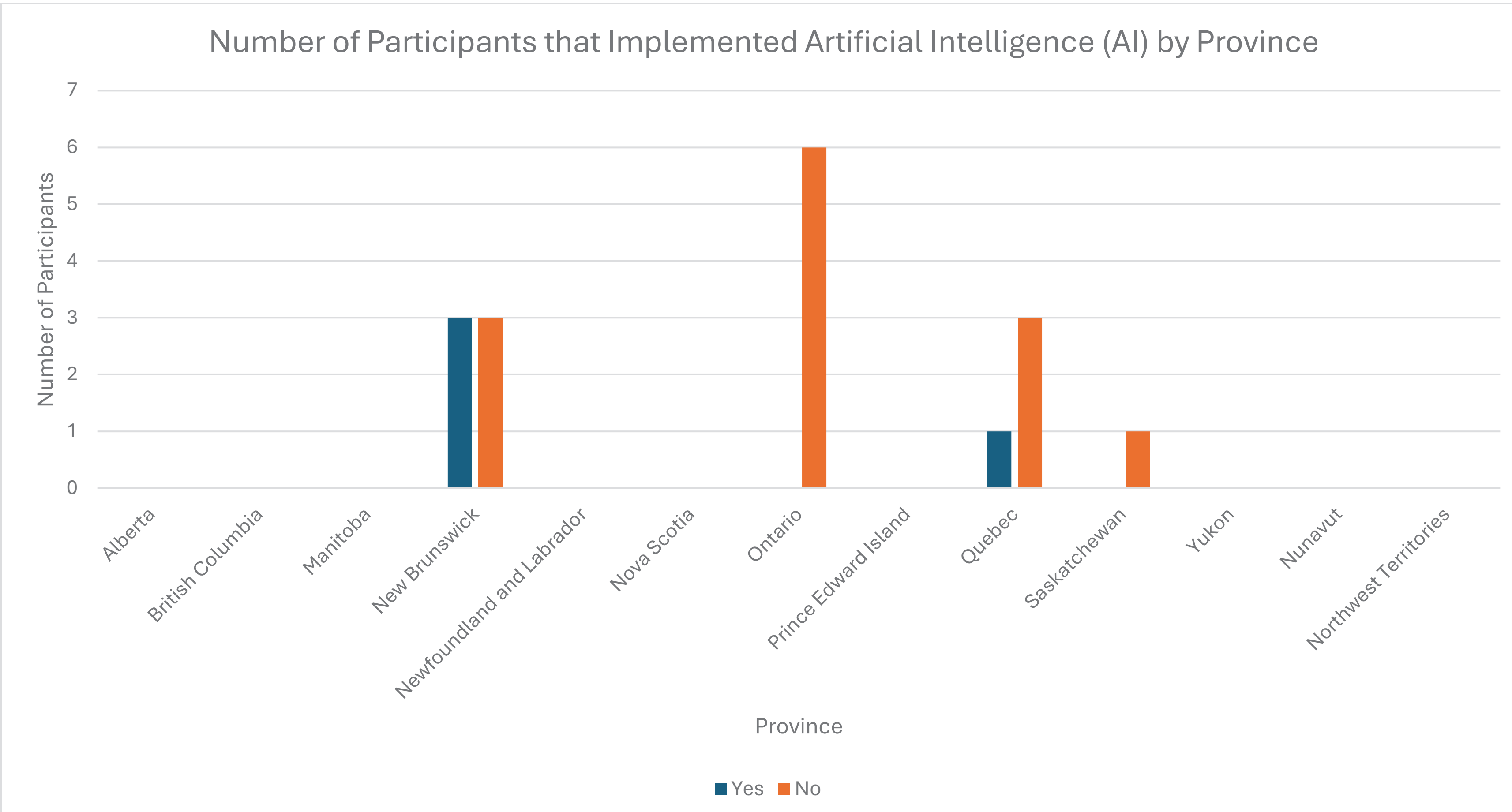
Appendix W

Figure 33: *Number of Participants by Knowledge Level of Agriculture 4.0 (A4.0) by Province*



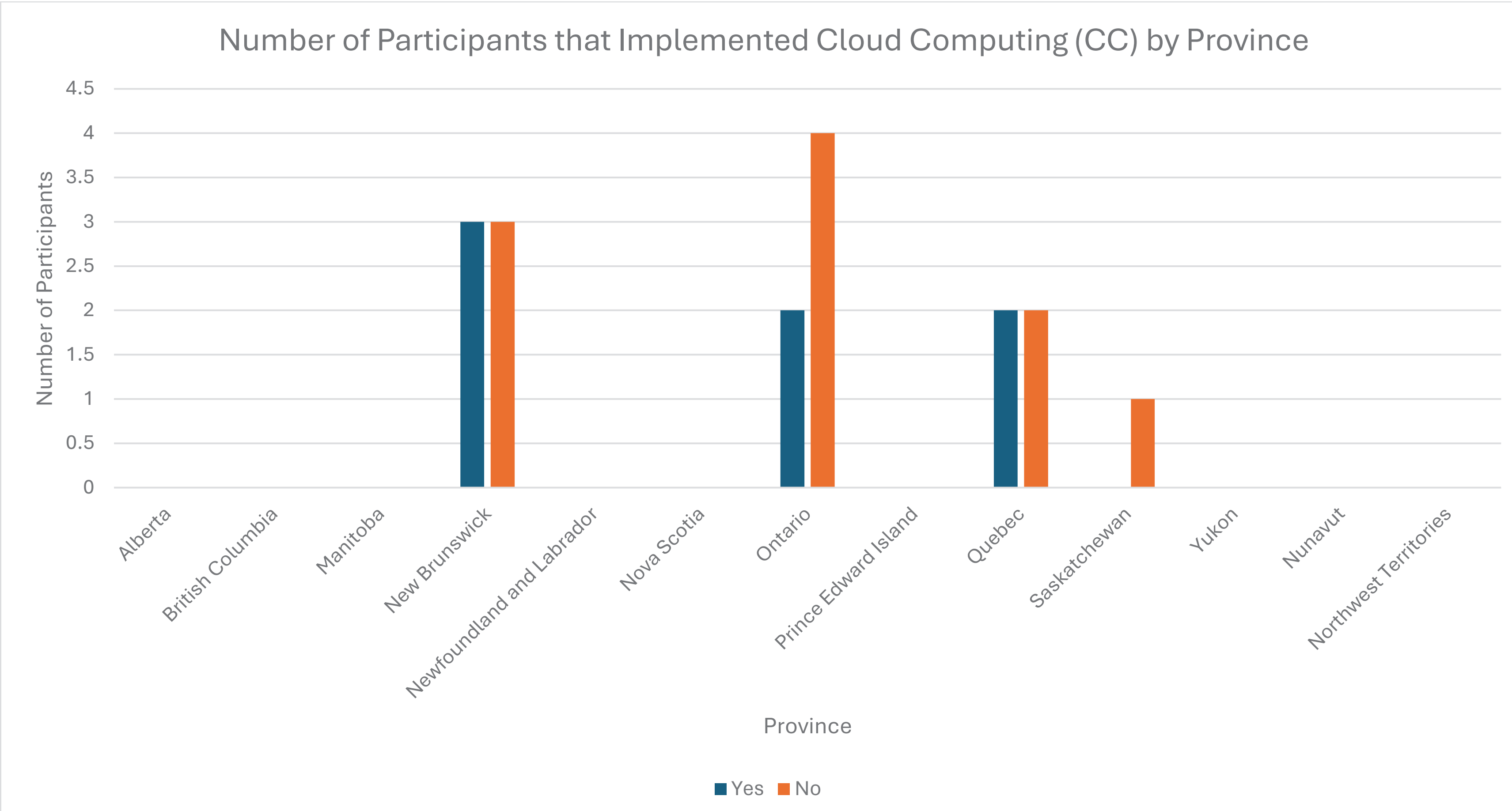
Appendix X

Figure 34: *Number of Participants that Implemented Artificial Intelligence (AI) by Province*



