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CHALLENGES AND OPPORTUNITIES OF INDUSTRY 4.0 ON JORDANIAN FOOD INDUSTRY'S SUSTAINABILITY

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The aim of this dissertation is to obtain a doctoral (PhD) degree in the scientific field of "**Economics**"

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Full Form
AI	Artificial Intelligence
ANOVA	Analysis of Variance
BD	Big Data
CC	Carbon Capture
CFA	Confirmatory Factor Analysis
CoFA	Common Factor Analysis
CoI	Chambers of Industry
CPS	Cyber-Physical Systems
CSR	Corporate Social Responsibility
DoS	Department of Statistics
EFA	Exploratory Factor Analysis
EMS	Environmental Management Systems
FSC	Food Supply Chain
GDP	Gross Domestic Product
ITC	International Trade Centre
KPI	Key Performance Indicators
I4.0	Industry 4.0
IoS	Internet of Senses
IoT	Internet of Things
IT	Information Technology
ML	Machine Learning
MoITS	Ministry of Industry, Trade and Supply
MSMEs	Micro, Small, and Medium Enterprises
NERC	National Energy Research Center
NCARTT	National Center for Agricultural Research and Technology Transfer
PCA	Principal Component Analysis
PFA	Principal Axis Factoring
PLC	Programmable Logic Controllers
PPD	Public-Private Dialogue
SBM	Sustainable Business Models
SLR	Systematic Literature Review
SAM	Sustainability Assessment Model
SPSS	Statistical Package for the Social Sciences
TBL	Triple Bottom Line
WCED	World Council of Environment and Development

INTRODUCTION

In the modern era, the global food industry stands at a crossroads, grappling with the urgent need for sustainability amidst a backdrop of technological advancement and shifting consumer demands. Industry 4.0, also known as the Fourth Industrial Revolution, refers to the integration of digital technologies and automation into manufacturing (BAG *ET AL.,* 2021). These technologies include the Internet of Things, big data analytics, artificial intelligence, and cloud computing. Implementing Industry 4.0 in the food industry can bring about various challenges and opportunities while also impacting sustainability (BAI *ET AL.*, 2020).

Coined by the German government as a strategic framework to usher in the era of smart factories and digital economies, Industry 4.0 presents both challenges and opportunities for sustainable development within the food industry (DASTBAZ-COCHRANE, 2019). At its core, sustainability in the food sector encapsulates a multifaceted approach encompassing environmental stewardship, economic viability, and social responsibility. From farm to fork, each stage of the food supply chain confronts complex sustainability dilemmas, ranging from resource depletion and waste generation to ethical considerations and social equity. In this context, the emergence of Industry 4.0 introduces a dynamic dimension, offering innovative solutions and disruptive technologies that have the potential to revolutionize traditional food production practices. However, realizing the full potential of Industry 4.0 in fostering sustainability requires a nuanced understanding of its implications, challenges, and transformative pathways (KHAN *ET AL.,* 2021).

The emergence of Industry 4.0 introduces a new dimension to these sustainability challenges and opportunities. On one hand, the integration of digital technologies and automation holds the promise of improving efficiency, reducing waste, and enhancing transparency throughout the food supply chain. For example, IoT sensors and AI algorithms can enable real-time monitoring and optimization of agricultural practices, leading to higher yields and reduced environmental impact. Similarly, blockchain technology can enhance traceability and transparency in food supply chains, allowing consumers to make more informed choices about the products they purchase (BAG *ET AL.,* 2021).

On the other hand, the adoption of Industry 4.0 technologies in the food industry also poses significant challenges to sustainability. The increased reliance on digital infrastructure and data-driven decision-making raises concerns about data privacy, cybersecurity, and the digital divide. Moreover, the rapid pace of technological change may exacerbate existing inequalities within the food system, particularly for small-scale farmers and marginalized communities who lack access to advanced technologies and digital literacy (THOMAS *ET AL.,* 2018).

In this context, the successful integration of sustainability principles with Industry 4.0 in the food industry requires a comprehensive and inclusive approach. It necessitates collaboration and partnership among stakeholders across the entire food value chain, including farmers, processors, distributors, retailers, policymakers, and consumers. By fostering dialogue and cooperation, stakeholders can identify shared sustainability goals and co-create innovative solutions that leverage the potential of Industry 4.0 technologies while addressing the unique challenges and needs of different actors within the food system (BAI *ET AL.*, 2020).

Furthermore, it is essential to recognize that achieving sustainability in the food industry is not solely a technical challenge but also a social and cultural one (LUTHRA-MANGLA, 2018b). It requires a shift in mindset and values towards more sustainable consumption patterns, as well as policies and regulations that incentivize sustainable practices and discourage harmful ones. Education, awareness-raising, and capacity-building are also crucial components of any strategy aimed at promoting sustainability in the food industry.

This research explores the intricate interplay between sustainability imperatives, technological innovations, and the evolving landscape of the food industry in the era of Industry 4.0. Through a comprehensive analysis of key concepts, case studies, and emerging trends, we delve into the drivers and barriers shaping the integration of sustainability principles within the context of Industry 4.0. Furthermore, we examine the diverse strategies and initiatives employed by stakeholders across the food value chain to harness the power of digitalization and automation in pursuit of sustainable food systems. By synthesizing insights from academic research and industry reports, this research aims to elucidate the potential synergies and trade-offs inherent in the convergence of sustainability and Industry 4.0 within the realm of food production and consumption.

As we navigate the complex terrain of sustainable food systems in the age of Industry 4.0, it becomes evident that collaboration, innovation, and holistic thinking are imperative. By fostering dialogue, fostering interdisciplinary collaboration, and embracing disruptive technologies, we can pave the way for a more resilient, equitable, and environmentally sustainable food future. From precision agriculture and smart packaging to blockchain-enabled traceability and decentralized food production, the possibilities are limitless. However, realizing this vision requires collective action, visionary leadership, and a steadfast commitment to balancing economic prosperity with ecological integrity and social equity. In the following sections, we delve deeper into the various facets of sustainability in the food industry, examining the transformative potential of Industry 4.0 and the imperative of forging a path towards a more sustainable food future.

1. INTRODUCTION OF THE TOPICS AND OBJECTIVE

Why the sustainability and food Industry in the context of Industry 4.0? "Ministry of Education and Research" and the "Ministry for Economic Affairs and Energy" of the German government presented a report titled "Industrie 4.0" (Industry 4.0) that proposes a new strategy that focuses on building a digital economy and society and increasing the interconnection of goods, value chains and business models with digital manufacturing (DASTBAZ-COCHRANE, 2019). It can be seen that the performance and quality of this change would increase. The fact that the entire cycle of production is handled, managed and controlled in an integrated way, makes the production process combined, yet flexible (PEDERSEN *ET AL.,* 2016). The evolution of the industrial sectors has had a huge effect on people's lives at both local and global levels.

The manufacturing sector's activities have developed into advanced complex methods and processes, increasingly dependent on the latest technological advancements.. It appears that the environment of food industry is ready for major economic and environmental sustainability improvements since the challenges for remaining sustainable of food industry are expanding (THOMAS *ET AL.,* 2018). Food industries should constantly evolve their production systems to meet the changing market demand and remain competitive in the global environment. The rise in demand for customized products and higher quality by consumers and the innovation of digital technology have collaborated in emerging Industry 4.0 (KAGERMANN *ET AL.,* 2013). Giving solutions to the ecological problems faced by production was not an essential issue for the guiding principle of Industry 4.0, instead, it focused more on increasing revenue growth, competitiveness, and productivity. However, in order for Industry 4.0 to be embraced successfully, it has to cope with the inherent challenges.

1.1 Justification for the study and Problem Context

The challenges for remaining sustainable in the fourth Industrial revolution era are expanding (THOMAS *ET AL.*, 2018). The need to pursue sustainable development while constantly evolve the production systems and meet the changing market demand and remain competitive in the global environment are increasingly recognized by industries. Organizations are seeking to make a balance between the triple bottom line (TBL) perspectives (environmental, economic and social) (KIEL *ET AL.*, 2017). In the upcoming years, a number of research should initiative in order to attempt to examine and evaluate how the food industries in Jordan is responding to the difficulties of incorporating Industry 4.0 into its manufacturing processes and how does it affect the sustainability. A conceptual model has been proposed by DUARTE-CRUZ-MACHADO (2018) that integrates concepts of Industry 4.0 into green and sustainable supply chains. However, developing sustainability in the operations of industries is not an easy job to do (LUTHRA-MANGLA, 2018b). Therefore, researchers are giving more attention to the impacts of Industry 4.0 on supply chain in terms of sustainability (GHOBAKHLOO, 2020). The generated inequality of job opportunities in various economic sectors of the world, the waste, pollution and emissions generated by industries during the entire life cycle of the supply chain are just some of the issues that call for a change and shift towards a more sustainable world. Where does the scholarly world stand in sustainability and supply chain? What are the main areas of sustainability in supply chain 4.0? How does implementing Industry 4.0 affects food Industry's sustainability ? What are the opportunities and challenges of this integration on food industry's sustainability ? Those research gaps need to be filled.

1.2 Research aims and objectives

The aim of this study is to create and confirm a framework that provide an overview of the effect of integration of Industry 4.0 with industries that is connected to investigation of sustainability from economic, social and environmental point of view. Moreover, it will demonstrate how food industry will become more efficient and effective by this integration. This research will show as well what are the challenges and risks of the implementation, exploring the significance of Industry 4.0-related opportunities and challenges as catalysts for implementing Industry 4.0 within the framework of sustainability, while considering distinct perspectives across different sectors in Jordan food industry, and their role as an Industry 4.0 user. To accomplish the research goal, we have divided the aims into specific target objectives, which include the following identified objectives:

1. To find how Industry 4.0 affects the sustainability performance within food industries.
2. To explore recent literature and identify main sustainability areas affected by Industry 4.0 integration in order to propose a sustainability assessment model.
3. To evaluate the impacts of Industry 4.0 integration on the environmental pillar of sustainability across the Jordanian food industry.
4. To evaluate the impacts of Industry 4.0 integration on the economic pillar of sustainability across the Jordanian food industry.
5. To evaluate the impacts of Industry 4.0 integration on the social pillar of sustainability across the Jordanian food industry.
6. To critically appraise and document the key opportunities associated with implementing Industry 4.0 on sustainability (environmental, social and economic) in food industry.
7. To critically appraise and document the main challenges associated with implementing Industry 4.0 on sustainability (environmental, social and economic) in food industry.

1.3 Research questions

Based on the preceding discussion, aim, and objectives, the following research questions have been addressed:

RQ1: How does Industry 4.0 adoption influence the sustainability performance of food Industries?

RQ2: What are the main sustainability areas affected by Industry 4.0 implementation in the food industry?

RQ3: Does Industry 4.0 integration impact the environmental pillar of sustainability across the food industry positively or negatively?

RQ4: Does Industry 4.0 integration impact the economic pillar of sustainability across the food industry positively or negatively?

RQ5: Does Industry 4.0 integration impact the social pillar of sustainability across the food Industry positively or negatively?

RQ6: What are the key opportunities associated with implementing Industry 4.0 on sustainability (environmental, social and economic) in the food industry?

RQ7: What are the key challenges associated with implementing Industry 4.0 on sustainability (environmental, social and economic) in the food industry?

The research questions are designed to build over each other in order to build a coherent and logical structure. RQ1 and RQ2 will focus on creating collaborative knowledge and sharing influences of Industry 4.0 on overall sustainability performance of food industries and categorizing areas and subthemes in food industry's sustainability. RQ2 will form the basis of the following research questions. RQ3, RQ4 and RQ5 will focus on exploring the effects of industry 4.0 implementation on those areas of sustainability in Jordanian food industry. RQ6 and RQ7 aims to find the opportunities and challenges of implementing Industry 4.0 on food industry's sustainability. Figure 1 illustrates a schematic overview of the structural approach of the research questions that will be used through this research study.

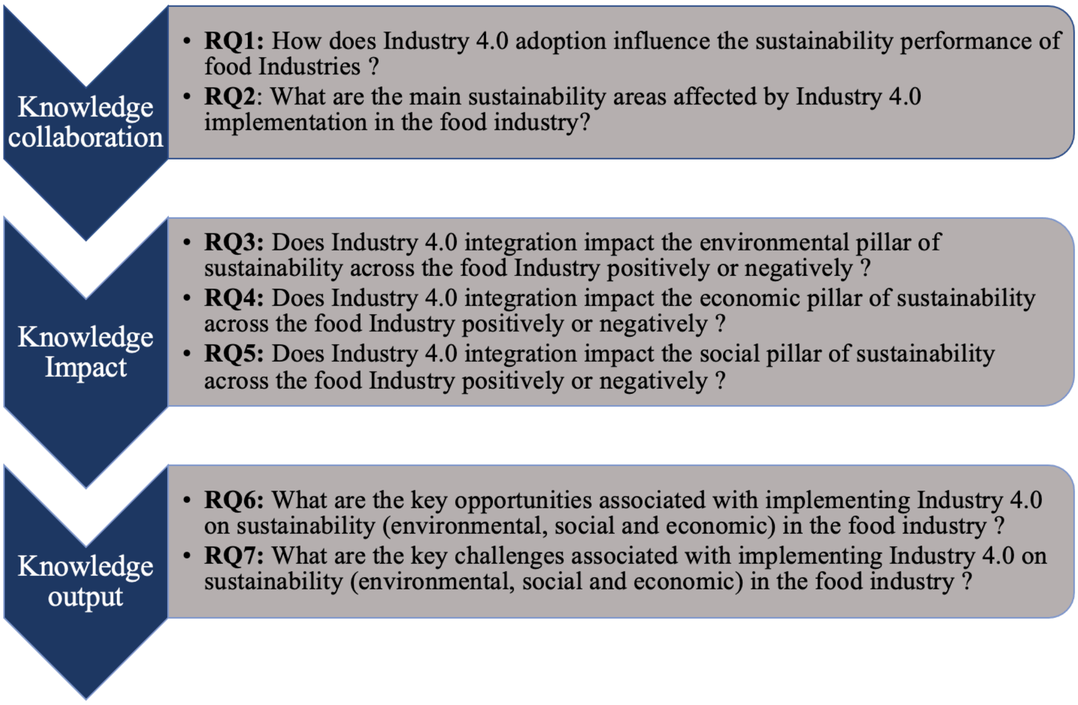

Figure 1: Logical structure of the research questions.

Source: Author's own contribution

1.4 Research contribution to knowledge and Research model for this study

There exists a substantial amount of information and published works regarding sustainability and Industry 4.0 practices, as demonstrated by academic research. However, much of this knowledge is scattered and presented in a manner that proves challenging for practitioners to grasp and assess the impact of implementing Industry 4.0 on sustainability within the food industry. Furthermore, while there has been a lot of study and assessment frameworks on the topic of sustainability indicators in general, there hasn't been much on the topic of sustainability specifically to environmental, economic and social evaluation of Industry 4.0 adoption by food industries. As a result, no comprehensive and extensive case studies on the food industry have been conducted to explore and evaluate what opportunities and challenges that can be delivered from Industry 4.0. As a result, doing this study will help practitioners and other stakeholders fill gaps in the literature, as well as assist them in the following areas below:

- The practitioners and other stakeholders' understanding and knowledge of the sustainability areas that are influenced by Industry 4.0 will be broaden.
- The sustainability assessment model developed will act as a roadmap for sustainability practitioners and policymakers tasked with assessing the effectiveness and evaluating the food Industry's sustainability. The sustainability assessment model formulated will

assist practitioners in their endeavor to adopt and implement the industry 4.0 considering environmental, economic and social factors that enable the successful implementation of Industry 4.0.

- Provide an overview of how Industry 4.0's intrinsic features and the changes it encourages impacts either positively or negatively the food industry's sustainability from economic, social and environmental point of view.
- This research will serve as a foundation for future research and will act as a reference document. The accomplishment of the research target will also help to enhance academic treatment of the evaluation and delivery of Industry 4.0 sustainability advantages.