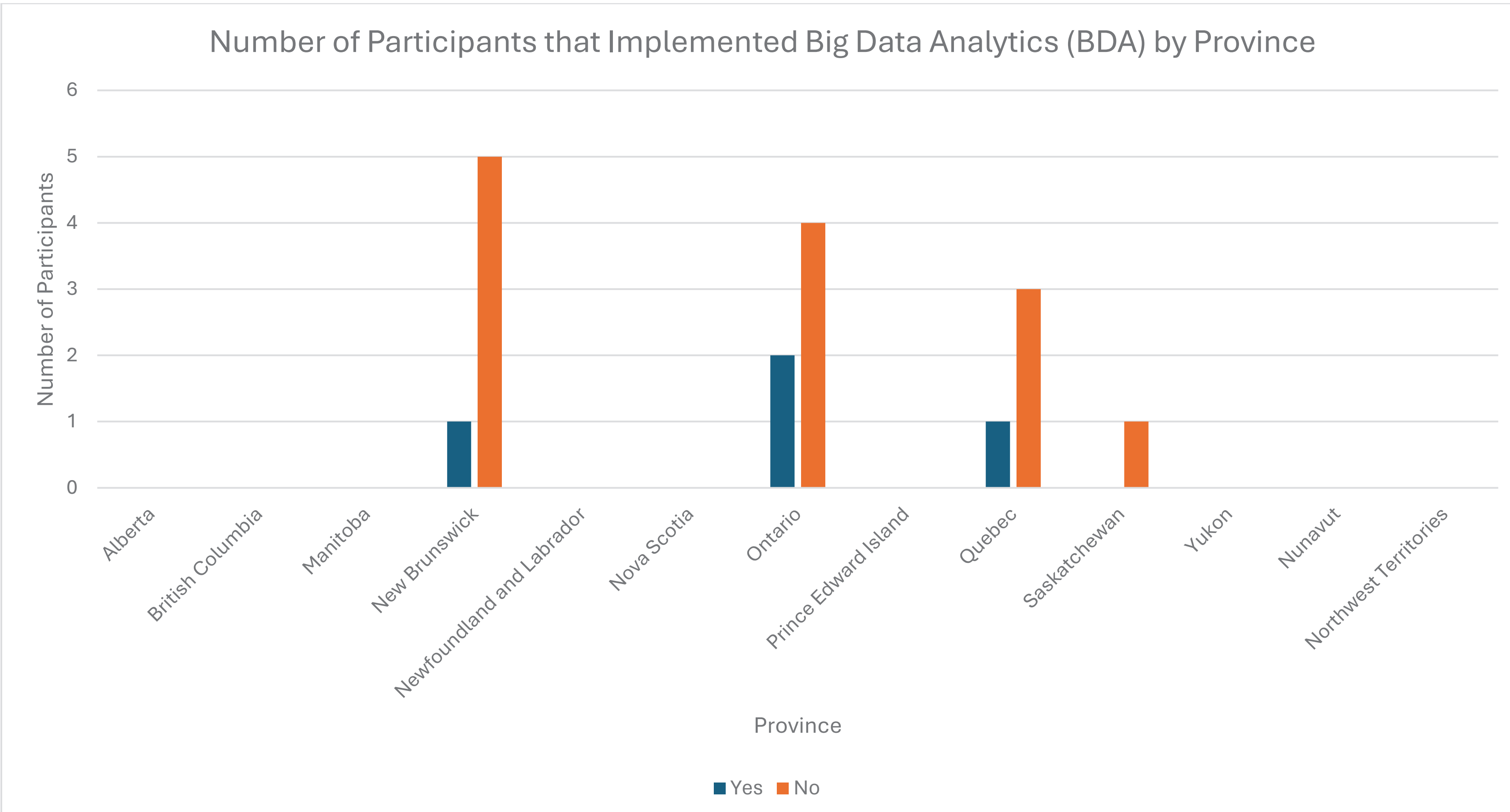
Appendix Y

Figure 35: *Number of Participants that Implemented Cloud Computing (CC) by Province*



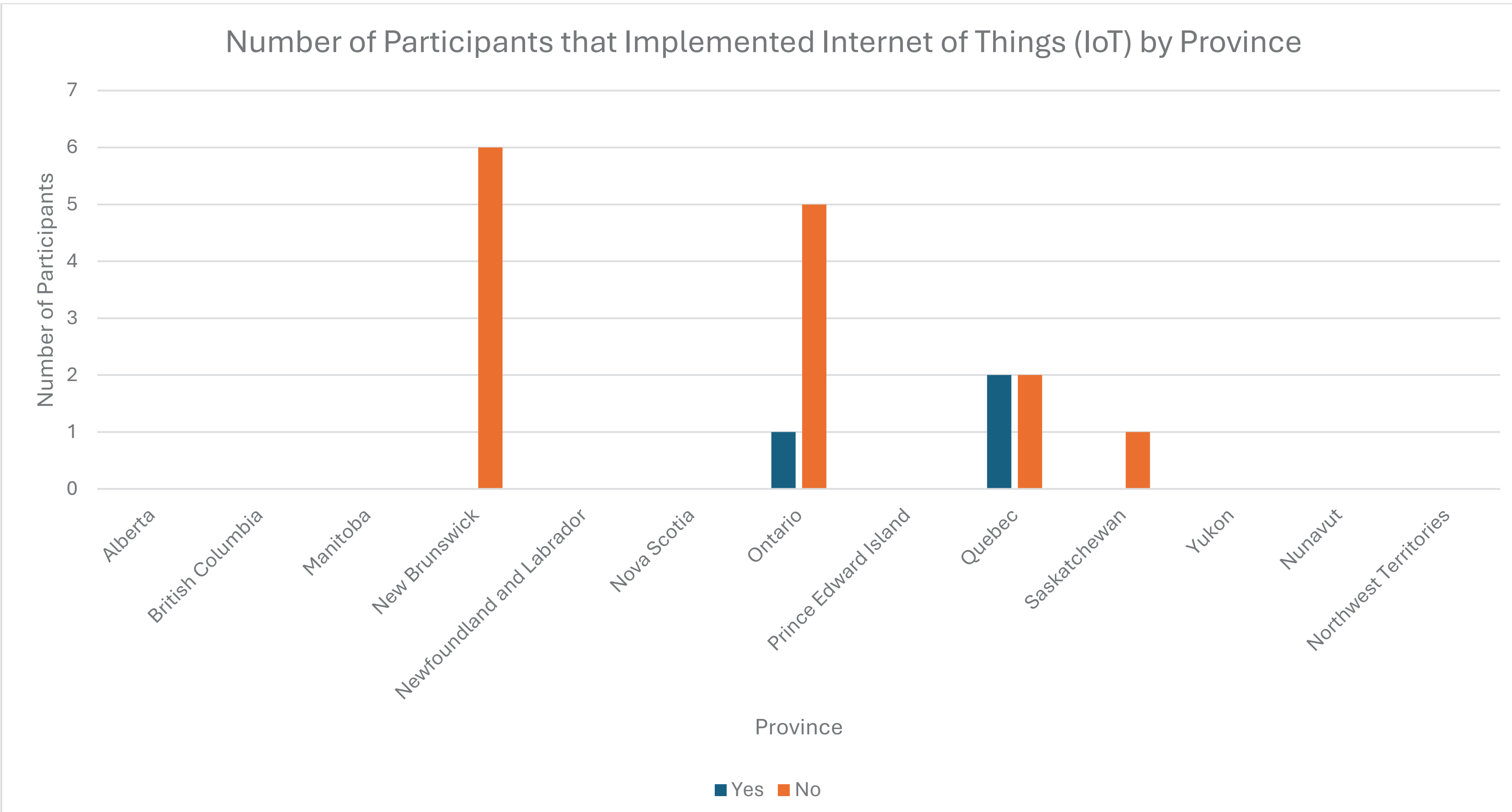
Appendix Z

Figure 36: *Number of Participants that Implemented Big Data Analytics (BDA) by Province*



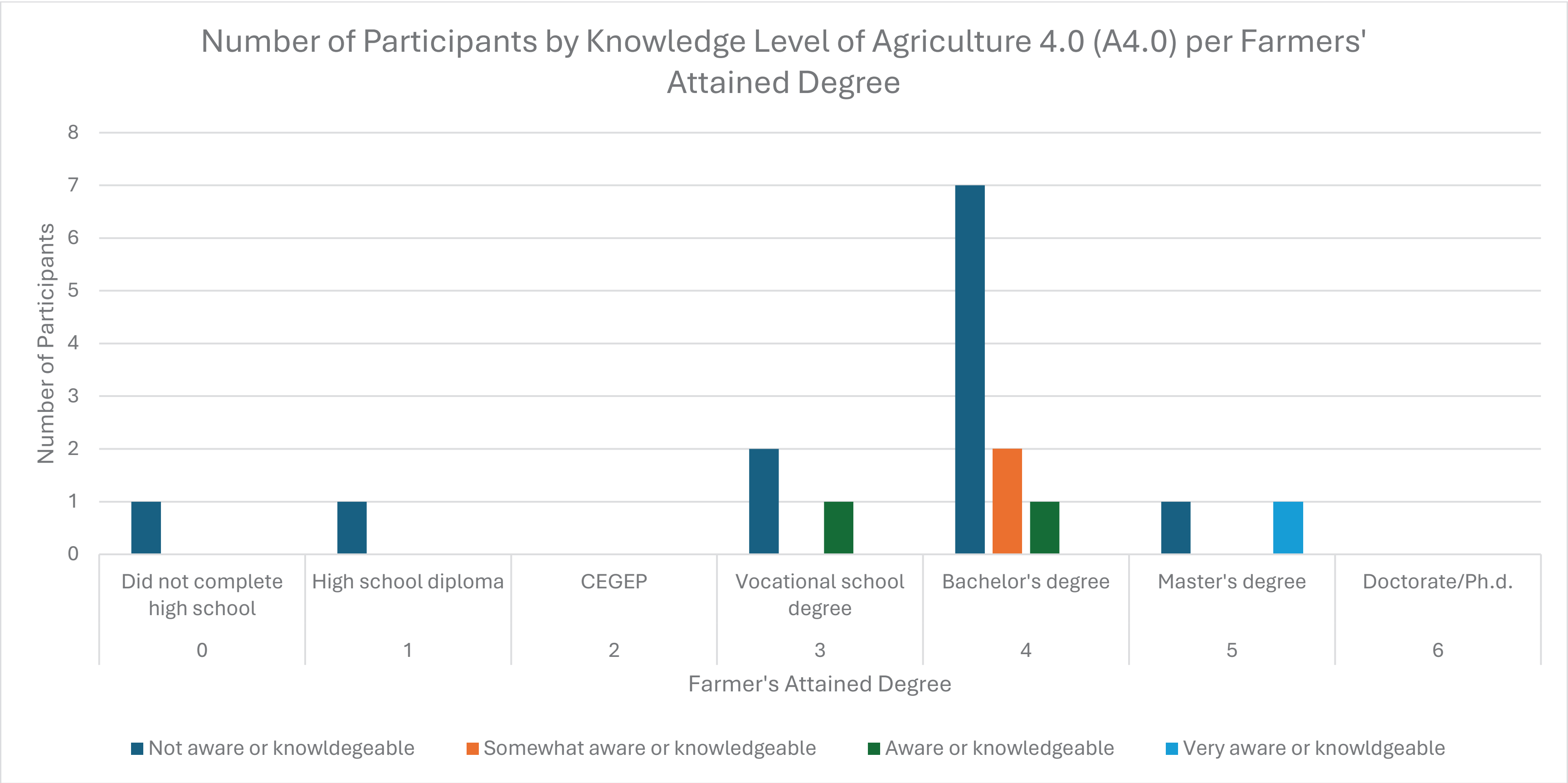
Appendix AA

Figure 37: *Number of Participants that Implemented Internet of Things (IoT) by Province*