The research process followed during the study has been presented in Figure 2 below:

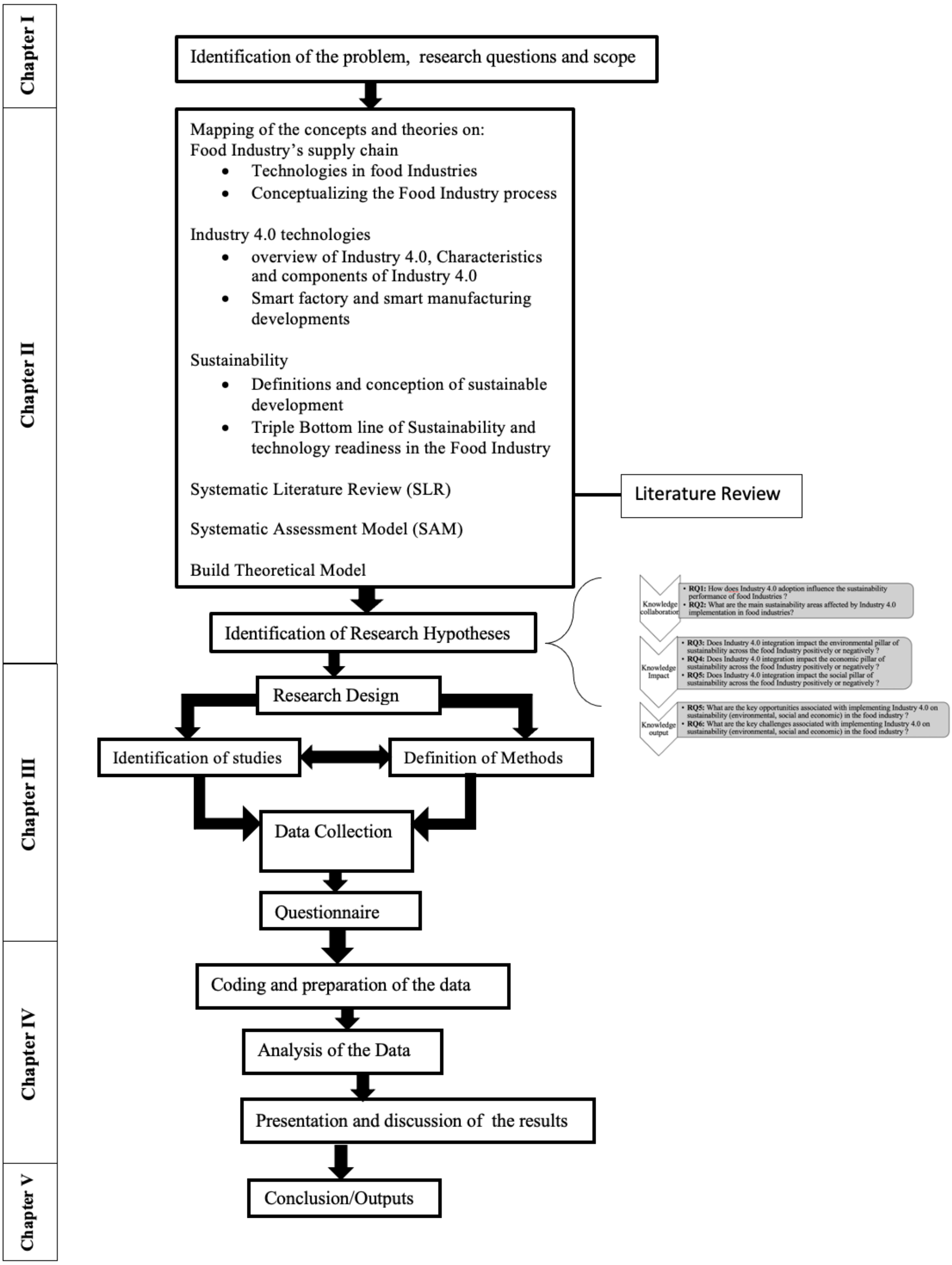

Figure 2: Research model.

Source: Author's own contribution

2. LITERATURE REVIEW

2.1 Introduction

This chapter will present the literature review on food industry, Industry 4.0, and sustainability as outlined in Figure 3. At the beginning, the concepts of food industry and Industry 4.0 are defined, where their characteristics and components are previewed in details. Later in this chapter, the sustainability and sustainable development concepts in relation to the concerning operations within the food industry in general will be explored. It then goes on to the Systematic Literature Review (SLR) of sustainability in the context of Industry 4.0, as well its linkages with the three pillars of sustainability. Additionally, it reviews the literature for generating the Sustainability Assessment Model (SAM), providing different factors areas of each pillar of sustainability that might be impacted by implementing Industry 4.0 on food industry. Finally, this research proceeds to introduce the I4.0 capabilities, drivers and challenges of I4.0 adoption to form the theoretical model and the research hypotheses.

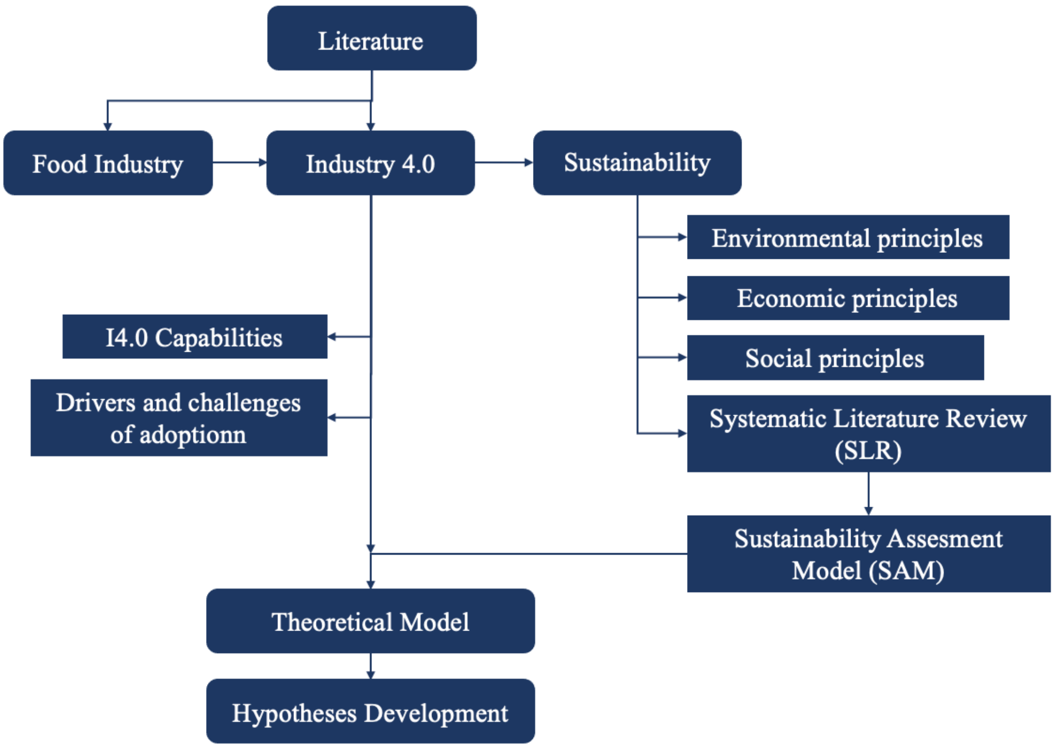

Figure 3: Outline of literature review.

Source: Author's own contribution

2.2 Food industry's supply chain

Nowadays, the food industry is moving towards a more interconnected structure connecting multiple actors with a variety of relationships. All entities which are involved in production, processing, distribution and the disposal of food and food-based items are integrated in the food supply chain (AHUMADA-VILLALOBOS, 2009; VAN DER VORST *ET AL.*, 2009; VAN DER VORST *ET AL.*, 2000). Food supply chain was distinguished by VAN DER VORST *ET AL.*, (2009) as fresh firm products, process food products and consumer products, where fresh firm products are potential actors involving growers, farmers, producers, retailers, wholesalers, importers, exporters, and other professionals involved the logistics in food industry. Focal firms which add higher value to the inputs from growers producing consumer products and process food products. Because of the recycling and conditioning methods, consumer goods are less perishable than fresh firm products. Generally, features such as safety of food, food quality, perishability (short-shelf life) and weather-related variability make food industry distinguishable from other industries (VAN DER VORST, 2006). As a result, the food supply is more challenging and multifaceted than other industries.

In Europe's Road transport, large goods vehicles used for transporting goods are responsible for almost 25% of CO_2 emissions, affecting traffic, safety, and pollution. Around 70% of global freshwater is consumed and polluted by the food industry, aggravating the worldwide scarcity of potable water (ALLAOUI *ET AL.,* 2018). As a result, ensuring food supply chain sustainability is critical. By 2030, it is expected that global food demand will have increased by 50%. To meet demand, food production must be increased, placing enormous strain on already limited resources including water, land and energy. This will result in higher transportation and CO_2 emissions, all of which will have a significant effect on climate change. In addition, food waste in food industries is generally known for its environmental effects. The food industry has a variety of effects on the environment and society, including deforestation, waste generation, emissions of greenhouse gases and natural resource use (MENA *ET AL.,* 2011). Therefore, companies should consider social and environmental practices, as well as their SC partners, in order to minimize environmental effects, improve social benefits, and increase economic income for their businesses.

SELLITTO *ET AL.* (2018) have discovered that ethical considerations and the adoption of sustainability dimensions such as, social, economic and environmental aspects to be crucial success factors in the UK food supply chains. An optimistic moral outlook and encouraged ethical differentiation between producers and consumers can be created by sustainable food production

Patterns and main characteristics of food supply chains which can shape the future of food transportation, as well as the difficult areas for researchers to examine, were identified by (GHAREHGOZLI *ET AL.,* 2018). They have mentioned that socioeconomic developments, digitalization, and innovation, as well as trans-boundary challenges, will greatly influence the transportation of food and the advancement of digitalization.

Implementing information and communication technology and e-business solutions will turn the FSC into E-FSC, which will facilitate goods and services, and make it easier to transport goods, supplies, and knowledge through the whole food industry chain. Collaboration with stakeholders in the upstream supply chain is critical to facilitating integrated e-FSCs, requiring information exchange and multiple shared activities. These difficulties can be greatly reduced by integrating Industry 4.0 and food industries.

2.2.1. Technologies in food industry

Generally, businesses are compelled to embrace new technology in order to maximize operating performance and gain a competitive advantage. The operation entails a diverse collection of tasks which could be divided into two categories. The first category involves reorganization and operation of existing technologies, whereas second category requires the incorporation of new technologies into existing structures (SONNTAG, 2003). This viewpoint emphasizes the significant time commitment that businesses must make in order to achieve effective technology adoption. Participating companies in the food industry must keep up with the rapid speed of technological advances.

2.2.2. Conceptualizing the food industry process

The food Industry starts with agriculture on one end and ends with consumer consumption on the other (YAKOVLEVA, 2007). Components of food industry are presented in Figure 4 beginning at one end with agriculture and ending with customers, representing an unbroken chain of connections from the primary producer to the end user. The current evolution and dynamics of the FSC are drive by power of economics, including retailer control, new technology, societal changes, and policy and regulations (HM GOVERNMENT, 2010). Concerns about food protection, safety, worldwide supply and demand, along with a host of other issues like competitiveness, enhanced production, consumer health, and premium convenience foods, have continued to be layered on top of resources. Understanding how the food industry's operations and environmental issues like environmental pollution are intertwined is crucial (FLYNN-BAILEY, 2014; OOSTERVEER-SONNENFELD, 2012). Moreover, the food industry, as a significant economic field, provides jobs and direct income to many individuals and families.

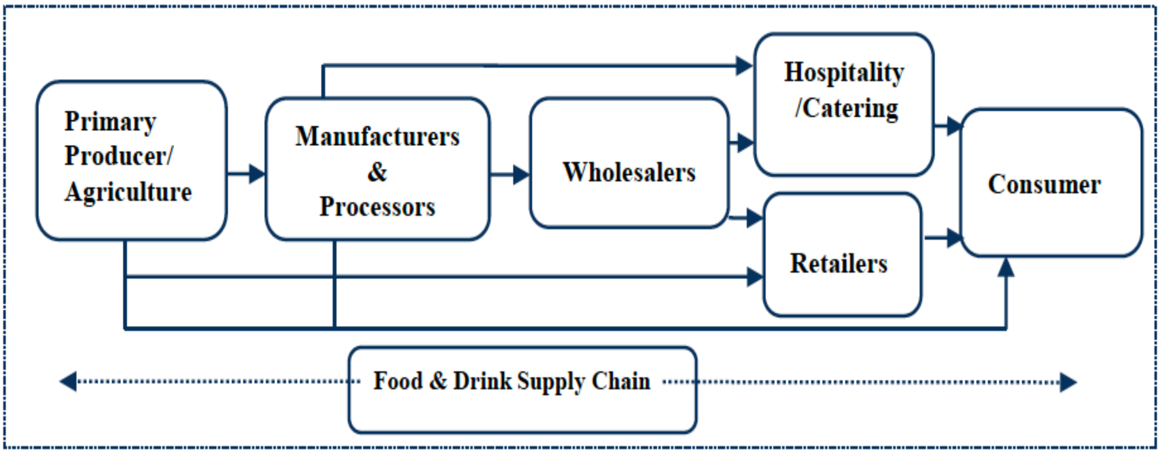

Figure 4: Major elements of FSC.

Source: Author's own contribution

2.2.3. Food Sector in Jordan

The food industry stands as one of the pivotal economic sectors in Jordan, significantly aiding the country's economic and social progress. Food industries, encompassing activities such as dairy product manufacturing (yogurt, butter, jameed) and olive pressing for olive oil, holds deep roots in Jordanian culture, spanning centuries. Numerous Micro, Small, and Medium Enterprises (MSMEs), particularly in newly urbanized and rural regions, rely on traditional food manufacturing techniques. Given that these traditional skills are often passed down through generations, with a significant role undertaken by women, numerous national initiatives which target empowering women and fostering rural development prioritized support for food manufacturing endeavors.

The sub-sector data utilized in this research is the most recent information accessible, sourced from the Chambers of Industry (CoI), Department of Statistics (DoS), and the International Trade Centre (ITC). Based on 2017 data, the combined workforce in the food manufacturing, agriculture, and animal husbandry sectors amounts to 49,935 employees (Jordan Chamber of Industry, 2018). These sectors generated revenues totaling JOD 4.122 billion, contributing to 6.3% of the Gross Domestic Product (GDP) as of 2015. Additionally, in 2016, the sector's exports reached JOD 524.8 million. constituting 10.2% of Jordan's overall industrial exports (JORDAN CHAMBER OF INDUSTRY, 2018).

Between 2013 and 2017, the main subsectors experienced an average annual growth (turnover) rate of approximately 4.9%, primarily due to the expansion of households and the influx of Syrian refugees. Regarding market penetration, specific Jordanian goods are increasingly dominating the domestic market, supplanting imports, particularly in categories like dairy products, Arabic sweets, and specific processed fruits and vegetables such as dried dates. Concerning food exports, indications suggest that Jordan still possesses untapped market opportunities, with certain sub-sectors showing growth potential progressing consistently and expanding into fresh Western markets (DOS, 2019).

The significance of this sector is rooted in its extensive diversification, accommodating businesses of all scales, with over 95% being Micro, Small, and Medium Enterprises (MSMEs), of which approximately 80% are classified as micro and small enterprises. Furthermore, its importance is underscored by its extensive forward and backward connections within the economy, as well as its level of integration, resulting in substantial added value. Significantly, the industry accounts for 25.9% of the net value added within Jordan's industrial sector, thus establishing itself as a strategic sector with implications for both industry and agriculture.

HUNDAILEH–FAYAD, (2019) has drawn a study about the food sector in Jordan, by evaluations with stakeholders, and adhering to the International Standard Industrial Classification (ISIC) guidelines, the sub-sectors within Jordanian food Industries were classified as follows:

• Manufacture of dairy products

• Manufacture of cocoa, chocolate, and sugar confectionery

• Manufacture of bakery products

• Manufacture of processed and preserved fruits and vegetables (F&V)

• Manufacture of vegetable oils and animal oils and fats

• Manufacture of grain mill products

• Manufacture of macaroni, couscous, noodles, and similar products

• Manufacture of processed and preserved meats

• Manufacture of prepared animal feeds

• Manufacture of other food products

• Processed and preserved fish, mollusks, and crustaceans

It's important to recognize that the data furnished by the Ministry of Industry, Trade and Supply (MoITS) encompasses 11 sub-sectors, whereas the information from the Department of Statistics (DoS) covers only 10 sub-sectors. The graph below represents findings from the Economic Survey administered by the DoS. Notably, the MoITS includes molluscs/fish and macaroni/pasta sub-sectors, which are absent in the DoS data; instead, the DoS references bakeries.

The significance of Jordan's food manufacturing sector today stems from its interconnections with other sectors in the economy, both forward and backward, and the value it adds through these connections. Together, the food manufacturing, agriculture, and animal husbandry sectors contribute to 25% of Jordan's industrial output and account for 25.9% of the net added value within the country's industrial economy (JORDAN CHAMBER OF INDUSTRY, 2018).

The food industry sector demonstrates notable levels of added value alongside a wide array of diverse sub-sectors. High added value indicates relative competitiveness, enabling the sector to vie in export markets. This assertion is reinforced by the fact that local production accounts for 47.2% of local consumption. Intermediate consumption signifies the volume of goods or services procured from local enterprises to finalize their products, reflecting the degree of integration among local businesses. (DOS, 2019).

Examining Figure 13 below, processed meats, processed fruits and vegetables (F&V), dairy, and bakery products emerge as the sub-sectors with the highest levels of added value within the processed foods sector. Despite processed meats being among the top three sub-sectors in terms of added value, it wasn't deemed a priority sub-sector due to import constraints on most meat products.