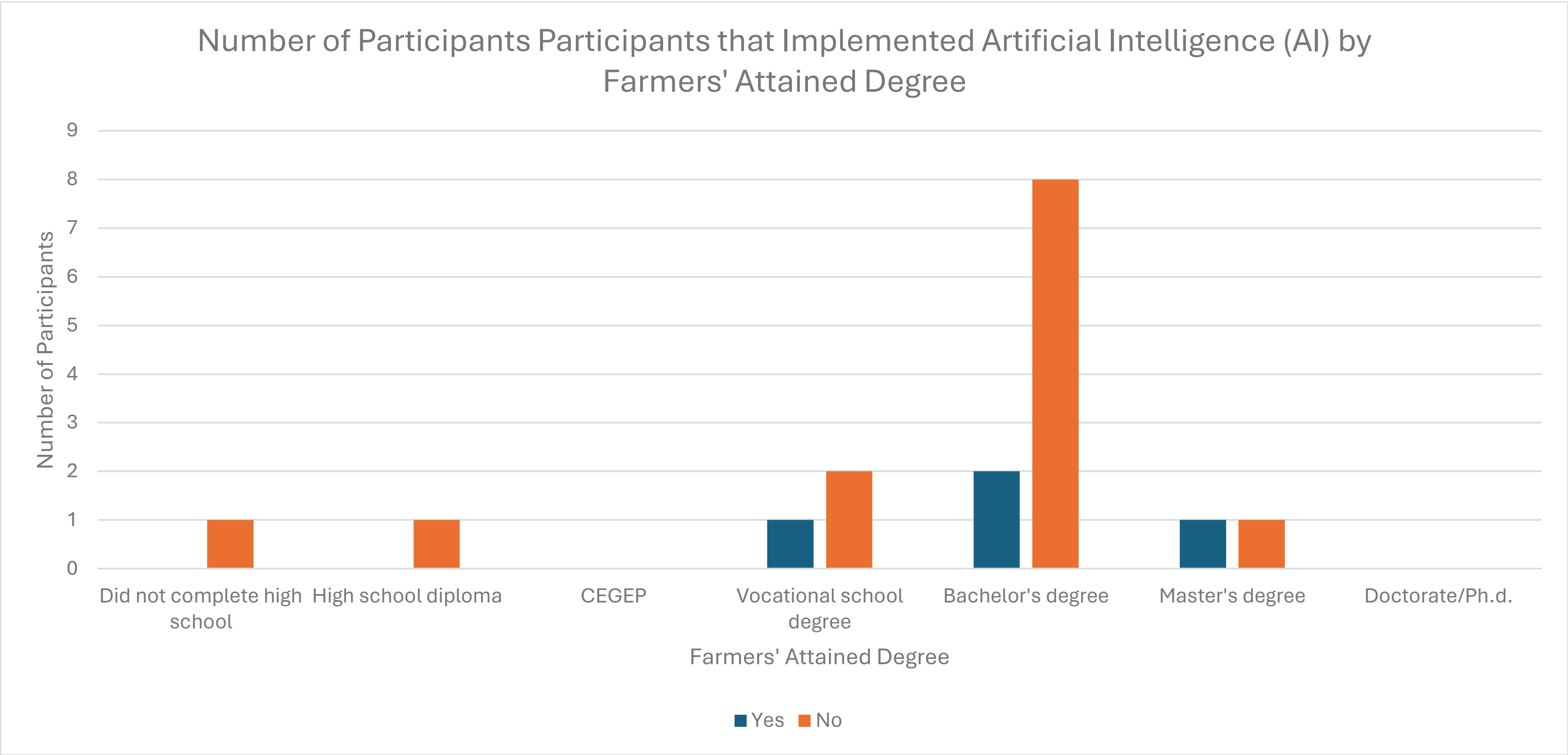
Appendix AB

Figure 38: *Number of Participants by Knowledge Level of Agriculture 4.0(A4.0) per Farmers' Attained Degree*



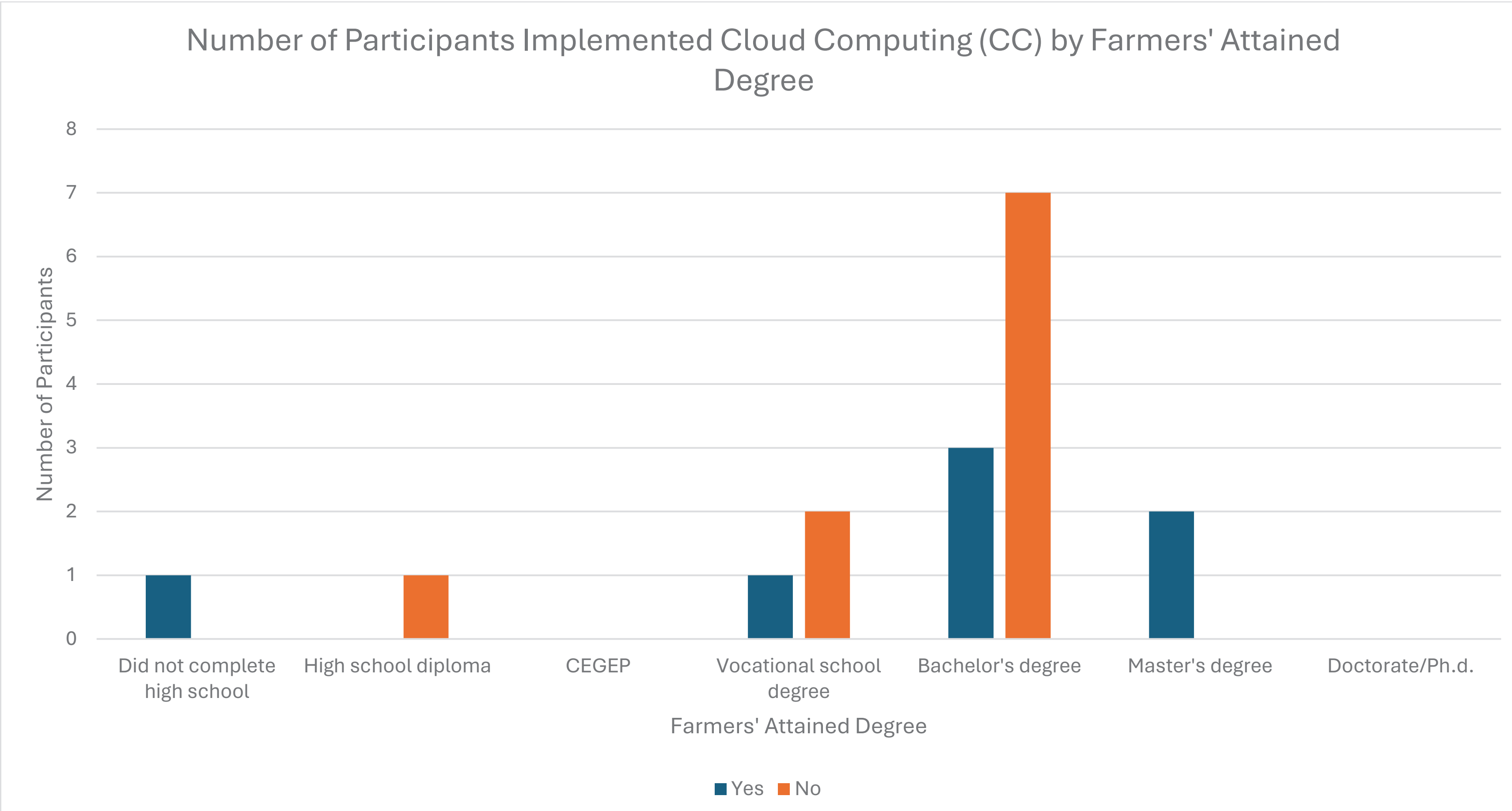
Appendix AC

Figure 39: *Number of Participants that Implemented Artificial Intelligence (AI) by Farmers' Attained Degree*