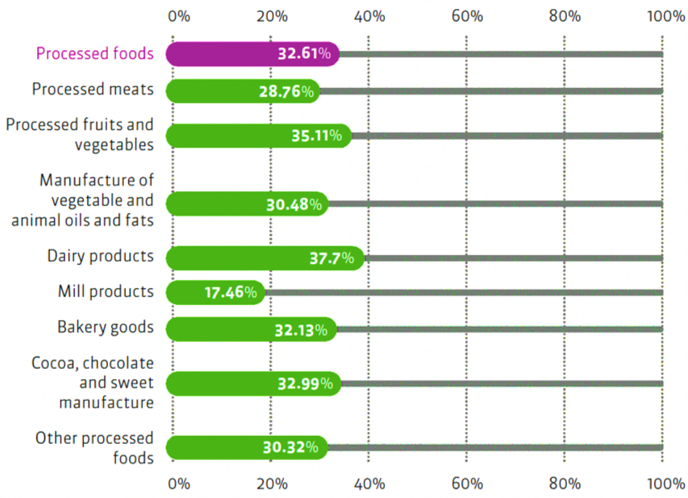

Figure 5: Aggregate level of added value in the food manufacturing sector and its sub-sectors

Source: HUNDAILEH–FAYAD, 2019; DOS.

The different sub-sectors within the food manufacturing industry witnessed an increase in average annual growth after 2013, indicating rising consumption and exports. The surge in consumption is likely attributed to the expanding refugee population, which not only consumes but may also engage in micro-level production. It's notable that higher-value items, like processed meat, experienced less growth compared to competitively priced categories such as dairy products, processed fruits and vegetables (F&V), bakery products, and other food items. This can be attributed to the absence of economies of scale in importing raw meats for processing or raising livestock in Jordan. The rise in grain mill products is logical as grain mills supply flour to bakeries (HUNDAILEH–FAYAD, 2019).

However, recent declines in growth rates can be attributed to the closure of certain traditional regional markets like Syria and Iraq due to political instability. Nevertheless, this decline reflects a degree of enhanced competitiveness, and overall growth remains positive. Nonetheless, reinforcement at both macro and micro levels is recommended.

Jordan's institutional framework comprises numerous institutions that directly or indirectly influence the food manufacturing sector. Figure 14 below offers a comprehensive overview of the institutional structure and key stakeholders involved.

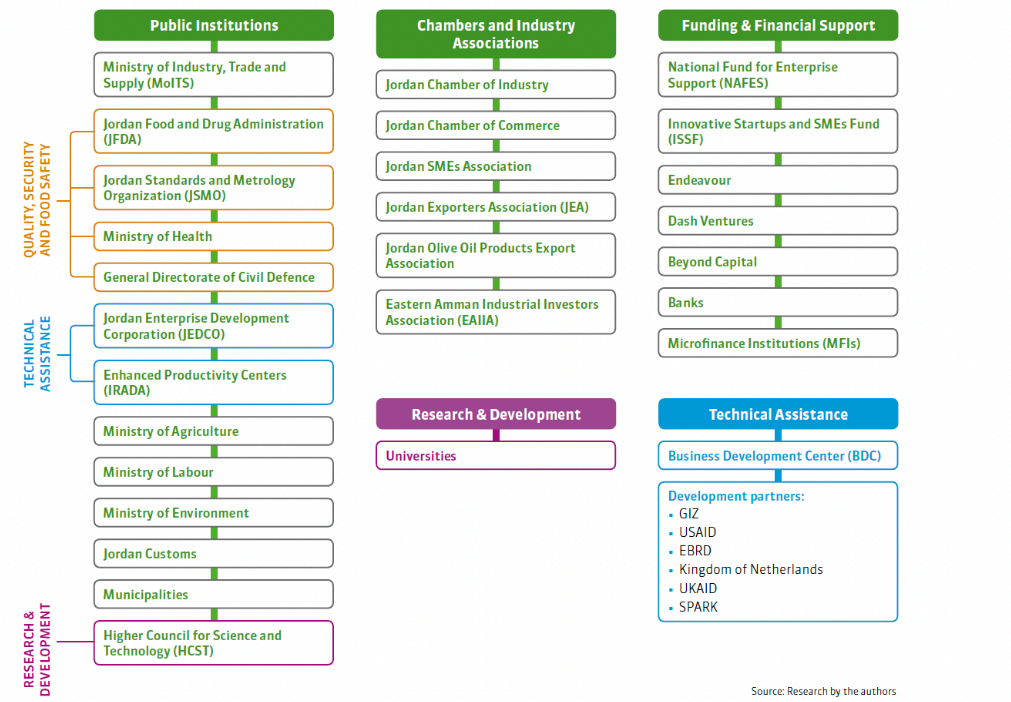

Figure 6: Institutional structure and key stakeholders involved in the food Manufacturing in Jordan

Source: HUNDAILEH–FAYAD, 2019.

Investing in new equipment and processes is essential for adopting new technologies designs across all sub-sectors. However, securing funds for such endeavors poses a significant challenge, particularly for start-up companies who typically spearhead these initiatives (HUNDAILEH–FAYAD, 2019).

Facilitating innovation can be achieved by aligning industry needs with academic expertise. The effectiveness of applied research projects hinges on a mutual understanding between both parties regarding the desired outcomes, as well as access to subsidized financing or grants. Micro, Small, and Medium Enterprises (MSMEs) stand to benefit from leveraging public research institutions such as the National Energy Research Center (NERC), the National Center for Agricultural Research and Technology Transfer (NCARTT), public universities, and technology schools. The success of such collaborations heavily relies on awareness and comprehension of cost and time constraints, as well as the specific industrial sectors relevant to the services and outputs provided. Enhancing this awareness will enhance collaboration efficiency (HUNDAILEH–FAYAD, 2019).

Technological progress should encompass the entire production chain, moving from upstream (raw materials) to downstream (market), while also enhancing understanding of factory processes, product specifications, and market demands, whether domestic or international. Furthermore, adherence to international standards is imperative to establish credibility. Agricultural methods should be refined to diminish product contamination and enhance consistency, a necessity for both the fruits and vegetables (F&V) and dairy sub-sectors. Upgrading outdated machinery is essential to boost efficiency and decrease waste or energy consumption. Moreover, there's a pressing need to foster technical skills across all levels of the workforce (HUNDAILEH–FAYAD, 2019).

Enhanced and focused government initiatives are required to bolster the food industry's role in GDP growth, particularly through the reinforcement of agriculture. Government assistance can take the form of transferring technical expertise and extending services to modernize agricultural technology, thereby improving crop yields and diversifying varieties. Additionally, support for the development of water-efficient irrigation systems is essential, given that agriculture is the largest consumer of water in Jordan (HUNDAILEH–FAYAD, 2019).

Enhancing the competitiveness of Jordan's manufacturing food sector demands a comprehensive strategy involving coordinated actions at the macro (infrastructure), meso (institutional), and micro (enterprise) levels. Interventions aimed at the micro level emphasize innovation through product development and diversification, as well as strategic investment in contemporary, energy-efficient technology (HUNDAILEH–FAYAD, 2019).

Collaborating with international organizations such as Senior Experten Service (SES) in Germany or Netherlands Senior Experts (PUM) in the Netherlands could involve engaging retired professional experts in food manufacturing and food engineering. These experts could offer valuable assistance to Jordanian entrepreneurs in enhancing their technical expertise and implementing new technologies within their operations (HUNDAILEH–FAYAD, 2019).

Strategic interventions are essential for addressing challenges and enhancing the competitiveness of the sector. Key interventions include promoting product development through innovation, modernizing industry processes with advanced technologies, facilitating expedited access to financial loans for companies, including micro-enterprises, fostering collaboration between academia and industry to bolster applied research, facilitating partnerships between small and large businesses to drive new product development and market access, and encouraging public-private dialogue (PPD) in areas such as export promotion and research. Understanding the steps and barriers in testing and reporting data due to gaps in data of the latest years (2019-2021) during the COVID-19 pandemic.

2.3 Industry 4.0 technologies

Currently, one of the most widely discussed topics among researchers, academics, professionals, and governments worldwide is the concept referred to as Industry 4.0 or I4.0. (DRATH-HORCH, 2014). This term was born in an initiative by the government of Germany named "Industrie 4.0," which was first proposed in 2011 as part of the strategy for industry in Germany (KAGERMANN *ET AL.,* 2013). This unusual combination of the words Industry and number 4.0 is used to characterize the fourth industrial revolution. Figure 5 represents the four industrial revolutions. In the 18th century, the era of industrialization has begun, introducing mechanical manufacturing facilities. The second has introduced electrification and division of labor during the end of 19^{th} century. In the 1970s, the third industrial revolution began with the advent of PLCs (programmable logic controllers), which used information technology and advanced electronics to develop industrial process automation. Finally, the emergence of cyber-physical structures and linked smart items are driving the fourth industrial revolution (DRATH -HORCH, 2014).

A smart manufacturing environment that is dominated by intelligent systems, machines and networks with the ability to exchange and respond independently to information is envisioned by Industry 4.0 (MACDOUGALL, 2014). Cyber-Physical Systems (CPS) and Internet-of-Things (IoT) are two primary components of Industry 4.0 (QIN *ET AL.,* 2016; MOSTERMAN-ZANDER, 2015; JAZDI, 2014). Manufacturers can now utilize and gain advantages from certain distinctive aspects of Industry 4.0., such as real-time collaboration and visualization, due to both computerization and integration phenomenon (POSADA *ET AL.,* 2015).

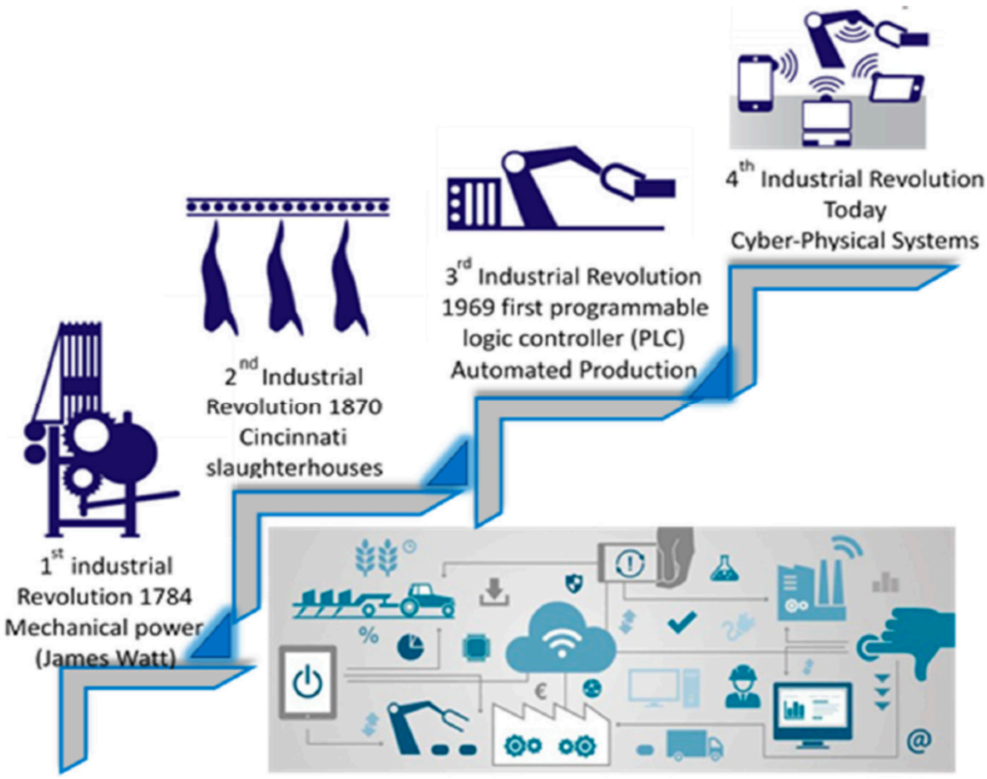

Figure 7: Evolution of manufacturing and industrial revolutions.

Source: KAGERMANN *ET AL.,* 2013.

2.3.1. An overview of Industry 4.0

Industries, academia and governments have great expectations for Industry 4.0, perceived as a catalyst poised to revolutionize the manufacturing paradigm, and, as a result, will change the world, according to HERMANN *ET AL.* (2016): *"Because Industrie 4.0 promises much improved operational performance as well as the creation of completely new business models, services, and products, the economic impact of this industrial revolution is expected to be enormous"*. Despite the fact that many concepts, elements, and components of Industry 4.0 have been recognized, a broad variety of definitions are still being used to derive such expectations at various levels within industries (product-specific, individual business, individual industries, and industry-wide).

Industry 4.0 topics are articulated at different degrees of abstraction and from different angles. For instance, FALLER-FELDMÜLLER (2015) focused on defining industry 4.0 narrowly from an IT standpoint, calling it "*IT integration across the planning and production levels, as well as between customers and suppliers*". Some academics view Industry 4.0 as "*a larger* *endeavour that includes developments to working procedures, organizational and hierarchical structures, market conditions, and client demands*". "*The methodical creation of an intelligent, real-time, horizontal and vertical networking system that connects people, things, and systems is known as Industry 4.0*" according to KIRAZLI-HORMANN (2015), who offered a description with a broader perspective.

The popularity of the topic can be traced to two main aspects, according to (DRATH-HORCH, 2014). To begin with, the projected advantages and economic effects of the industrial revolution are enormous. Benefits in operational efficiency, as well as the ability to enable and develop new products, services, and business models that have the power to completely change the industrial sector (KAGERMANN *ET AL.,* 2013). Secondly, for the first time in history, it is true that an industrial revolution is expected and encountered both before and during the process, instead than being watched after several years have passed (DRATH-HORCH, 2014). This allows business and academics to evaluate the possible opportunities, challenges, and effects of such a revolution on the future, including its protentional effects on sustainability.

Industrial vision of Industry 4.0 entails a multitude of manufacturing enterprises establishing worldwide, transnational networks of interconnected machinery, factories, and distribution networks. These networks will be intelligently controlled through the sharing of vital information to enable coordinated responses. It should be noted that industries will consist of cyber-physical systems (CPS), leading to the creation of smart supply chains, smart factories, smart machinery, and smart industries (KAGERMANN *ET AL.,* 2013). The manufacturing industry as a whole will see improvements to its industrial processes by such integration at all levels, via engineering, supply chains, design, material utilization, and product life cycle management. This integration, which is referred to as "horizontal integration" in I4.0, is at the heart of the vision.

2.3.2. Characteristics and components of Industry 4.0

Numerous technologies are used to drive industry 4.0, researchers argue that components of I4.0 include data integration, cloud computing or internal intranet, intelligent collaboration and self-organizing, flexible machine adaptation, systems optimization and secure communication (VOGEL-HEUSER-HESS, 2016). However, they have added that manufacturers might face challenges to effectively combine these characteristics. According to them, the challenge for manufacturers will continue to be on how to successfully incorporate these characteristics together.

Today, there are many developments which can fit into IoT and CPS spectrums. IoT and CPS provide a variety of visual computing tools (POSADA *ET AL*., 2015; GEORGAKOPOULOS *ET AL.,* 2016). Industrial automation, intelligent robotics, big analytics and data analysis and processing, semantic technologies, product lifecycle management (PLM), cloud-based technologies and encryption, could be viewed as visual computing technologies and unifying factor for a variety of Industry 4.0 applications. GEORGAKOPOULOS *ET AL.* (2016) and POSADA *ET AL.* (2015) have suggested a range of visual computing technologies that reflects the breadth of Industry 4.0, as summarized by Figure 6. The innovations highlighted are examples of physical and cyber elements combinations. Based on Figure 6, robotics and automation thought to be the most prominent developments with CPS association (ROBLEK *ET AL.,* 2016; HERMANN *ET AL*., 2016).

Figure 8: Industry 4.0 technology Pillars.

Source: SATURNO *ET AL.,* 2018.

According to Figure 6, big data analytics involves collecting and intelligently analyzing extensive data from interconnected computers, tools, machines, and devices in industrial processes like manufacturing. This data, along with external factors like economic conditions, market trends and decisions businesses make strategically are influenced by both future requirements and the resources available to the enterprise (LEE *ET AL.,* 2015). Providing a universal means of communication among machines and applications is referred by semantic, where interaction and data sharing takes place between different components, and signal processing is allowed. Moreover, dynamic and scalable computing mode can best describe cloud computing, of which multiple resources which include servers, storage, network, computing and application are rendered virtual and delivered as accessible services provided online (LEE *ET AL.,* 2015). As a result, all that pertains to cloud computing services are included in cloud technologies.

As highlighted before THAMES-SCHAEFER (2016) defined IoT as "*a group of tangible objects with mechanisms for computer, communication, mechanical, and electrical functions that allow data exchange and internet-based connectivity*". Manufacturing businesses, empowered by Industry 4.0 technologies for effective monitoring and management of equipment, machinery, and manufacturing processes, can swiftly and flexibly adjust their production processes in real-time. This includes tracking parts and goods and introducing novel services and interactions within the value network through innovative business models (LU, 2017; SHAFIQ *ET AL.,* 2016). By making firms gain those new technologies, it can translate to better operating efficiency, for example, shorter lead time in development, flexibility in design flexibility, and volume adjustments (SHAFIQ *ET AL.,* 2016), improve reliability and efficiency of equipment (LEE *ET AL.,* 2015), and raise the transparency of production (SCHUH *ET AL.,* 2014).

The necessary automation technology can be enhanced through the application of flexible, self-learning, self-aware, self-predicted, self-optimized, self-configured, and self-maintained techniques. This is a distinctive characteristic for business models that radically alter the production of goods and services (CHEN, 2016). Table 1 represents some of these expected capabilities and improvements due to the adoption of Industry 4.0. After defining what i4 is, as well as its components and design concepts, the Smart Factory concept is briefly discussed in the following section.

2.3.3. Smart factory and smart manufacturing developments

The terms "smart factory" and "smart manufacturing" are often used to outline the ultimate goal of Industry 4.0 for manufacturing plants and factories (ESMAEILIAN *ET AL.,* 2016; LIAO *ET AL.,* 2017). They are based on the idea that the capacity to enhance procedures through independent decision-making and self-optimization will be enabled by manufacturers due to the equipment of autonomous systems, sensors and actors (THAMES-SCHAEFER, 2016; ROBLEK *ET AL.,* 2016). Smart manufacturing provides a plethora of innovations and process transformations, and the concept of the "smart factory" symbolizes the ultimate objective. expected to be achieved by manufacturing firms when adopting Industry 4.0. Figure 7 shows the concept of smart factory as the hub of Industry 4.0 and its elements, where various interconnected functions are used to support it.

Table 1: Improvements enabled by adopting Industry 4.0 in manufacturing processes.

Authors	Improvements enabled by Industry 4.0
THAMES AND SCHAEFER (2016)	Ability to deploy network devices that share a common software provides the flexibility for manufacturers to configure machines and tools based on changes in processes; thus, reduces machine downtime.
CHENG *ET AL.*, (2016)	Dynamic configuration mode for production process that enables design, assembly, and testing of product to be done in modules that can be combined via software applications; thus, reducing product prototyping turnaround time.
WANG *ET AL.*, (2015)	Virtual-to-real remote component assembly in real-time, where an off-site operator can manipulate a physical robot instantly via virtual robot control in cyber-workspace; thus, reducing product assembly turnaround time.
LEE *ET AL.*, (2015)	Ability to process and analyse machining data, evaluate the health condition of critical machine and tool components, and improve the overall equipment efficiency and reliability by predicting upcoming failures, scheduling maintenance beforehand and adaptive control.
BRETTEL *ET AL.*, (2014)	Rapid product development as data is exchanged among humans, machines and products.
SCHUH *ET AL.*, (2014)	Simplify complexity of the value chain through virtual sharing of participants' output and performance, as well as problems and bottlenecks; which increases production transparency.

Source: Author's own contribution

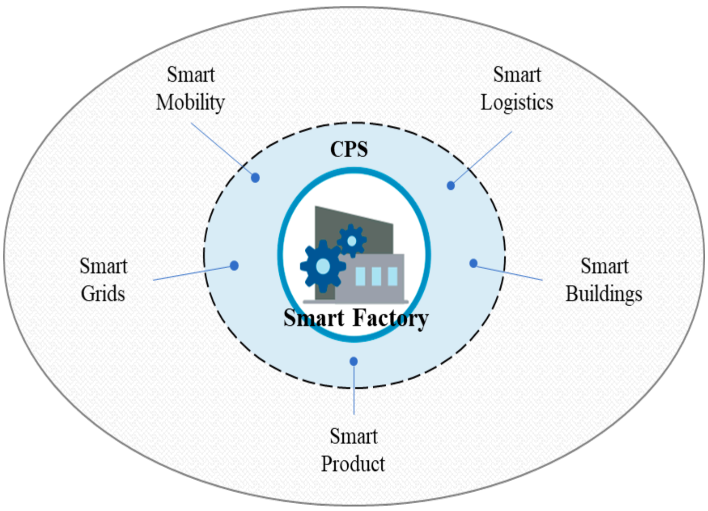

Figure 9: Framework around the central concept of the smart factory within Industry 4.0.

Source: KAGERMANN *ET AL.,* 2013.

"Smart manufacturing" and "smart factories," where the physical manufacturing value chain can be seamlessly integrated with its virtual counterpart in cyberspace through CSP and IoT, and then integrated with IoS, are becoming a reality today thanks to advancements in digitalization and the internet (LASI *ET AL.,* 2014; KAGERMANN *ET AL.,* 2013).

The Smart Factory, as a result of the pervasiveness of manufacturing technology, not only manufactures goods more effectively, but also means that products can be traced back to their raw material combinations; thus, the concept of smart products (ROBLEK *ET AL.,* 2016). The smart factory's integration with both its external and internal networks is showcased by means of its integration with logistics and smart mobility, buildings, and grids. This emphasizes the incorporation and interoperability of all components within the smart factory concept.

Moreover, automation, mechanics, and internet applications will contribute to the optimization of manufacturing resources, minimizing waste of resources and unnecessary labor, automation is important to sustain manufacture in accordance with the quality and standards demanded.

As a consequence of research and development, the smart sector is heading towards an automated and well-organized model. The CPS defines smart factory goods, tools, and processes, providing significant real-time advantages over conventional manufacturing systems in terms of quality, time, resources, and cost. Building and orienting the smart factory in accordance with service-oriented and sustainable business practices is possible (LASI *ET AL.,* 2014).

2.3.4. Industry 4.0 capabilities

Generally speaking, Industry 4.0 technologies are supposed to have a variety of effects on organizational components, such as innovation in business models (NASCIMENTO *ET AL.,* 2018), manufacturing management (FETTERMANN *ET AL.,* 2018), and the production of products and services (FRANK *ET AL.,* 2019A). These contributions profoundly change how people behave and carry out their responsibilities (STOCK *ET AL.,* 2018; SAHI *ET AL.,* 2019). However, despite the emphasis on technology in Industry 4.0, factors related to people, such as staff engagement and involvement in problem solving, will continue to be crucial for enhancing operational performance (TORTORELLA *ET AL.,* 2018). Thus, technologies of the Industry 4.0 not only have an impact on the technical aspects of organizations but also influence sociocultural factors.

Digital integration is supported by Industry 4.0 (I4.0) technologies from three main perspectives: vertical, horizontal, and end-to-end engineering (FATORACHIAN-KAZEMI, 2018). This integration facilitates connectivity and information exchange throughout the entire value chain (LIAO *ET AL*., 2017), potentially promoting improved cooperative learning and methodical instruction at all levels.

Several writers have proposed several frameworks for I4.0 implementation. The four tiers of LU (2017) conceptual framework—operational (organizational), systematic (applicable), technical, and semantic—focus on I4.0 interoperability. After a thorough examination of the literature, MITTAL *ET AL*. (2019) compiled a list of eleven technologies, three enabling factors, and five defining qualities that are relevant to the implementation of I4.0. In general, these frameworks have emerged from thorough literature reviews to serve as guidelines for implementing Industry 4.0 (I4.0). However, many of these frameworks still lack empirical validation and often overlook the potential influence of contextual factors.

Therefore, we contend that to effectively bolster sustainable performance enhancement during the Fourth Industrial Revolution era, it is essential to have a more thorough grasp of the connection between Industry 4.0 technologies and the capacities that I4.0 adoption towards sustainable performance.

2.4 Sustainability

Little was understood or appreciated about the relationship of planet Earth and humanity, not until the late of 20^{th} century. Humans have a diverse and wide-ranging effect on the world, and humanity is completely dependent on the planet to supply all of the material resources required for development and sustenance. In 1713, it was believed that Hans Carl von Carlowitz (1645–1714) was the first to present the idea of Nachhaltigkeit, or "sustainability" in German (WARDE *ET AL.,* 2018). With Thomas Malthus (1766-1834), probably the first to really address the potential effects of growing human populations, through his 1798 controversial essay on the Principle of Population (ibid). The relationship between population growth and food production was explored in the essay, arguing that while population grows geometrically, food production grows arithmetically, resulting in cycles of drought, food scarcity, and poverty. At that time sustainability was conceived as a local instead of global issues or phenomena that is too evident in today's globalized culture.

In the 18th and 19th centuries, advancements in technology, innovations and human movement led to the start of contemporary globalisation. A true understanding of these issues began to emerge in the twentieth century, especially in the latter half of the century.

2.4.1. Definitions of Sustainability

Since sustainability has arisen, hundreds of different ways have been used for describing it, with various contexts and fields of study (SHRIVASTAVA, 2010; HOFFMAN-BAZERMAN, 2005; LEAL-FILHO, 2000). DU PISANI (2006) mentioned that the sustainability definition that has been recognized internationally by "World Council of Environment and Development (WCED)" Thus, according to the World Congress of progress Economics (1987), sustainability is defined as "*growth that meets present demands without endangering the capacity of future generations to meet their own*" (WCED, 1987).

A modern approach for solving current environmental crisis is by adopting sustainability, which also ensures that degrading resources beyond point of renewal won't occur because of production (WCED, 1987). Sustainability is similar to the principles of truth and justice, which are difficult to define in a succinct manner and those terms mean varies widely between individuals and cultures, sustainability has risen to greater heights as a result of debates about its meaning (BELL-MORSE, 1999). DOBSON, (1996) mentioned that there are more than 300 definitions in literature of sustainable development.

- ***Sustainability 1980s definitions:***

REDCLIFT (1987) has defined sustainability as *"how well the system can continue to produce in the face of certain significant disruptions, such soil degradation, debt, and unexpected danger".*

- ***1990s definitions:***

Sustainability means *"the raising of human standards of living while maintaining the ecosystem's bearing capacity"* (GOODLAND, 1997).

Sustainability was also defined *as "match the requirements for development with the constraints on growth"* (DU PISANI, 2006).

- ***Millenniums definitions**:*

AGYEMAN-EVANS, (2004) had two definitions for sustainability: *"Even as the "environmental" components of sustainability are vital, they cannot be the only concerns when it comes to sustainability. A civilization that is really sustainable is one in which the environmental constraints placed by maintaining ecosystems are closely linked to broader issues of social needs, welfare, and economic opportunity"* or

"Sustainability is the requirement to maintain a higher standard of living for all people both now and in the future while living within the bounds of a healthy ecosystem".

The reason why there are many definitions for sustainability is because it is related to different components (environmental, economic and social) and each might be defined in a different way (BROWN *ET AL.,* 1997).

2.4.2. Concept of sustainable development

The terms sustainable development and sustainability are used correspondently (DRESNER, 2008). Apart from its gains, industrialization is linked to a number Several environmental and societal concerns with adverse effects consequences for the world. The claims that an industrialized nations' growth paths are unsustainable have been increasing in the world (AGYEMAN-EVANS 2004; TURNER II, 1997; HART, 1995; GOODLAND, 1995; WCDE, 1987). Sustainability was introduced as an alternative development approach to industrialization as a result of these protests over the issues created by industrialization. These debates have led to the urge for sustainability studies for determining the advantages and disadvantages on industries and regarding the sustenance of the planet. This research project is geared in the guidance for evaluation expected effects on sustainability after implementation of Industry 4.0 and positive and negative contributions of Industry 4.0 on food industry in the context of sustainability.

Around the world, sustainable development has arisen as a novel model and guiding concept for developmental endeavors (UNITED NATIONS, 2011; JAILLON-POON, 2008). Sustainable development agenda has been driven by the United Nations (EDUM-FOTWE-PRICE, 2009). According to them, the Brundtland Commission's effort established the norm for considering sustainable development in a wide range of policy decisions, is responsible for the current motivation of sustainable development.

The Rio conference reaffirmed the connection among environmental challenges, economic circumstances, and social equity concerns in the face of increasing demand for an enhanced quality of life (BRANDON-LOMBARDI, 2011), and outlined national policies, as well as reaffirming the political commitment to achieving long-term goals for development (UNITED NATIONS, 2011).

2.4.3. Triple Bottom line of Sustainability

ATKINSON (2008) argued that initially, sustainable development primarily concentrated on protection of the environment.. Then with time, it has evolved into social and economic considerations (MALIENE *ET AL.,* 2008). Ensuring harmony between the three pillars of sustainability—also known as the triple bottom line—is the main goal of sustainable development, as depicted in Figure 8 (HAWKINS-SHAW, 2004).

TBL (Triple bottom line) can be called in so many ways like: *"Pillars of sustainability, the 3Es' (Economic, Environmental and Equity), the 3Ps (Profits, Planet and people) of sustainability, elements of sustainability, components of sustainability, constituents of sustainability*". TBL was introduced in Rio de Janeiro at the Earth Summit of 1992 (GOPALAKRISHNAN *ET AL.,* 2012; MARKLeY-DAVIS, 2007; UN, 1995). Equal focus to environmental, economic and social pillars of sustainability in industries should be provided to achieve TBL. The TBL are connected with a network of intricate relationships of cause and effect. Since development cannot take place in the face of dwindling resources, and the environment cannot be preserved when expansion leads to environmental degradation (DYLLICK-HOCKERS, 2002). As a result, a sustainability plan for incorporating environmental policies into growth strategies is needed (WCED, 1987). The biggest issue is figuring out how to incorporate these three aspects of sustainability into industries (LINTON *ET AL.,* 2007). This is significant because Industry 4.0's effect on sustainability is still with no evidence.

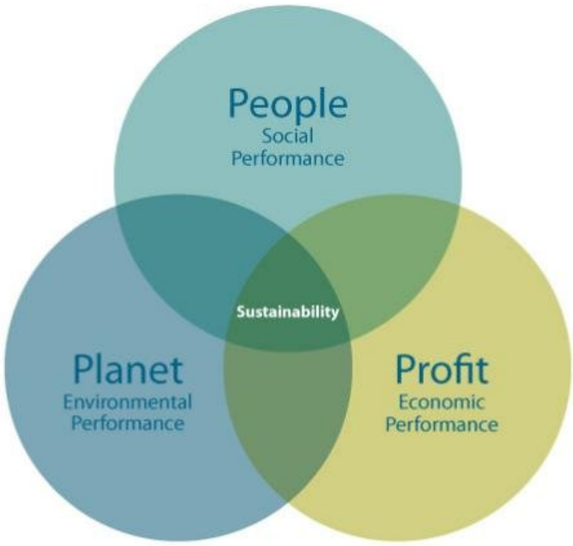

Figure 10: Sustainability's triple bottom line.

Source: ARSLAN-KISACIK, 2017.

2.4.4. Sustainability strategies

A variety of motives are found for implementing sustainability strategies (STEAD-STEAD, 1995). Cost savings of water and energy, increased reputation, energy enhanced value, brand differentiation, cost savings of capital and strengthened marketability are all reasons for businesses to participate in environmentally friendly practices (NEWELL, 2009). Most of the motives are concerned with ecological dimensions including pollution and waste reduction

(AYRES, 1989; STEAD-STEAD, 1995, UN, 2004). There are two classifications for sustainability strategies:

- Process Driven Sustainability Strategies
- Market Driven Sustainability Strategies.

Sustainability plans that are aimed at improving an organization's production process to increase its competitive advantage and environmental efficiency are known as process-driven strategies (STEAD-STEAD, 1995). According to STEAD-STEAD (1995), "market-driven sustainability strategies are those that give organizations a competitive edge by environmentally differentiating their products and/or markets from their competitors".

2.4.5. Sustainability and technology readiness in the Food Industry

The population's wellbeing can be determined by a well-functioning and stable biosphere's life support systems, which include its ecological and physical structures. Despite the fact that the planet is becoming more urbanized and separated from nature, human actions continuously introduce new pollutants into the ecosystem, which can disrupt the cycle of these systems, as in the case of the earth's natural greenhouse effect, which is currently being intensified by the massive amount of greenhouse gases released (MCMICHAEL, 2003).

The increasing visibility of global environmental change is evidenced by events like the global water crisis, global warming, and biodiversity loss. Society and economists are increasingly recognizing the imperative to address current sustainability challenges by examining human interaction with nature and our responsibility towards each other and future generations (BAUMGÄRTNER-QUAAS, 2010).

Individual customer requirements can be met while maintaining the productivity gained from automated manufacturing, implying that even one-off goods, products, or components with a batch size of one can be produced profitably can be allowed by smart factory. By Industry 4.0, the dynamic processes of engineering and businesses would offer the ability to respond flexibly to failures and disruptions and would also enable last-minute production changes. The production process would become transparent from beginning to end, allowing for better decision-making and design. It appears that the environment of food processing is ready for major economic and environmental sustainability improvements since the challenges for remaining sustainable of food industry are expanding. The synthesis of literature from food industry, industry 4.0 and sustainability developments, as well as supply chain from the industries in this era is the main driver for novel innovations to face the arising challenges, as represented by Figure 9.