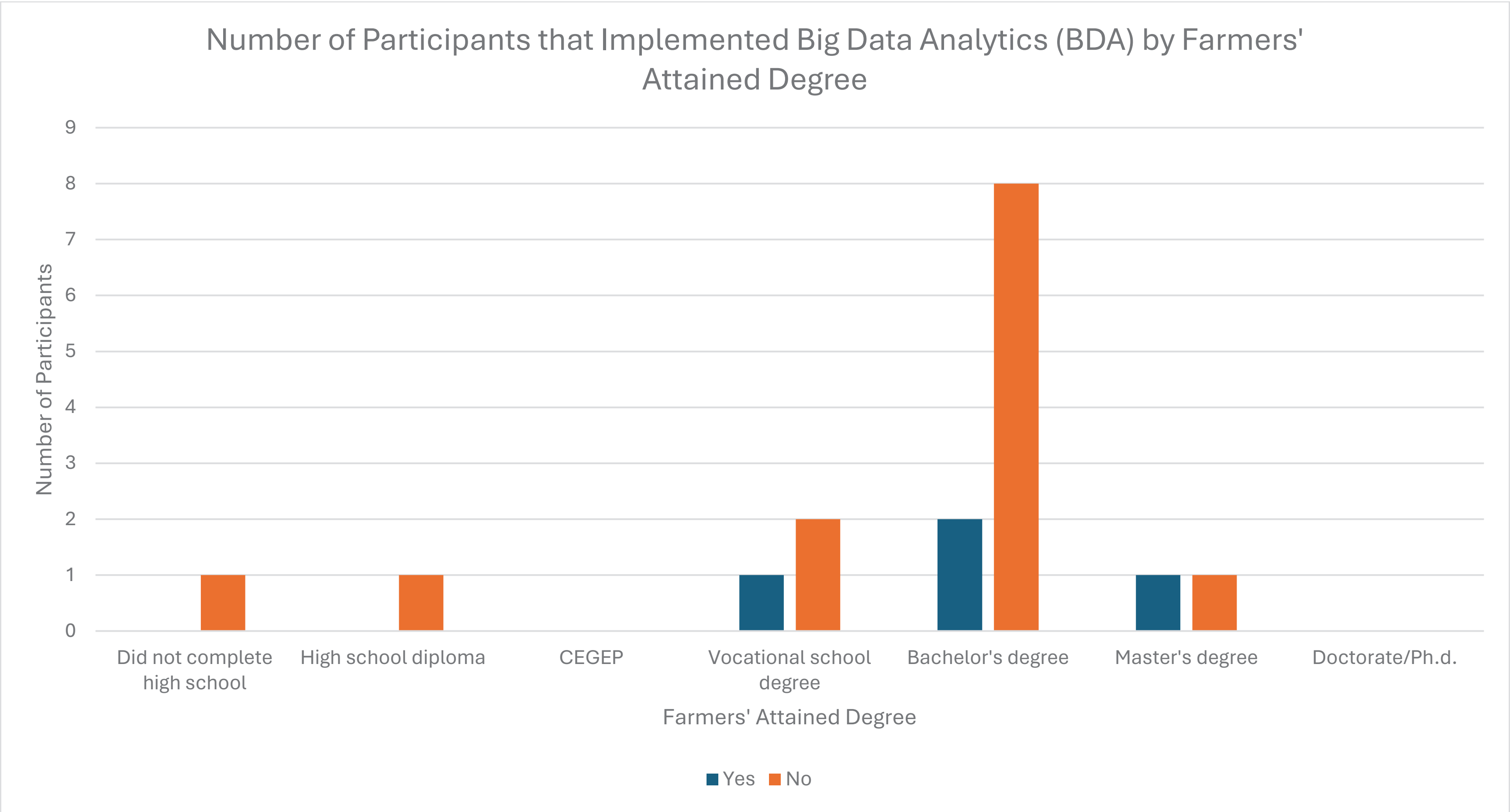
Appendix AD

Figure 40: *Number of Participants that Implemented Cloud Computing (CC) by Farmers' Attained Degree*



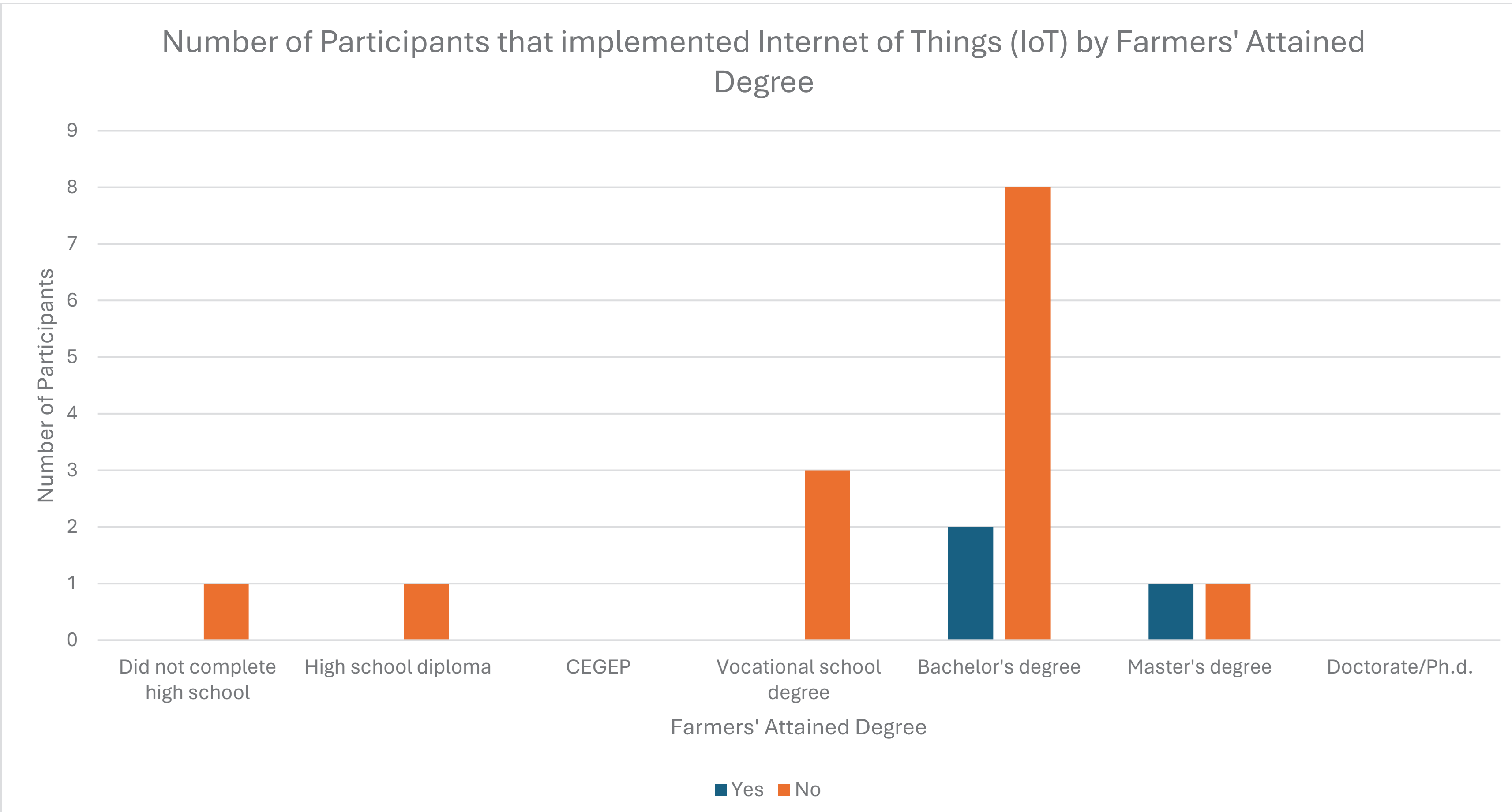
Appendix AE

Figure 41: *Number of Participants that Implemented Big Data Analytics (BDA) by Farmers' Attained Degree*