2.5 Sustainability literature review process

To achieve the objective of this study, a systematic literature review in the fields of Industry 4.0 and sustainability, with specific reference to the supply chain was first developed. "*A systematic literature review has been defined as objective, transparent, and complete, and it should allow replicability"* (TRANFIELD *ET AL*., 2003). To ensure reliability and validity of the process, specific steps should be carried out, the four main stages of the systematic review of literature are 'planning', 'searching', 'screening' and 'Analysis. The following subsection describes the steps in further details.

Step 1: Planning

In order for the systematic method to be achieved, a review has been planned to establish the whole procedure. First step includes limiting and narrowing the target of the research by finding potential subject areas that should be explored.

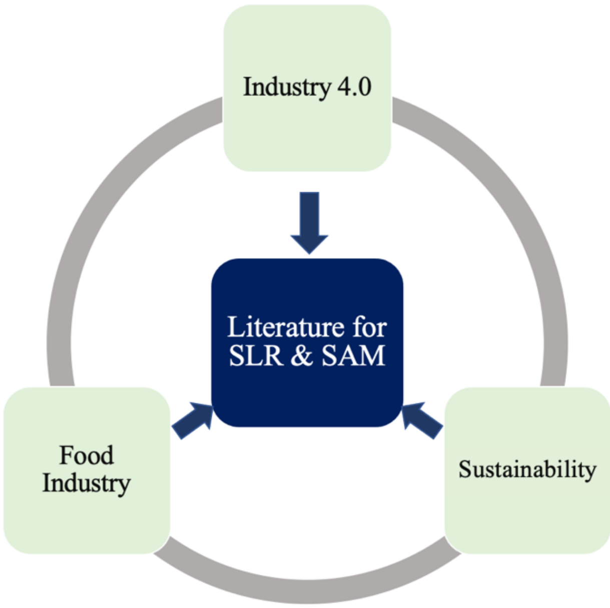

Figure 11: Knowledge synthesis of food industry, Industry 4.0 and sustainability.

Source: Author's own elaboration be interpreted and assessed, and the direction of future

Step 2: Systematic Literature Research

In order to investigate the research questions, it is necessary to synthesize previous studies through a literature review (FINK, 2019). This process illuminates existing knowledge, disparities among various papers, and current gaps in the research domain. As highlighted by GOUGH *ET AL.* (2017), employing this method facilitates the interpretation and evaluation of the strength of both past and present research, thereby guiding future research endeavors effectively. For this purpose, data from Scopus, Science Direct, and IEEE were utilized as sources for literature. A structured keyword search was conducted to identify relevant papers, with a focus on the themes of Industry 4.0 and sustainability within the context of the supply chain. The initial search terms included 'sustainability' AND 'Industry 4.0' AND 'supply chain', restricted to titles, keywords, and abstracts, and limited to the period from 2017 to 2020. This search yielded 160 papers, with additional relevant papers identified, totaling 172 papers potentially pertinent to the objectives of this article.

Step 3: Screening

A specific criterion for including and excluding papers was followed for further in-depth analysis, see Table 2, two rounds of screening were used to choose relevant articles. During the first screening, title and abstract were scanned roughly. Secondly the papers were read more intensively, and researches that did not focused specifically at the sustainable level were removed. At last, 35 papers were chosen for the systematic literature review.

Table 2: Inclusion criterion for the selected papers.

Filter	**Inclusion Criteria**
Document Type	Article
Databases	Science Direct, Scopus and IEEE
Keywords	Sustainability, sustainable, Industry 4.0, supply chain, social, economic, environment
Years	2017-2020
Language	English
Selected articles	35

Source: Author's own elaboration

Step 4: Reporting

TRANFIELD *ET AL.* (2003) said that an important step in systematic literature review is reporting. A descriptive and thematic analysis has been carried out, focusing on the sustainability approaches used in the study (empirical/theoretical), area subjects and sustainability pillars (economic/environmental/social) referring to the supply chain integrated with Industry 4.0. Thus, qualitative approach has been adopted for analyzing the papers. Figure 10 summarizes stages of systematic review of literature.

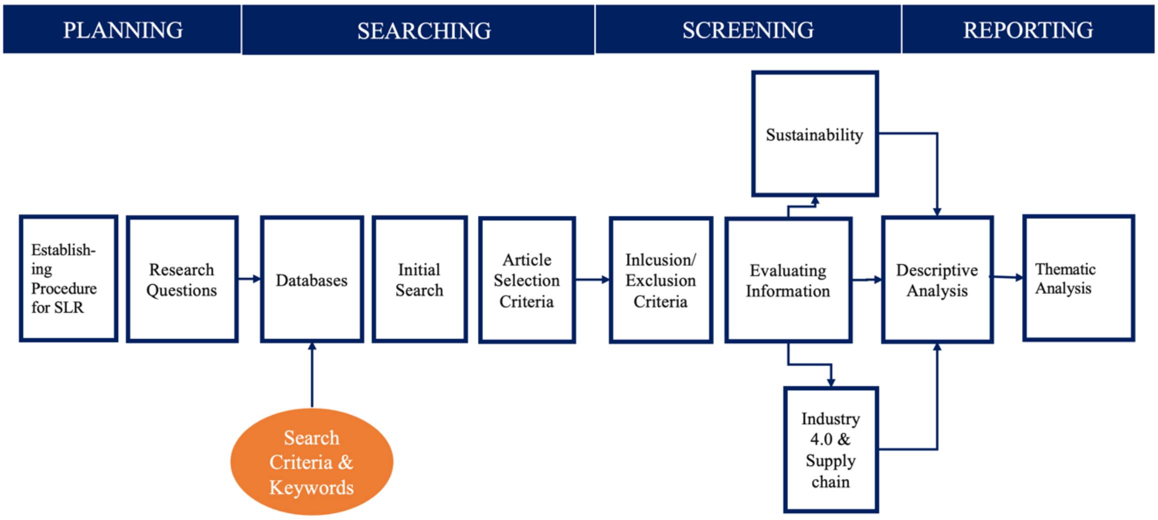

Figure 12: Summary for Systematic literature Review (SLR).

Source: TRANFIELD *ET AL*., (2003), Author' s own editing, (2021).

2.5.1. Descriptive Analysis

After identifying the articles of sustainability and supply chain in the context of Industry 4.0 with total number of 35 articles, a descriptive analysis was performed. Table 3 shows sources of the papers chosen for the study of literature and the frequency of each source. The dominant sources for discussing sustainability issues are Sustainability and Proceedings. Regarding the research institution's country of origin, Figure 11 represents percentage of contributions by each country. The United Kingdom has shown highest number of contributions (31%) followed by Switzerland and United states (20%). This can be explained by the fact that that United Kingdom Research and Development expenditure as a percentage of GDP stood at 1.7% in 2017 and they are aiming by 2027 to reach 2.4%, where the sector of manufacturing will play a huge role in reaching that target. In the United Kingdom, automation has been integrated in almost every manufacturing and logistics sectors.

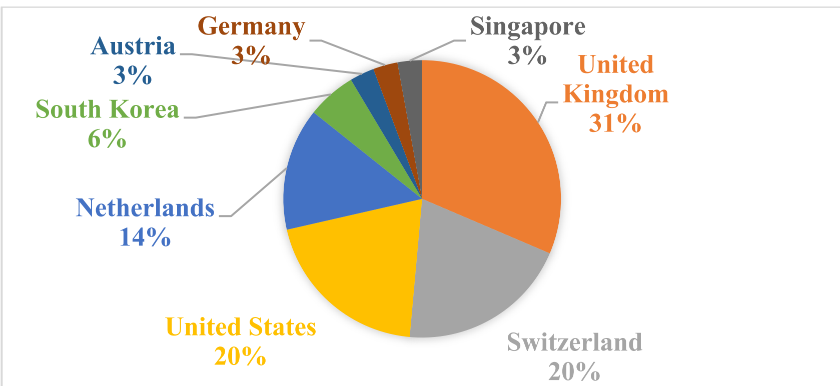

Figure 13: Percentage of contribution by each country

Source: Author's own elaboration.

Table 3: Academic journal of articles

Journal Name	**Frequency**
Computers and Industrial Engineering	3
Energies	1
Energy Procedia	1
IFAC-PapersOnLine	1
International Journal of Innovation Management	1
International Journal of Precision Engineering and Manufacturing-Green Technology	2
Journal of Cleaner Production	1
Journal of Manufacturing Systems	1
Journal of Manufacturing Technology Management	1
Journal of Sensors	1
Procedia CIRP	1
Procedia Manufacturing	2
Proceedings	6
Process Safety and Environmental Protection	4
Studies in Computational Intelligence	1
Sustainability	6
Technological Forecasting and Social Change	1
Waste Management and Research	1

Source: Author's own elaboration.

2.5.2. Thematic Analysis

The thematic analysis was performed so that the papers were reviewed and the sustainability three pillars (economic, environmental and social) were classified into factors that are influenced positively and negatively by supply chain four. Papers were explored in depth and have been divided into different factors. Some articles addressed issues of ecology specifically pointing to the energy conservation (DE MAN-STRANDHAGEN, 2017). The key points and findings for each sub-theme are then discussed in the following sections.

Environmental Sustainability

The first dimension of supply chain sustainability to be analyzed was the environmental dimension. The use of upgraded industry and technology will promote energy savings and environmental protection. Recent literature of supply 4.0 has focused on the area of productivity and efficiency of processes, adoption of Industry 4.0 pillars in the supply chain like big data, 3D printing, IoT has showed flexibility and efficiency of processes which enable them to production mass customization, making them more energy and environmentally efficient (MANAVALAN- JAYAKRISHNA, 2019; DING, 2018). Several studies have emphasized that the green issue is one of the main aspects of environmental sustainability, a mathematical model was proposed by (TSAI-LU, 2018). It should be mentioned that searches about IoT technology of Industry 4.0 are stressing to improve energy efficiency for the environmental aspect. Table 4 presents a brief list of the environmental factors of sustainability that are impacted by industry 4.0 on supply chain.

Table 4: Positive and negative factors of environmental pillar.

Related subjects in Articles	Positive	Negative
Natural Resource/Renewable Energy use	KIEL *ET AL.*, (2017); MONTELEONE *ET AL.*, (2020); STOCK *ET AL.*, (2018); DE MAN & STRANDHAGEN (2017);	KUMAR *ET AL.*, (2018); BIRKEL *ET AL.*, (2019);
Life cycle/ Resource circularity/Circular economy/Resource optimization	AXELSSON *ET AL.*, (2018); NASCIMENTO *ET AL.*, (2019); STOCK *ET AL.*, (2018); JABBOUR *ET AL.*, (2018); DING (2018); FRANCIOSI *ET AL.*, (2018); MIRANDA *ET AL.*, (2019);	BIRKEL *ET AL.*, (2019); MOGHADDAM *ET AL.*, (2018); WISNIEWSKA-SAŁEK (2018); BONILLA *ET AL.*, (2018);
Energy savings/Conservation	SHERAZI *ET AL.*, (2018); KUMAR *ET AL.*, (2018); BRACCINI & MARGHERITA (2018);	HIDAYATNO *ET AL.*, (2019); STOCK *ET AL.*, (2018); FRANCIOSI *ET AL.*, (2018);
Performance	DE MAN & STRANDHAGEN (2017); STOCK *ET AL.*, (2018); BELAUD *ET AL.*, (2019); BRACCINI & MARGHERITA (2018); SHROUF *ET AL.*, (2020);	LUTHRA & MANGLA (2018); BIBAUD-ALVES *ET AL.*, (2019);
Cleaner Processes	NASCIMENTO *ET AL.*, (2019); STOCK *ET AL.*, (2018); BRACCINI & MARGHERITA (2018); SHROUF *ET AL.*, (2020);	LUTHRA & MANGLA (2018); BONILLA *ET AL.*, (2018); FRANCIOSI *ET AL.*, (2018);
Productivity	BELAUD *ET AL.*, (2019); DING (2018); MÜLLER *ET AL.*, (2018);	MOGHADDAM *ET AL.*, (2018);
Efficiency	FRANCIOSI *ET AL.*, (2018); DEL CAMPO ET AL., (2018); MONTELEONE *ET AL.*, (2020); FRITZSCHE *ET AL.*, (2018); MIRANDA *ET AL.*, (2019);	LUTHRA & MANGLA (2018);
Green logistics/SC/Manu/design	BRACCINI & MARGHERITA (2018); KAMBLE *ET AL.*, (2018); NASCIMENTO *ET AL.*, (2019); KUMAR *ET AL.*, (2018); JABBOUR *ET AL.*, (2018);	KAMBLE *ET AL.*, (2018); BIRKEL *ET AL.*, (2019);
Biodiversity	MÜLLER *ET AL.*, (2018); FRITZSCHE *ET AL.*, (2018); STOCK *ET AL.*, (2018);	KAMBLE *ET AL.*, (2018); BIRKEL *ET AL.*, (2019); FRANCIOSI *ET AL.*, (2018);
Solid Waste	DING (2018); NASCIMENTO *ET AL.*, (2019); STOCK *ET AL.*, (2018); BELAUD *ET AL.*, (2019);	MANAVALAN & JAYAKRISHNA (2019); BIRKEL *ET AL.*, (2019);
Hazard Materials	JABBOUR *ET AL.*, (2018); NASCIMENTO *ET AL.*, (2019); KUMAR *ET AL.*, (2018);	KUMAR *ET AL.*, (2018); FRANCIOSI *ET AL.*, (2018);
Low carbon processes	MANAVALAN & JAYAKRISHNA (2019); KUMAR *ET AL.*, (2018); TSAI (2018); TSAI & LU (2018); STOCK *ET AL.*, (2018); NASCIMENTO *ET AL.* (2019);	KUMAR *ET AL.*, (2018);
Emission reduction	WISNIEWSKA-SAŁEK (2018); NASCIMENTO *ET AL.*, (2019);	MANAVALAN & JAYAKRISHNA (2019); BIRKEL *ET AL.*, (2019);

Source: Author’s own editing, 2021.

Economic Sustainability

When it comes to economic sustainability, the struggle is to control expenses while achieving sustainability, the need to achieve both goals has led the economic logic to evolve. Usually, reduction of services or quality can be the result of cost-cutting, instead of focusing on efficiency improvements or waste reduction, etc. Researches has shown that standardization of processes can improve efficiency, which can happen by introducing protocols and standards in service delivery. In NASCIMENTO *ET AL.* (2019) study, a circular economy business model has been raised for waste recycling according to the Industry 4.0 approach. In addition, several studies have given attention to the financial performance while applying supply chain 4.0, especially for those implementing green and eco-friendly practices. Table 5 lists the economic factors of sustainability and how they are affected by supply 4.0.

Table 5: Positive and negative factors of economic pillar.

Related subjects in Articles	Positive	Negative
Increase profit and cost reduction	KIEL *ET AL.*, (2017); MANAVALAN & JAYAKRISHNA (2019); BRACCINI & MARGHERITA (2018); KAMBLE *ET AL.*, (2018);	LUTHRA & MANGLA (2018); DE MAN & STRANDHAGEN (2017); KUMAR *ET AL.*, (2018); KAMBLE *ET AL.*, (2018); PARAVIZO *ET AL.,* (2018);
Productivity and efficiency	MANAVALAN & JAYAKRISHNA (2019); YAZDI *ET AL.*, (2018); BRACCINI & MARGHERITA (2018); SHERAZI *ET AL.,* (2018); FRANCIOSI *ET AL.,* (2018);	LUTHRA & MANGLA (2018); MOGHADDAM *ET AL.,* (2018); BIBAUD-ALVES *ET AL.*, (2019);
Product longevity and durability	DE MAN & STRANDHAGEN (2017); DING (2018); KAMBLE *ET AL.,* (2018); MIRANDA *ET AL.,* (2019);	LUTHRA & MANGLA (2018);
Transparency between companies	KIEL ET AL., (2017); DING (2018); SHROUF *ET AL.*, (2020);	LUTHRA & MANGLA (2018); BIRKEL *ET AL.,* (2019);
Reliability of Data	SHROUF *ET AL.*, (2020); AXELSSON *ET AL.*, (2018); DE MAN & STRANDHAGEN (2017);	KIEL ET AL., (2017); LUTHRA & MANGLA (2018); BIRKEL *ET AL.*, (2019); MOGHADDAM ET AL., (2018);
Business models product and process quality supply chain integration	KIEL *ET AL.*, (2017); MÜLLER & VOIGT (2018); STOCK *ET AL.*, (2018); NASCIMENTO *ET AL.*, (2019);	LUTHRA & MANGLA (2018); BIRKEL *ET AL.*, (2019); MOGHADDAM *ET AL.*, (2018);
Competitiveness	KIEL *ET AL.*, (2017); BRACCINI & MARGHERITA (2018); WISNIEWSKA-SAŁEK (2018);	LUTHRA & MANGLA (2018); BIRKEL *ET AL.*, (2019); MÜLLER & VOIGT (2018);
Economic Growth	HIDAYATNO *ET AL.*, (2019)	LUTHRA & MANGLA (2018); BIRKEL *ET AL.*, (2019);
Circular economy	HIDAYATNO *ET AL.*, (2019)	LUTHRA & MANGLA (2018);

Source: Author's own editing, 2021.