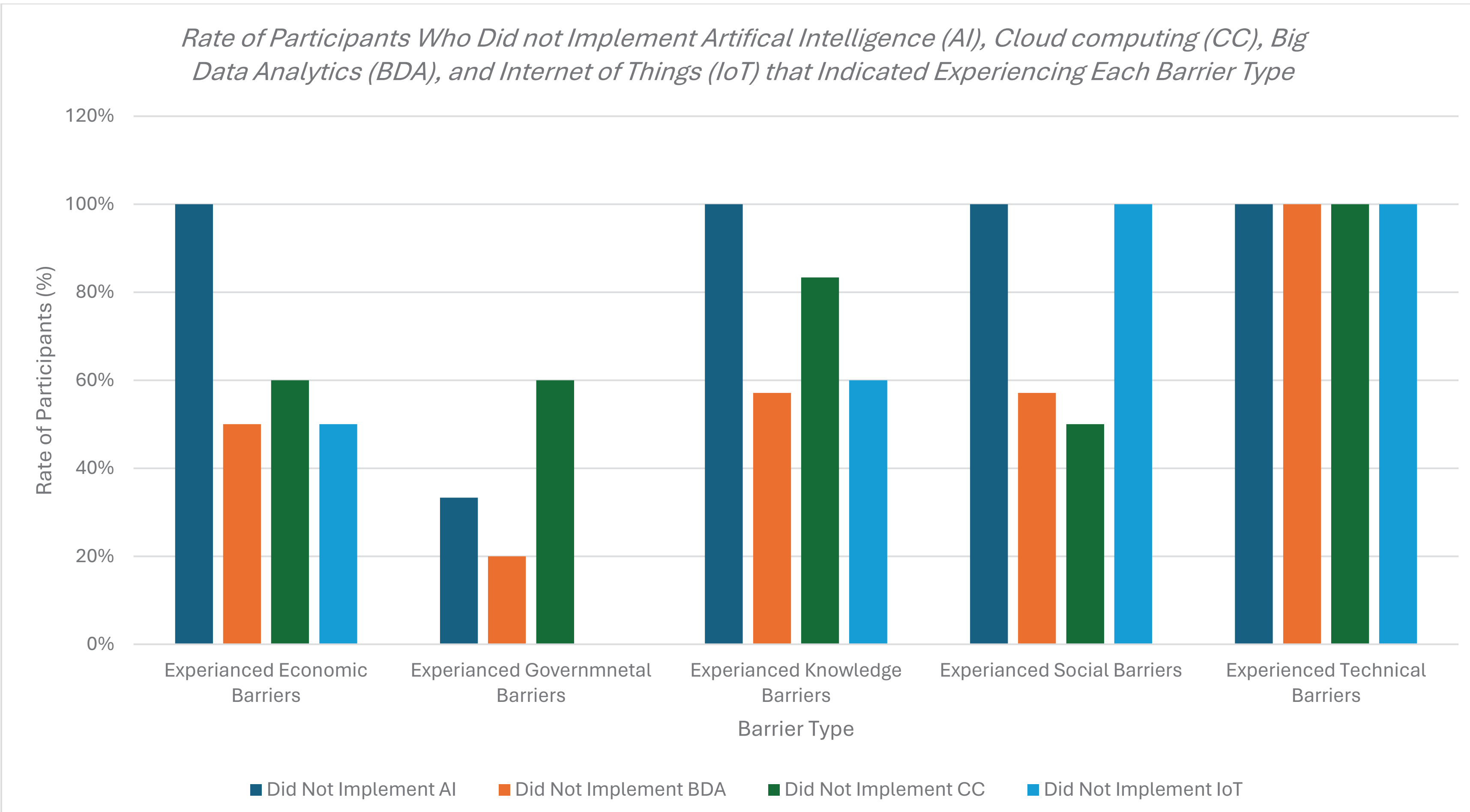
Appendix AF

Figure 42: *Number of Participants that implemented Internet of Things (IoT) by Farmers' Attained Degree*



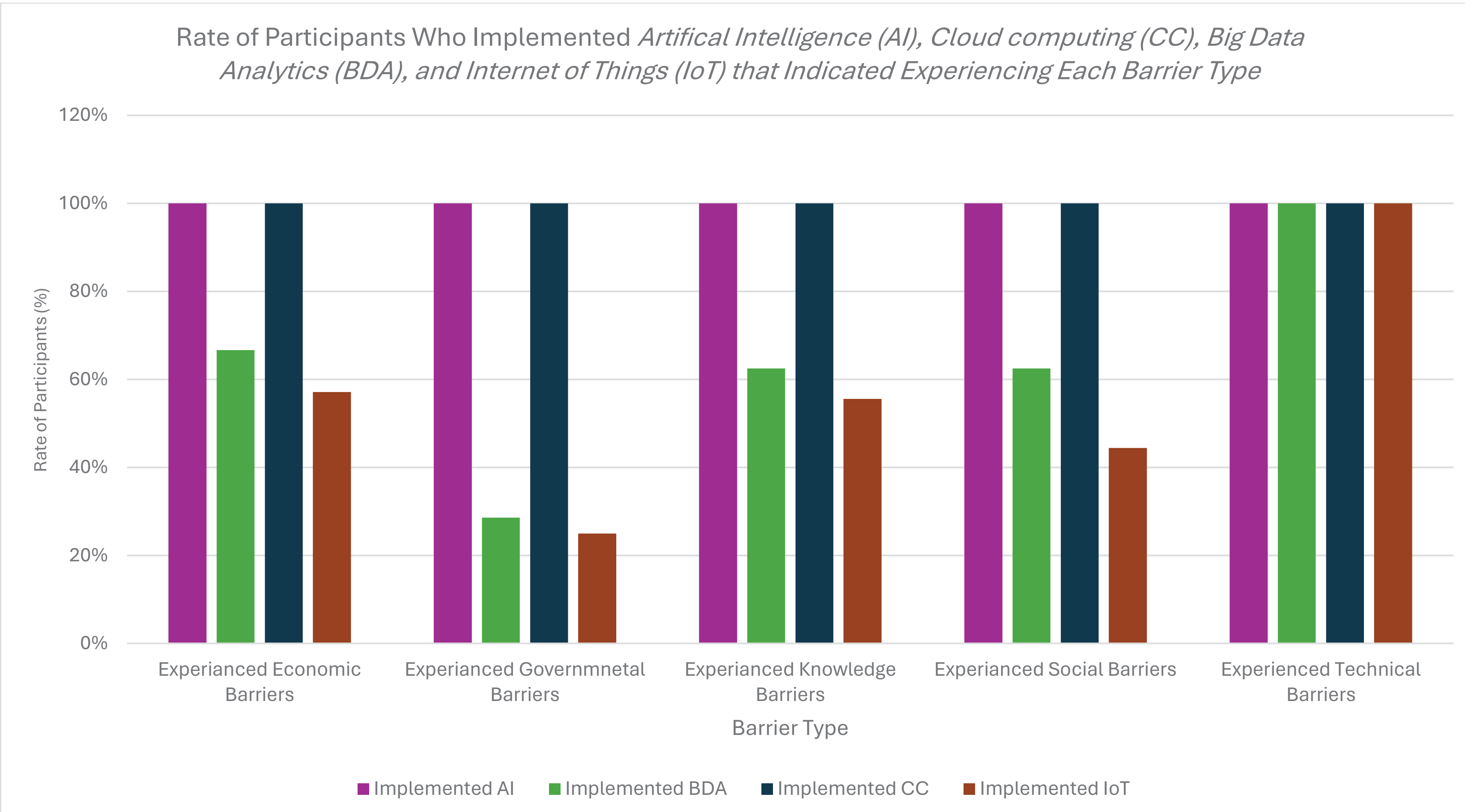
Appendix AG

Figure 43: *Rate of Participants Who Did Not Implement Artificial Intelligence (AI), Cloud Computing (CC), Big Data analytics (BDA), and Internet of Things (IoT) that Indicated Experiencing Each Barrier Type*



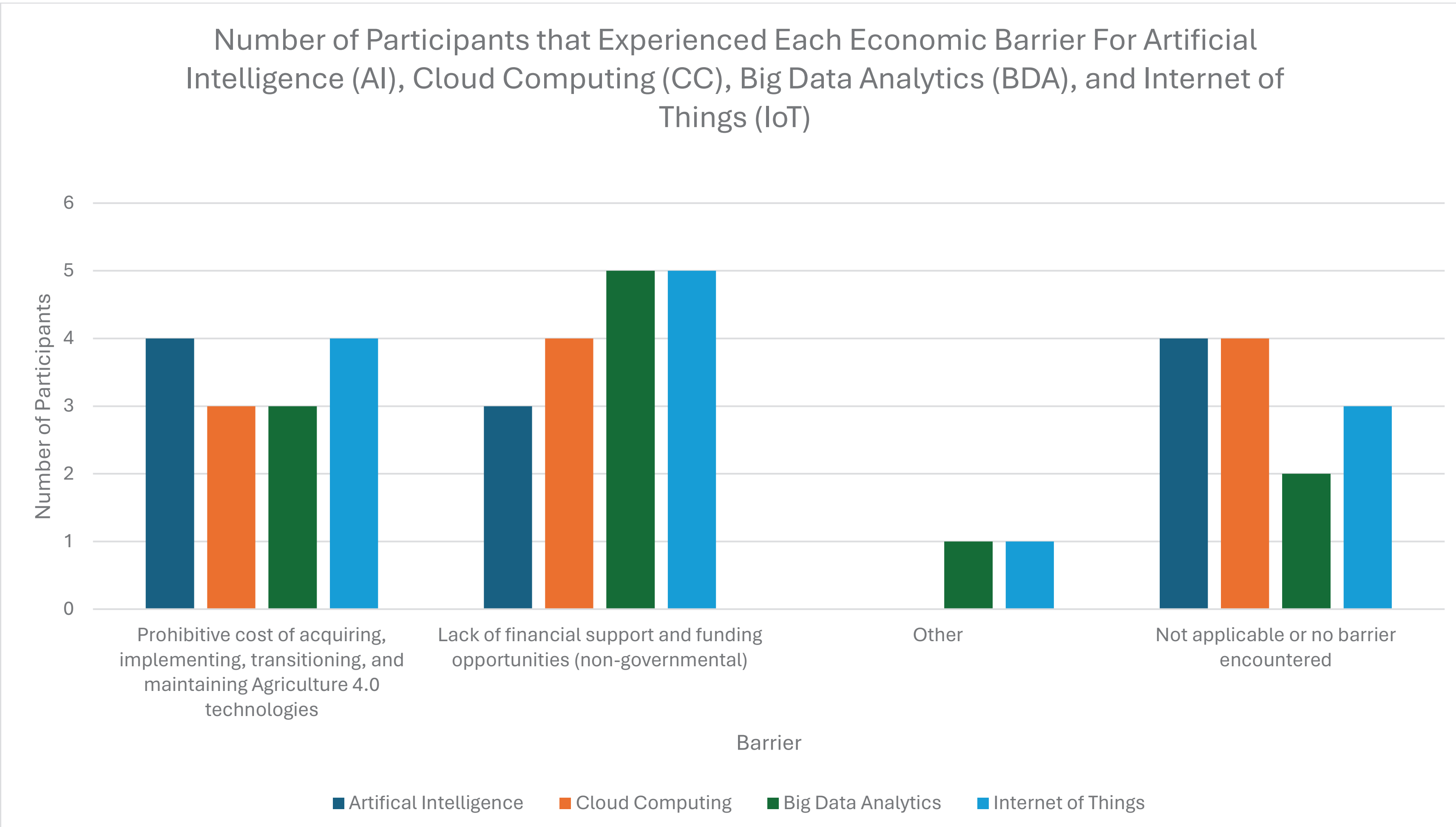
Appendix AH

Figure 44: *Rate of Participants Who Implemented Artificial Intelligence (AI), Cloud Computing (CC), Big Data analytics (BDA), and Internet of Things (IoT) that Indicated Experiencing Each Barrier Type*



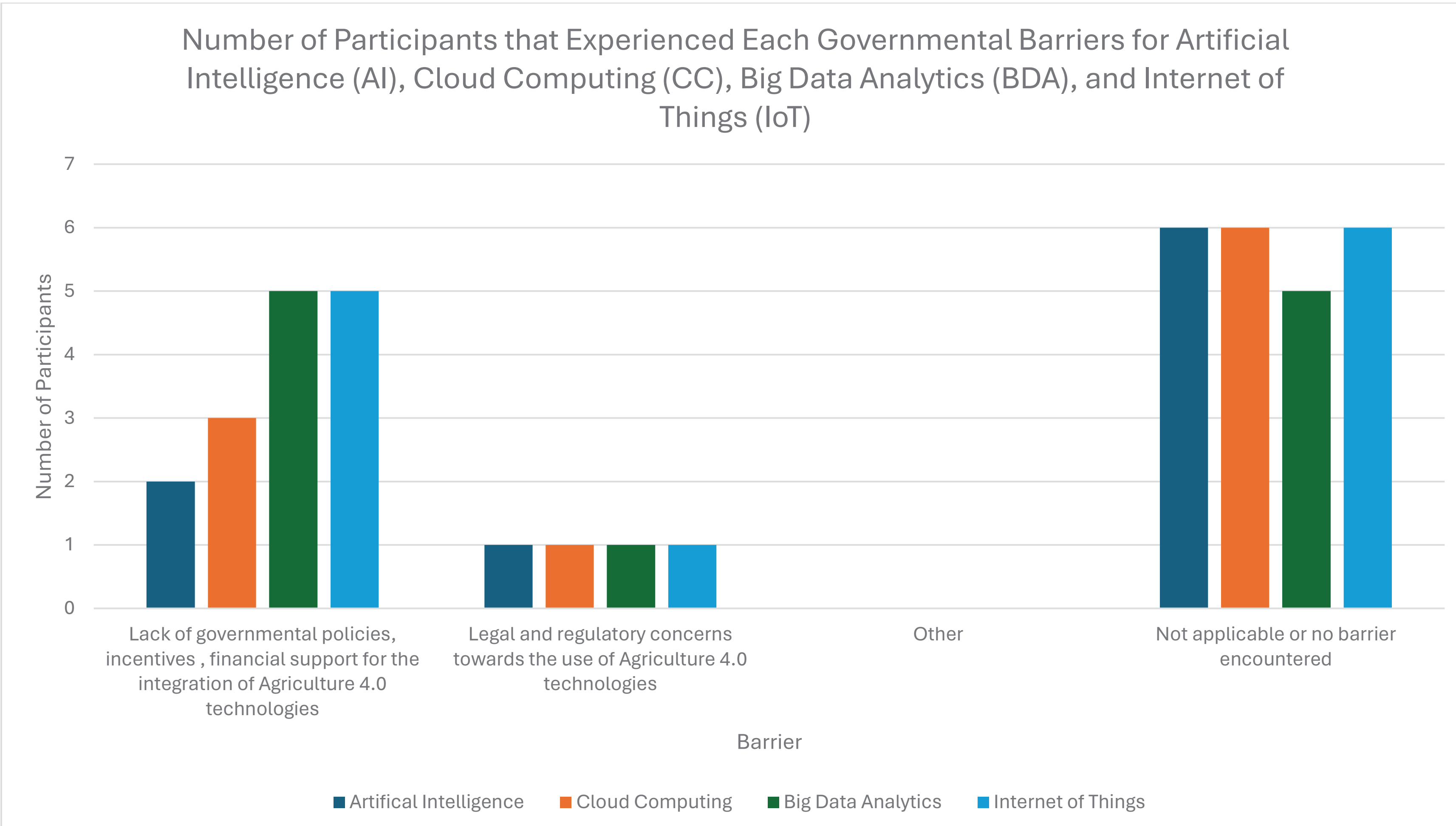
Appendix AI

Figure 45: *Number of Participants that Experienced Each Economic Barrier for Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*