Social Sustainability

In regards to the third pillar of sustainability in supply chain 4.0 environment, which is the social pillar, a literature review was created by (STOCK *ET AL.,* 2018). The aim of this literature was to build value through an approach focused on social and environmental aspects in the I4.0 sense. An "intelligent cube production", was used by the authors to analyze and evaluate results of Industry 4.0 potential on both social and environmental dimensions. This "intelligent cube production" consists of RFID technology smart product based in (the Sino-German Research Institute), a Chinese institute. CHAIM *ET AL.* (2018) have discussed the opportunity to integrate (KPIs) key performance indicators for measuring sustainability outcomes of I4.0 context in a virtual learning environment. Indicators such as work conditions and job opportunities can be authenticated as social issues. Challenges in this field can be linked to the effects of technological systems substitution of many jobs. Table 6 shows the impacted factors of social sustainability.

Table 6: Positive and negative factors of social pillar.

Related subjects in Articles	Positive	Negative
Standard of living	CHAIM *ET AL.*, (2018); DE MAN & STRANDHAGEN (2017); PARAVIZO *ET AL.,* (2018); FRANCIOSI *ET AL.*, (2018); HIDAYATNO *ET AL.*, (2019),	BIRKEL *ET AL.*, (2018); BONILLA *ET AL.*, (2018); BRACCINI & MARGHERITA (2018);
Education	MÜLLER *ET AL.*, (2018); PARAVIZO *ET AL.*, (2018); STOCK *ET AL.*, (2018);	LUTHRA & MANGLA (2018); KIEL *ET AL.*, (2017); BIRKEL *ET AL.*, (2019); WISNIEWSKA-SAŁEK (2018);
Include employees with some degree of disability	KAMBLE *ET AL.*, (2018); KIEL *ET AL.*, (2017);	
Job Opportunities	BRACCINI & MARGHERITA (2018);	BIRKEL *ET AL.*, (2019); DING (2018); MIRANDA *ET AL.*, (2019); MÜLLER & VOIGT (2018); STOCK *ET AL.*, (2018); TSAI (2018);
Quality of work conditions	DE MAN & STRANDHAGEN (2017); KIEL *ET AL.*, (2017); MÜLLER *ET AL.*, (2018); KAMBLE *ET AL.*, (2018); MIRANDA *ET AL.*, (2019);	BIRKEL *ET AL.*, (2019); LUTHRA & MANGLA (2018); MOGHADDAM *ET AL.*, (2018);
Relationship between organizations	DING (2018); KAMBLE *ET AL.*, (2018); MÜLLER & VOIGT (2018);	BIRKEL *ET AL.*, (2019); KIEL *ET AL.*, (2017); LUTHRA & MANGLA (2018); MÜLLER *ET AL.*, (2018);
Corportate Social Responsibility (CSR)	DE MAN & STRANDHAGEN (2017); PARAVIZO *ET AL.*, (2018); KAMBLE *ET AL.*, (2018); MÜLLER *ET AL.*, (2018); RODA-SANCHEZ *ET AL.*, (2018);	BIRKEL *ET AL.*, (2019); KAMBLE *ET AL.*, (2018); LUTHRA & MANGLA (2018); MOGHADDAM *ET AL.*, (2018);
Workplace safety management (decrease working accidents)	MANAVALAN & JAYAKRISHNA (2019); BRACCINI & MARGHERITA (2018); KAMBLE *ET AL.*, (2018); RODA-SANCHEZ *ET AL.*, (2018);	FRANCIOSI *ET AL.*, (2018); KUMAR *ET AL.*, (2018);

Source: Author's own editing, 2021.

2.5.3. Sustainability Assessment Model (SAM)

A tool for sustainability evaluations has emerged that has a specific purpose towards guide planning and decision for long-term sustainability (SINGH *ET AL.*, 2011). Assessment of sustainability has been receiving increased focus from scholars and in policy making through practical application in managing the industries (STREIMIKIENE *ET AL.,* 2009). The Sustainability assessment aims to provide a measuring tool for local and global intertwined nature-society systems for both immediate and future considerations, aiding decision-makers in determining appropriate courses of action., and which should be avoided, in order to mold society and businesses to become more sustainable (NESS *ET AL.,* 2007). The underlying rationale behind implementing sustainability in companies primarily revolves around ecological concerns, such as resource conservation, emissions reduction, and waste reduction. Other economic reasons include increased revenue turnover, profit margins, market expansion, and competition. A Sustainability assessment should be performed when implementing Industry 4.0 on food industries.

Sustainability assessment model (SAM) is a "*a method for estimating a project's sustainability and introducing sustainable development ideas to those inside organizations*" (BEBBINGTON -FRAME, 2003; BAXTER *ET AL.,* 2002). Any form of Industry 4.0 application require decision making that has effects on sustainability. Activities performed in food industry should maximize financial and economic benefits and at the same time know the corresponding effects on the society and the environment. A tool that will help organizations to assess the consequences of their actions is the SAM (BEBBINGTON-FRAME, 2011).

After classifying the factors of sustainability which are affected by Industry 4.0 and supply chain management, it is clear that supply chain 4.0 impacts different areas of each pillar of sustainability. Based on the synthesis of the created factors and classifications, the relations between supply chain management, Industry 4.0 and sustainability have been analyzed, leading to developing sub-goals or subthemes of sustainability. The subthemes were divided as follows: Production & Resourcing, Technology and Innovation, Macro-economics, Materials & Energy, Environmental Management, Emission, Waste and Pollution Prevention, Community, Individuals) through the triple bottom line. Based on the content analysis the eight subthemes of sustainability will improve to understand how sustainability can be affected during the adoptions of digital technologies. Figure 12 shows a SAM based on thematic analysis synthesis organized by each dimension and subtheme of sustainability after integrating both Industry 4.0 and supply chain management pillars. The most-valued sustainability factors include outcomes of Industry 4.0 integration on supply chain management.

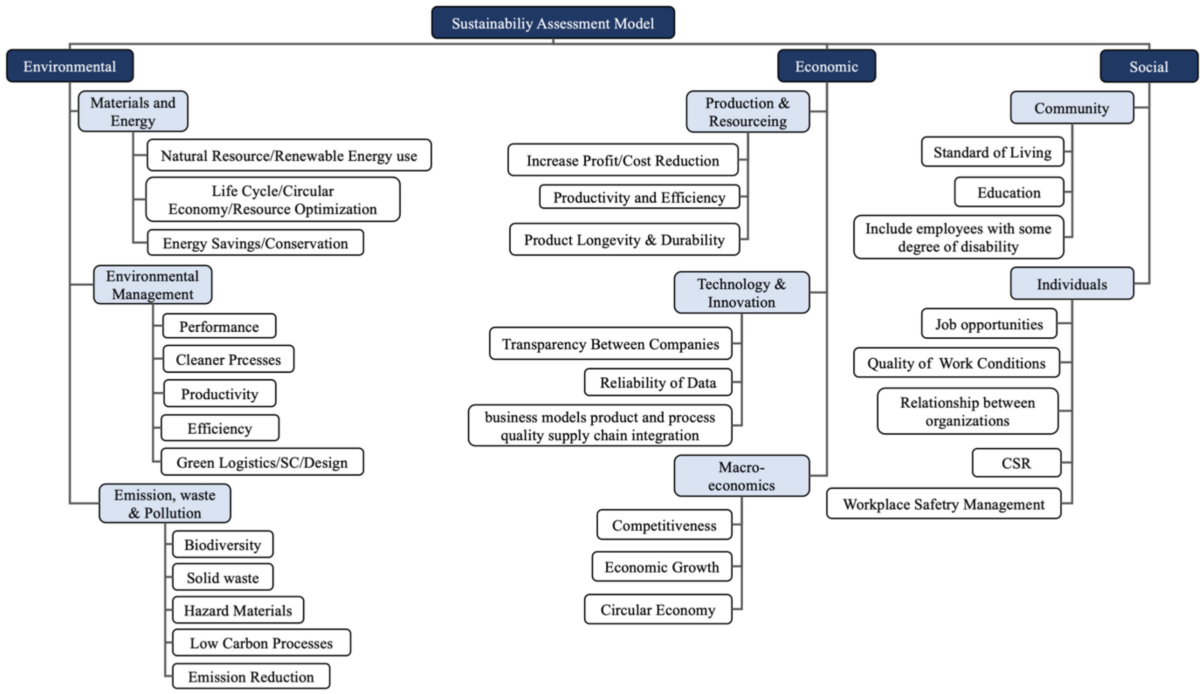

Figure 14: Framework of sustainability assessment tools.

Source: Author's own elaboration.

2.6 Development of the theoretical model of and conceptual framework

To understand the drivers and challenges of adopting Industry 4.0 in the food industry's sustainability, an integrated theoretical model should be developed. This model would analyze the key drivers, such as the potential for resource optimization and improved efficiency in sustainable food production. It would also consider the challenges, including the initial investment required, changes in organizational structure and workflow, job displacement concerns, and cybersecurity risks. Additionally, the model would examine the impact of Industry 4.0 on food industry's sustainability, focusing on factors such as reduced waste, improved traceability, and increased transparency in the supply chain. This model would provide a comprehensive understanding of the complex relationship between Industry 4.0 and sustainability in the food industry, helping stakeholders identify opportunities and overcome challenges to successfully implement Industry 4.0 initiatives and achieve long-term sustainability goals.

2.6.1. Impacts of Industry 4.0 in on food Industry's sustainability

The term "industry 4.0," or "the Fourth Industrial Revolution," has the potential to revolutionize the food industry and drive sustainable practices. By leveraging technologies such as simulation, the Industrial Internet of Things, autonomous robots, and big data and analytics, the food industry can improve efficiency and reduce its environmental impact. Additionally, the integration of Industry 4.0 technologies with supply chain systems can enhance the sustainability of food production. By implementing Industry 4.0, food manufacturers can monitor and optimize their production processes in real-time, leading to more efficient use of resources and reduction of waste. Overall, the implementation of Industry 4.0 in the food industry has the potential to significantly enhance sustainability practices (BAI *ET AL.,* 2020).

By incorporating advanced technologies and digitalization, food producers may minimize their environmental effect, cut waste, and optimize their manufacturing methods. These technologies can enable more efficient inventory management, improved supply chain visibility, and better traceability of food products. Additionally, the use of automation and robotics in manufacturing processes can lead to lower energy consumption and reduced greenhouse gas emissions. Furthermore, the application of Big Data analytics and artificial intelligence can help identify patterns and optimize resource allocation, leading to improved resource efficiency (VAIDYA *ET AL.,* 2018). Overall, the integration of Industry 4.0 in the food industry can contribute to the development of a more sustainable food production system.

Industry 4.0 technologies have the potential to facilitate the execution of sustainable practices in the food industry by promoting transparency and accountability. By digitizing and automating processes, Industry 4.0 can enable real-time monitoring and data collection, allowing for better tracking of sustainability measurements like energy and water use, and waste generation. This data-driven approach can help food manufacturers find areas for development and take well-informed judgements to enhance their sustainability performance. In summary, Industry 4.0 implementation in the food industry has the potential to revolutionize sustainable food production. By leveraging advanced technologies and digitalization, the food industry can optimize processes, reduce waste, enhance supply chain visibility, and improve resource efficiency. This, in turn, can contribute to the overall sustainability of the food industry by addressing key challenges such as food safety, waste reduction, and sustainable sourcing (VAIDYA *ET AL.,* 2018).

2.6.2. The scope of I4.0 implementation

To develop a theoretical framework for this study, it would be crucial to pinpoint the levels that Industry 4.0 capabilities relevant within the context of adopting I4.0 within food industry. This research employs the concept "I4.0 implementation" to denote a gradual integration of manufacturing technologies within food industry over time. Specifically, I4.0 adoption encompasses acquiring I4.0 components such as equipments, tools, equipment, techniques, systems and methodologies, by integrating them into particular manufacturing procedures for their intended purposes. This acknowledges that successful technology adoption necessitates understanding not just the individual tangible and computational systems but also their interconnections. The extent of empirical testing regarding I4.0 adoption lacks relating to industrial and organizational. Consequently, this study assumes that the characteristics and obstacles associated with I4.0 adoption acknowledges the significance of examining diverse pertinent concerns over time when assessing technology utilization in manufacturing, including the accessibility and preparedness of technologies and the degree of industry adoption regarding their practicality.

A greater degree of automation is brought about by Industry 4.0, which also makes use of information and communication technology to facilitate factory communications. As a result, the industrial ecosystem becomes increasingly sophisticated and networked, with real-time interaction amongst all value chain participants. The transition to Industry 4.0 makes it possible to integrate cutting-edge technologies like big data analytics, simulation, and the Internet of Things, creating a manufacturing environment that is more productive and efficient. Manufacturing companies may get greater degrees of organization and control throughout the whole value chain of product life cycles with Industry 4.0. This includes the capacity to reduce waste and continuously improve manufacturing processes, as well as the flexibility to customize goods to fit specific client requirements (VAIDYA *ET AL.,* 2018).

Industry 4.0 brings a range of industrial and organizational capabilities to manufacturing. These capabilities enable manufacturing organizations to achieve higher levels of productivity, efficiency, and customer satisfaction. The industrial and organizational capabilities of Industry 4.0 empower manufacturing organizations to optimize their production processes, adapt to changing customer needs, and drive innovation (VAIDYA *ET AL.,* 2018). Industrial capabilities include enhanced IoT/Food Safety Management Systems, Blockchain Technology, Big Data Analytics, Automation and Food Traceability Systems, AI & ML. Industrial capabilities are summarized in Table 7.

Table 7: Industry 4.0 Industrial Capabilities.

Category	Dimension	Purpose in Food industry	*Author*
I4.0 Industrial Capability	**IoT/Food Safety management**	IoT devices can monitor various aspects of food production, storage, and transportation, such as temperature, humidity, and inventory levels. This helps optimize processes, ensure food quality, and prevent waste.	LU, 2017; ALCÁCER AND CRUZ, 2019
	Blockchain technology	Blockchain can be used to create transparent and traceable supply chains, allowing consumers to track the journey of their food products from farm to table. This enhances food safety and enables quick identification and resolution of issues such as contamination or recalls.	KAYIKCI *ET AL.,* 2020; VAIDYA *ET AL.,* 2018
	Big Data Analytics	Analyzing large volumes of data collected throughout the food supply chain can provide valuable insights for improving efficiency, predicting demand, optimizing inventory management, and identifying areas for quality improvement.	KARADGI *ET AL.,* 2021
	Automation and Food Traceability Systems	Automation technologies can streamline food production processes, such as sorting, packaging, and labeling, increasing efficiency, reducing labor costs, and improving food safety and hygiene.	JAMWAL *ET AL.*, 2021
	Artificial Intelligence (AI) and Machine Learning (ML)	AI and ML algorithms can be used to analyze data from sensors, cameras, and other sources to detect anomalies, predict equipment failures, optimize production processes, and personalize consumer experiences.	AUJLA *ET AL.*, 2018

Source: Author's own elaboration.

Industry 4.0 also introduces various organizational capabilities that enable industries to leverage advanced technologies and data-driven approaches for improved efficiency, productivity, and innovation. The key Industry 4.0 organizational capabilities include: Data-Driven Decision Making, Agility and Flexibility, Operational Efficiency and Productivity, Innovation and Product Development, Visibility and Resilience, Centricity and Personalization, Connectivity and Collaboration. The I4.0 organizational capabilities are summarized in Table 8.

Furthermore, organizational readiness is indispensable for successfully transitioning to Industry 4.0. This readiness encompasses not only technological aspects but also cultural and strategic elements. Organizations need to foster a culture of experimentation and risk-taking to embrace the disruptive changes that come with Industry 4.0. Moreover, effective change management processes and a focus on upskilling and reskilling the workforce are essential for realizing the full potential of Industry 4.0 capabilities.

Overall, the industrial and organizational capabilities in the context of Industry 4.0 are intertwined and mutually reinforce each other (TORTORELLA *ET AL.*, 2020). The success of Industry 4.0 implementation relies on the collective abilities of industrial and organizations to adapt, innovate, and collaborate in a digital and automated manufacturing environment (VAIDYA *ET AL.,* 2018).