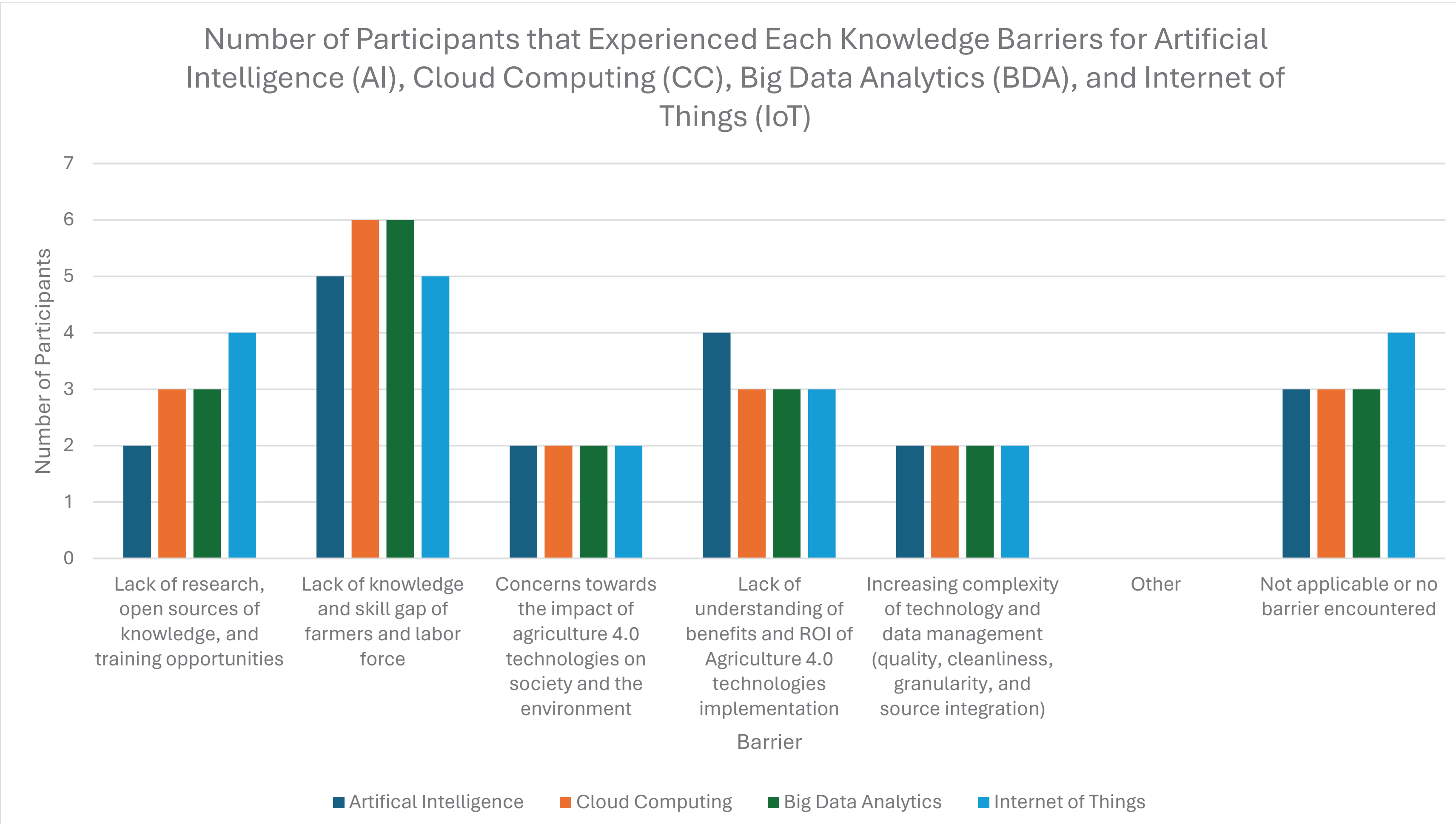
Appendix AJ

Figure 46: *Number of Participants that Experienced Each Governmental Barrier for Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*



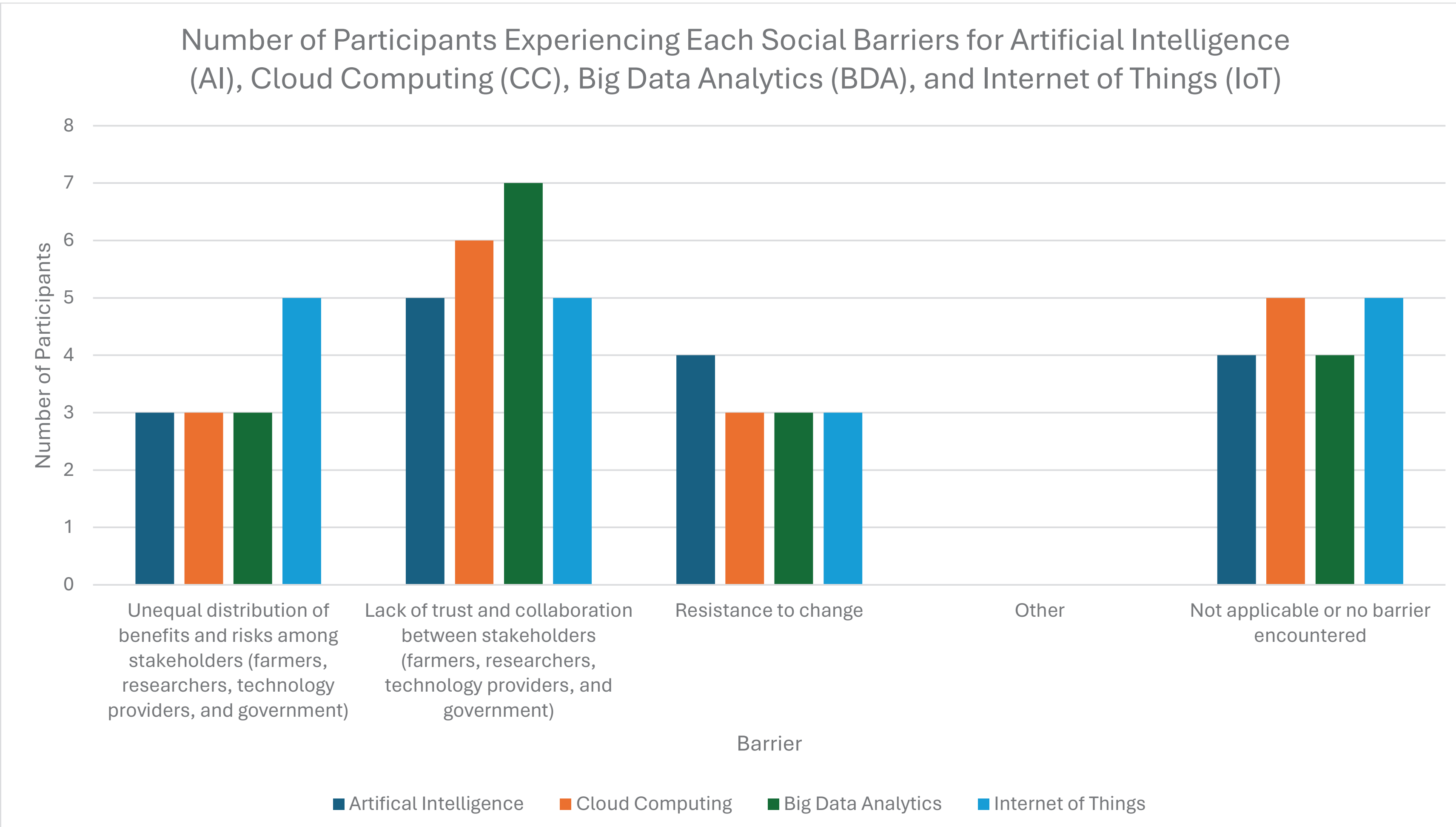
Appendix AK

Figure 47: *Number of Participants that Experienced Each Knowledge Barrier for Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*



Appendix AL

Figure 48: *Number of Participants that Experienced Each Social Barrier for Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*



Appendix AM

Figure 49: *Number of Participants that Experienced Each Technical Barrier for Artificial Intelligence (AI), Cloud Computing (CC), Big Data Analytics (BDA), and Internet of Things (IoT)*