In conclusion, the industrial and organizational capabilities of Industry 4.0, enabled by technologies such as cloud computing and the Internet of Things, revolutionize the manufacturing industry by providing opportunities for enhanced automation, real-time engagement, and interconnectedness. Industry 4.0 capabilities involve both industrial and organizational capabilities, encompassing technological, cultural, and strategic aspects (MÜLLER *ET AL.,* 2018). Therefore, after reviewing the literature on Industry 4.0 adoption in this chapter, two categories of Industry 4.0 capability technologies have been identified to represent Industry 4.0 capabilities.

2.6.3. Benefits and Performance of implementing Industry 4.0 for TBL

The adoption and implementation of Industry 4.0 (I4.0) leading to Triple Bottom Line (TBL) outcomes vary depending on the specific circumstances. For example, BRACCINI-MARGHERITA (2018) outlined two potential paths for integrating I4.0 technologies in their real-world study, which aimed to enhance organizational sustainability by addressing the social, economic, and environmental dimensions of TBL sustainability. Similarly, BEIER *ET AL.*, (2017) conducted an empirical comparison of manufacturing firms in both Germany where it has a highly industrialised economy, while China's industrial economy is expanding quickly. Their research indicated that digital transformation can contribute to environmental sustainability through improved resource efficiency and increased use of renewable energy sources, while advancements in less labour and the development of intelligent support systems can promote social and technological sustainability. As per MÜLLER *ET AL.* (2018), successful implementation of Industry 4.0 (I4.0) is primarily propelled by opportunities in the areas of strategy, operations, the environment, and society, while its main challenges revolve around maintaining competitiveness and ensuring future viability.

Table 8: Industry 4.0 Organizațional Capabilities.

Category	**Dimension**	**Purpose in Food industry**	***Author***
I4.0 Organizational Capability	**Data-Driven Decision Making**	Industry 4.0 enables organizations to collect vast amounts of data from interconnected devices, sensors, and systems. This data is then analyzed using advanced analytics and artificial intelligence algorithms to derive actionable insights, leading to more informed and data-driven decision-making processes.	LU, 2017
	Agility and Flexibility	With Industry 4.0 technologies, organizations can adapt more quickly to changing market conditions, customer demands, and competitive pressures. Agile manufacturing processes, enabled by technologies like additive manufacturing and digital twins, allow for rapid prototyping, customization, and production adjustments.	VAIDYA *ET AL.,* 2018
	Operational Efficiency and Productivity	Automation and robotics technologies streamline operations, reduce manual labor, and minimize errors, resulting in increased operational efficiency and productivity. Predictive maintenance powered by IoT and AI helps organizations optimize equipment uptime and minimize downtime.	OLSEN AND TOMLIN, 2019
	Innovation and Product Development	Industry 4.0 fosters innovation by providing organizations with tools and technologies for digital design, simulation, and prototyping. Digital twins allow companies to experiment with new ideas in virtual environments before physical implementation, accelerating the product development cycle.	JAMWAL *ET AL.,* 2021
	Visibility and Resilience	IoT sensors, blockchain technology, and real-time data analytics enhance supply chain visibility, enabling organizations to track and trace products throughout the entire supply chain. This transparency improves inventory management, reduces risks, and enhances supply chain resilience.	SALUNKHE AND BERGLUND, 2020
	Centricity and Personalization	Industry 4.0 enables organizations to gather and analyze customer data to gain insights into preferences, behavior, and needs. This information can be used to personalize products, services, and experiences, enhancing customer satisfaction and loyalty.	PYANKOVA *ET AL.*, 2019
	Connectivity and Collaboration	Industry 4.0 fosters global connectivity and collaboration by breaking down geographical barriers and enabling real-time communication and collaboration among distributed teams. Cloud computing, collaborative platforms, and digital workflows facilitate seamless collaboration across borders.	MÜLLER *ET AL.*, 2018

Source: Author’s own contribution

I4.0-driven autonomous Internet of Things (IoT) and other technologies have transformed conventional manufacturing businesses into smart factories. These smart factories are recognized for their sustainability, with IoT playing a crucial role in improving energy efficiency and tackling issues related to environmental sustainability (WU *ET AL.,* 2016). MENG *ET AL.* (2018), for instance, examined the relationship between sustainability and manufacturing, emphasising energy efficiency as a primary goal for smart factories. Similarly, WU *ET AL.* (2016) identified a connection between Big Data (BD) and environmental concerns like sustainability, proposing two measures to address environmental issues through BD: effective resource efficiency and effective energy efficiency.

Technologies built on the Internet of Things (I4.0) have completely changed the supply chain, from raw materials to end-of-life procedures. The responsibilities that suppliers, manufacturers, and consumers play in promoting long-term, sustainable solutions that benefit the environment, the economy, and society have all been profoundly influenced by this shift. In their 2020 study, LUTHRA *ET AL.* (2020) examined the variables that are driving Industry 4.0 and sustainability in supply chains, emphasizing the need of "government supportive policies" and "collaboration and transparency" in attaining Triple Bottom Line (TBL) sustainability, especially in developing nations such as India.

Furthermore, RAMIREZ-PENA *ET AL.* (2020) investigated the relationship between important I4.0-enabling technologies and supply chain archetypes in the shipbuilding industry, including lean, agile, resilient, and green. They found that the shipbuilding supply chain was both lean and green, suggesting a link between social sustainability and green supply chain models. It has been determined that I4.0 technologies such as augmented reality, carbon capture (CC), autonomous robots, cybersecurity, additive manufacturing, and cybersecurity improve the economic and environmental sustainability of shipbuilding supply chains. They also classified simulation, Internet of Things, and Big Data (BD) as drivers of social sustainability.

JEBLE *ET AL.* (2018) conducted an empirical analysis on the influence of Big Data (BD) as well as forecast analysis for the growth of sustainable businesses. Their findings indicated that gaining a competitive edge might result from merging organizational capacities and resources. Additionally, they noted that Triple Bottom Line (TBL) results are positively impacted by BD and predictive analysis. particularly when moderated by the complexity of the supply base, resulting in technological and organizational benefits related to Sustainable Business Models (SBMs).

PRAUSE (2015) discussed the effect of Industry 4.0 (I4.0) on sustainable business modeling, focusing on how fractal-based information points within supply chain product life cycles can enhance BD traceability and transparency, supporting organizational and societal sustainability in the process. Although there isn't much research on SBMs for sustainable supply chains, greater study on business models with a focus on social and environmental advantages is required. These advantages must to be viewed as potential for the commercialization of social and environmental benefits throughout whole supply chains, not only as byproducts of economic gains (BIRKEL- MÜLLER, 2021).

KHAN *ET AL.* (2021) explored A comprehensive framework driven by policy was used to address the Circular Economy (CE), Sustainable Business Models (SBMs), Triple Bottom Line (TBL), and Sustainable Development (SD). This framework places a strong emphasis on utilizing Industry 4.0 (I4.0) to maximize social and corporate value while improving resource efficiency in order to create sustainable value. The economy, society, and the environment all gain from such a strategy. In addition to creative policies within a wide-ranging social and institutional framework, a well-thought-out I4.0 implementation strategy should take into account the quintuple helix (business, government, education, environment, and society) and the quintuple bottom line (social, economic, environmental, and technological).

2.6.4. Drivers and Challenges of implementing Industry 4.0 in the food Industry

Integration of sustainability and sustainable practices have become crucial in the food industry to meet customer expectations and improve corporate social responsibility (MÜLLER *ET AL.,* 2018). Apart from meeting customer expectations and enhancing corporate social responsibility, the adoption of sustainable practices in the food industry is driven by the need to efficiently manage production and services, address food safety and security concerns, control perishability, respond to competitive pressures, and predict demand accurately. Integrating Industry 4.0 technologies, also known as "smart factory" technologies, can help address these challenges and provide solutions for sustainable food production.

Industry 4 0 offers several drivers for the adoption of sustainable practices in the food industry (MÜLLER *ET AL.,* 2018). These drivers include:

- Strategic opportunities: Industry 4.0 provides opportunities for companies to develop and implement sustainable strategies that align with their goals and values.
- Operational opportunities: Industry 4.0 offers technological advancements such as automation, artificial intelligence, and data analytics that can optimize operations and improve efficiency in sustainable food production.

- Environmental opportunities: Industry 4.0 enables the implementation of green technologies and processes, such as energy-efficient machinery and waste reduction measures, that contribute to environmental sustainability in the food industry.
- Social opportunities: Industry 4..0 can enhance social sustainability by improving worker safety, job satisfaction, and well-being through the use of robotics and automation.
- Efficiency Improvement: Industry 4.0 technologies enhance efficiency throughout the food supply chain, reducing waste, energy consumption, and resource usage, which aligns with sustainability goals.
- Traceability and Transparency: Technologies like blockchain and IoT enable better traceability and transparency in the food supply chain, which can improve food safety, reduce food fraud, and increase consumer trust in sustainability practices.
- Data-Driven Decision Making: Data gathering and analysis at many phases of food production and distribution are made possible by Industry 4.0. This data-driven methodology facilitates improved decision-making for process optimization, minimize environmental impact, and enhance sustainability performance.
- Resource Optimization: Precision agriculture technologies and smart resource management systems help optimize water usage, minimize chemical inputs, and reduce environmental impact in food production, contributing to sustainability goals.
- Consumer Demand for Sustainable Products: There is a growing demand from consumers for sustainable food products and transparent supply chains. Industry 4.0 technologies can help food companies meet these demands by providing verifiable information about the sustainability of their products.

While Industry 4.0 presents numerous opportunities for sustainable food production, there are also various challenges that need to be addressed. These challenges include:

- Competitiveness and future viability: Implementing Industry 4.0 technologies can be costly and require significant investment, which may pose challenges for smaller businesses or those operating on tight budgets.
- Organizational and production fit: Integrating Industry 4.0 technologies into existing food production processes and systems can be complex and may require changes in organizational structure, workflow, and skills.

- Perception and acceptance: Some stakeholders in the food industry may be hesitant to adopt Industry 4.0 due to concerns about job displacement, cybersecurity risks, and the overall impact on the workforce.
- Resource utilization: While Industry 4.0 can optimize resource utilization in sustainable food production, it also requires a significant amount of energy and resources for its implementation.
- Maintenance, time, and cost: Implementing Industry 4. 0 technologies in the food industry requires ongoing maintenance, training, and investment in order to ensure proper functionality and efficiency. Furthermore, the integration of Industry 4.0 may initially require additional time and cost for training employees and upgrading existing systems.
- Cost of Implementation: Implementing Industry 4.0 technologies requires significant investment in infrastructure, technology, and workforce training. The initial costs may pose challenges for small and medium-sized food companies, particularly those operating on tight margins.
- Data Security and Privacy: Industry 4.0 involves the collection and sharing of large amounts of data across interconnected systems. Ensuring data security and privacy while maintaining transparency can be challenging, especially given the sensitive nature of food-related data.
- Interoperability and Standardization: The integration of various Industry 4.0 technologies, systems, and platforms in the food supply chain requires interoperability and standardization to ensure seamless data exchange and communication. Achieving interoperability among different technologies and stakeholders can be complex and time-consuming.
- Skills Gap and Workforce Training: Industry 4.0 requires a workforce with digital skills and competencies to operate and manage advanced technologies effectively. Bridging the skills gap and providing adequate training for employees, particularly in traditional sectors of the food industry, can be a challenge.
- Regulatory Compliance: Compliance with food safety, quality, and sustainability regulations is critical for food companies. Industry 4.0 technologies may introduce new regulatory challenges related to data management, cybersecurity, and product traceability, requiring companies to adapt their processes and systems accordingly.
- Supply Chain Complexity: The food supply chain is complex, involving multiple stakeholders, processes, and geographies. Implementing Industry 4.0 technologies

across the supply chain requires coordination, collaboration, and alignment of interests among diverse stakeholders, which can be challenging.

The complexity of Industry 4.0 technologies may result in unforeseen challenges and delays in implementation. One of the challenges in adopting Industry 4.0 in sustainable food production is the initial investment required. Another challenge is the need for changes in organizational structure and workflow to integrate Industry 4.0 technologies successfully. There may be concerns around job displacement and cybersecurity risks. Furthermore, ensuring the acceptance and perception of Industry 4.0 among stakeholders in the food industry can also be a challenge. These challenges can hinder the widespread adoption of Industry 4.0.

Addressing these challenges while leveraging the drivers for sustainability is essential for the successful implementation of Industry 4.0 in the food industry and achieving long-term sustainability goals. Collaboration among industry players, government agencies, and technology providers is key to overcoming these challenges and realizing the full potential of Industry 4.0 for sustainability in the food sector.

2.6.5. Theoretical Model of this research

The main aim of this section is to outline a model designed to elucidate the intricate dynamics within the implementation effects of I4.0 on food industries sustainability. It identifies six essential elements crucial for fostering a more sustainable food industry through implementation of I4.0. In section 2.7, a model has been developed through the systematic review of sustainability assessment tools to find the sustainability factors to be assessed, this model can explain the successful interventions of I4.0 adoption capabilities in the food sector. Subsequently, the model will elaborate on how I4.0 adoption capabilities synergize to influence the factors of the three pillars of sustainability developed. The changes advocated by I4.0 capabilities involve navigating the driver and challenges aspects of the I4.0 adoption, acknowledging that interventions must encompass more than just sustainability considerations. This study has underscored the sustainability factors within the food sector and emphasized the necessity of incorporating diverse perspectives to advance towards a more sustainable I4.0 adoption. Against this backdrop, a model has been formulated to elucidate successful implementations of I4.0 in the food sector. Figure 15 illustrates this model, which delineates the key aspects of I4.0 adoption impacts on sustainability within the food industries. The model comprises three distinct segments. The first segment outlines the crucial components that must converge to successful I4.0 adoption capabilities including industrial capabilities and organizational capabilities, drivers, and challenges. The second segment portrays various sustainability factors representing the three pillars of sustainability, as discussed in section 2.7, encompassing materials & energy, environmental management, emissions waste and pollution, production and resourcing, technology and Innovation, macroeconomy, community and individuals (see Figure 12). The underlying assumption of this model is that the effective interaction between the first two segments can engender the creation of the third segment—an inclusive, sustainable food Industry. This resultant model integrates the diverse and competing elements from parts 1 and 2 to achieve practical sustainability.

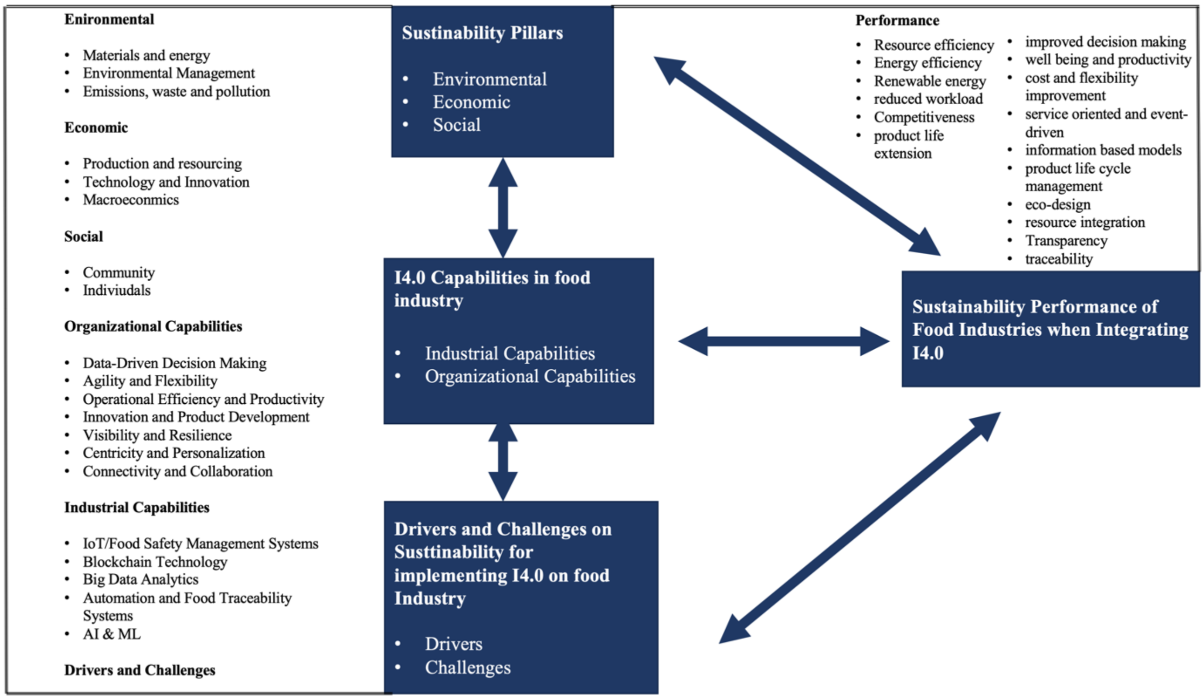

Figure 15: Key features and dimensions of food Industry's sustainability when implementing I4.0.

Source: Author's own elaboration.

2.6.6. Development of Hypotheses

Based on the model provided in the previous section, and the research problems that need to be solved, the hypotheses have been developed in order to set the scene. This thesis presents three primary propositions to elucidate the function of the variables and the interactions among them within the theoretical model depicted in Figure 15:

- **Proposition 1:** Implementing I4 Capabilities (I4 CAP) is expected to result in direct and beneficial impacts on food industry's sustainability performance (PER).
- **Proposition 2**: The presence of drivers (DR) and challenges (CH) of implementing I4.0 influence the I4.0 adoption on food industry's sustainability performance (PER).

- **Proposition 3**: Implementing I4 Capabilities (I4 CAP) is expected to result in direct and beneficial impacts on each pillar of sustainability, environmental (ENV), economic (ECO) and social (SOC).

To facilitate empirical examinations of the propositions for this study, five fundamental hypotheses are formulated. These hypotheses stem from the research questions, the hypotheses are shown in Figure 16.

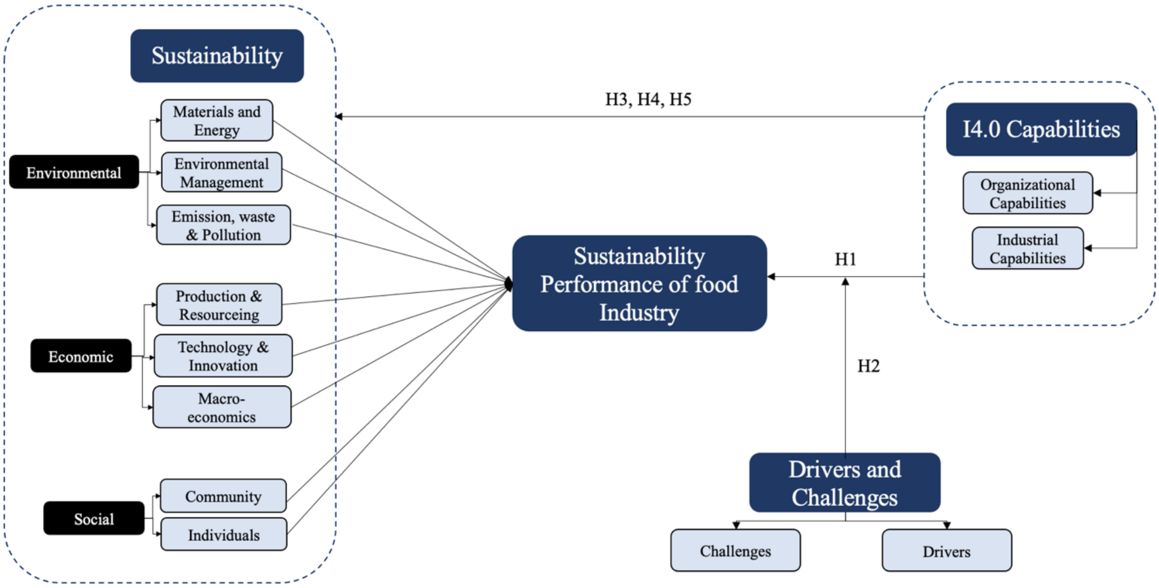

Figure 16: Theoretical Model showing hypotheses 1,2,3,4 and 5.

Source: Author's own collaboration.

Hypotheses (H1) and (H2) were built from the theoretical model to steer the examination of the influence of Industry 4.0 capabilities adoption on food industry's sustainability. Hypothesis 1 states that Industry 4.0 capabilities adoption positively impact food industry's sustainability performance. In accordance with the statement of proposition 2: *The presence of drivers (DR) and challenges (CH) of implementing I4.0 influence the I4.0 adoption on food industry's sustainability performance (PER)*", using the theoretical framework for this reserach, hypothesis 2 was formulated to investigate potential impacts that drivers and challenges of I4.0 adoption may have on the relationship between I4.0 industrial and organizational capabilities and food industry's sustainability performance. Table 9 provide a list of statements for hypotheses 1 and 2.

Based on proposition 3, as such, the thematic classification of sustainability pillars organized by each dimension and subtheme of sustainability after integrating both Industry 4.0 and supply chain management pillars into: materials & energy, environmental management, emissions waste and pollution, production and resourcing, technology and Innovation, macroeconomy, community and individuals. Hypotheses 3, 4, 5 theorizes state that there is a positive impact of Industry 4.0 capabilities on each pillar of sustainability, Table 9 presents a compilation of statements corresponding to hypotheses 3, 4 and 5 highlighting the hypothesized relationship of I4.0 capabilities effect on each of the environmental, economic and social subthemes.

Table 9: Hypotheses Statements.

Items	Hypothesis Statements
H1	There is a direct relationship between Industry 4.0 capabilities and sustainability performance of food industries
H1a	There is a direct relationship between Industry 4.0 Industrial capabilities and sustainability performance of food industries
H1b	There is a direct relationship between Industry 4.0 Organizational capabilities and sustainability performance of food industries
H2	Drivers and Challenges postively moderates the relationship Industry 4.0 capabilities and sustainability performance of food industries
H2a	Drivers and Challenges postively moderates the relationship Industry 4.0 Industrial capabilities and sustainability performance of food industries
H2b	Drivers and Challenges postively moderates the relationship Industry 4.0 Organizational capabilities and sustainability performance of food industries
H3	Industry 4.0 capabilities positively impact the environmental pillar of sustainability in food indsutry
32a	Industry 4.0 capabilities positively impact the materials and energy in food industry
H3b	Industry 4.0 capabilities positively impact the enviromental management in food industry
H3c	Industry 4.0 capabilities positively impact the emissions, waste and pollution in food industry
H4	Industry 4.0 capabilities positively impact the economic pillar of sustainability in food indsutry
H4a	Industry 4.0 capabilities positively impact the production and resourcing in food industry
H4b	Industry 4.0 capabilities positively impact the technlogy and Innovation in food indsutry
H4c	Industry 4.0 capabilities positively impact the macro-economics in food indsutry
H5	Industry 4.0 capabilities positively impact the social pillar of sustainability in food indsutry
H5a	Industry 4.0 capabilities positively impact the community in food industry
H5b	Industry 4.0 capabilities positively impact the individuals in food indsutry

Source: Author's own elaboration.

3. MATERIALS AND METHODS

3.1 Introduction

This chapter provides a framework for the research design, encompassing research philosophy, approach, design, strategy, methodological decisions, time frames, and data collection techniques and analysis. The primary data collection method employed in this study is a questionnaire survey.

The research process with the overall approach that the researcher follow is called the research design or research methodology, starting from the theoretical underpinnings to data collection and then performing the analysis (COLLIS-HUSSEY, 2003). The research design is much more than a plan, it was defined as *"gives a "framework" for the study by outlining the link between the research questions and the data that will be utilized to answer them, as well as the analytical method employed to do so"* (BRYMAN-BELL, 2011).

3.2 Research Design

3.2.1. Research Philosophy

The first step in designing the research is finding the research philosophy. Researching calls for forming a philosophy stance in the direction of worldview, choosing appropriate methods, and dictating the researcher's perspective on the study (CRESWELL, 2014). In generating knowledge, research relies on certain assumptions, which are essentially principles and beliefs governing what is known and how empirical observations are interpreted (CHUA, 1986). This is particularly significant in research of social science, where questions about its scientific status and the suitability of natural science methods persist. Unlike natural science studies, social science inquiries typically don't yield clear causal relationships between variables over different periods and settings (FABIAN, 2000).

Research philosophy has been defined "*as the requirement to accept a meaningful comprehension of a certain topic and the questioning of basic essential principles*" (BURKE, 2007). She has mentioned that research philosophy allows the researcher to find and understand the starting point of his research, and provides the researchers with a common language that is understood by all scholars. The research philosophy consists of two parts:

- Ontology
- Epistemology

Ontology and epistemology are two fundamental branches of philosophy that are particularly relevant in research and academic inquiry. Ontology pertains to the nature of reality, while epistemology pertains to the nature of knowledge, together, they form the philosophical foundation upon which research paradigms and methodologies are built (BURKE, 2007).

BLAIKIE (2003) described the ontology as "*the science, or study, of existence, and he continues by saying that it comprises assertions about what is real, how it appears, what components it is made of, and how these components interact*". The typical ontological stances utilized in research includes one of the three: objectivism, constructivism or subjectivism. In the fields related to business and management studies, positions of ontology are frequently discussed in relation to the concept of "organization." To put it in other words, ontology describes researcher's views of reality and its nature and in specific whether the objective reality is authentic and exists or if it is one that has been observed by people's minds and been constructed by social constructionism (Objectivism and subjectivism) (BRYMAN-BELL, 2011; BRYMAN, 2012).

Due to the varying perspectives on reality within ontology, the researcher can later address the epistemology, where raising questions on how the reality can be measured and what kind of knowledge the reality consists of (SAUNDERS *ET AL.,* 2012; BRYMAN, 2012; WILSON, 2010). The researcher's stance on epistemology relates to the processes of generating, obtaining, and disseminating knowledge. Consequently, it is essential for the researcher to define the framework of the study, which involves specifying the kind of evidence required, its sources, and the approach to interpreting data. There is an ongoing discussion regarding whether the social sciences should adhere to similar prepositions and methodologies similarly to people who work in the scientific sciences for collecting and analyzing data (BRYMAN, 2012). The research philosophies selected in this study are objectivism and positivism.

3.2.2. Research Approach

After selecting the research philosophy, the research approach can be determined. SAUNDERS *ET AL.* (2012) pointed out that there are two kinds of research approach: Inductive and deductive. Both depends on the research philosophy chosen. The deductive approach can be described as "*the process of generating hypotheses based on an established hypothesis and then formulating a research strategy to test those hypotheses*" (WILSON, 2010). However, when a researcher begins a study with a simple observation, he or she gradually progresses toward explaining the thought, finally arriving at a current or new theory, this is called the inductive approach (LODICO *ET AL.,* 2010). This study aims to test the proposed hypotheses that was built based on current and existing literature and the findings are likely to be generalizable.

Because the theoretical framework and hypotheses are crafted through an analysis of the current literature in the field of research, the deductive technique is the best match for this research (CRESWELL-CLARK, 2011; SAUNDERS *ET AL.,* 2012). Figure 17 summarizes the philosophical positions of the research.

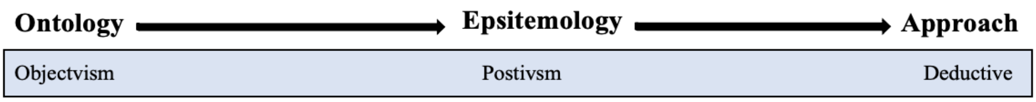

Figure 17: Philosophical positions of the research.

Source: Author's own collaboration.

3.2.3. Research Design

A researcher's research design may be thought of as the precise highlights of the study process. PARAHOO (1997) believes that study design outlines how, when, and where data will be gathered and processed. The research design, according to POLIT *ET AL.,* (2001), is the researcher's fundamental understanding of how the research question(s) will be approached and what methods will be used for testing the hypotheses. Three types of research designs exist: exploratory, explanatory, and descriptive research (SAUNDERS *ET AL.,* 2012). Table 10 represents distinctions among those categories.

Table 10: Distinctions among research design.

Type of survey	Description
Exploratory	• Applies during early stages of research into a phenomenon. • Objective is to gain preliminary insight on a topic that can provide the basis for an in-depth survey. • No theoretical model. • Can help provide preliminary evidence of association among concepts, thus, the valid boundary of a theory.
Confirmatory (or theory-testing or explanatory)	• Applies when knowledge of a phenomenon has been articulated in a theoretical model. • Objective is to test the adequacy of concepts developed in relation to the phenomenon, of hypothesised linkages among the concepts, and of the validity boundary of the models.
Descriptive	• Applies when there is a need to describe the distribution of the phenomenon in a population. • Objective is to understand the relevance of a certain phenomenon. • Although not intended for theory development, the facts described can provide useful hints for both theory building and theory refinement.

Source: Author's own collaboration.

According to the preceding description, this study created hypotheses based on existing literature in order to examine their link. Though the study phenomena are well-known in the food industry, it has yet to be demonstrated in food supply chains if Industry 4.0 implementation has an influence on each of the three sustainable performance pillars. As a result, the research's explanatory goal has been validated.

3.2.4. Research Strategy

A research strategy is a step-by-step roadmap for answering research questions, with the major concern being methodological alignment. The importance of methodological alignment lies in linking the illustrated research questions with the methodological choice. EASTERBY-SMITH *ET AL.* (2012) remarked that "*The internal consistency of four essential components of research—the amount of literature, the research questions, the study methodology, and the theoretical contribution—is referred to as methodological fit"*. NEUMAN (2013) stated that the type of the investigation (e.g., quantitative or qualitative) can influence research strategy. The correct research methodologies can aid in answering research questions and achieving overall research goals. The most frequently cited causes are the complexity and diversity of the research issues. Therefore, the quantitative method has been applied to satisfy the study's objectives.

3.2.5. Research Time Horizon

The designated time frame for a study simply refers to the amount of time it takes the researcher to collect the data needed for the study. The time horizon is usually divided into two types: cross-sectional studies and longitudinal studies (SAUNDERS *ET AL.,* 2012; BRYMAN-BELL, 2011). The 'snapshot' methodology is another name that is given for cross-sectional research. This is when study is carried out for a certain phenomenon at a certain period of time, taking into account the various views of individuals and variables. In contrast to cross-sectional research, researchers who perform longitudinal studies do research over a longer period of time. The time it takes to do such research varies depending on the researcher's needs, and in some cases, it might take several years (SAUNDERS *ET AL.,* 2012).

Due to time restrictions imposed by the concerned company to reduce operational disruptions and time limits inherent in the academic research, the cross-sectional methodology was used in this study. As a result, the data collecting procedure is expected to take three to four months to complete. Of course, if issues arise during the data collection procedure, further time will be provided proportionately.

3.3 Data Collection Techniques and Research Instrument

Data collection, which entails gathering participants' experiences, ideas, and opinions about the phenomena being studied, constitutes a crucial element of any research investigation (SEKARAN-BOUGIE, 2010). Data collection may be done using a variety of methods. However, the degree of information necessary, as well as the findings' level of accuracy and reliability, may influence the choice of a data collection technique (FELLOWS-LIU, 2003). According to FELLOWS-LIU (2003), collection of data is a *"The process of communication between the researcher and the participants serves as the foundation for investigating and comprehending the phenomena being studied".* It's an interactive part of the research process that, when done correctly, serves to assure the study results' validity (PANAS-PANTOUVAKIS, 2010). The type and nature of inquiry and information requested regarding a certain context or setting is a fundamental driver of the data gathering strategy (NAOUM, 2007)

The primary goal of data collection is to enable the researcher to get adequate proof and, as a result, draw the conclusions necessary to make crucial judgments regarding the results (TASHAKKORI-TEDDLIE, 2010). Nonetheless, choosing the right data collection approach may depend on the study methodology, questions and overall objectives of the research (NAOUM, 2007; FELLOWS-LIU, 2003).

The approach for collecting research data that were employed in this study was explained in this section. The data for this study came from one primary source: quantitative survey questionnaires. The goal was to achieve high reliability and validity through subjective results verification. Furthermore, the survey might be administered by a researcher or sent by mail utilizing postage, emails, and different electronic survey technologies, i.e., google forms (SAUNDERS *ET AL.,* 2012; ZIKMUND *ET AL.,* 2012).

3.3.1. Research Instrument (Quantitative : Questionnaire Survey)

To achieve research goals, a large number of social science studies employ questionnaire surveys, interviews, participant observations, and other methods to gather information from the field. However, among these data collecting strategies, many researchers have discovered that the questionnaire is the most commonly utilized tool to obtain such data for their investigations (FELLOWS-LIU, 2003). In comparison to the use of non-standardized data collecting approaches, the most popular survey tool for gathering information from a large geographic area for a variety of research purposes is the questionnaire (SAUNDERS *ET* AL., 2012; BRYMAN, 2012). "*It is more suitable to compiling mass information within the shortest* *possible time and at a minimum expense because of its adaptable characteristics"* (NAOUM, 2007). Another benefit associated with the questionnaire method is the unique freedom it provides respondents in responding to questions at their leisure, especially in situations where the solutions to these inquiries are not easily accessible, like in interviews (BRYMAN, 2012; NAOUM, 2007). According to SAUNDERS *ET AL.* (2012), the use of questionnaire methodology gives the researcher some degree of control over the information, collecting process, allowing the researcher to receive study results that are representative and generalizable to the whole community.

Utilising a questionnaire survey as the main means of gathering information, on the other hand, can lead to skewed results. They can also cause replies to deviate from the information the researcher seeks from the participants. When the researcher is not present, there is no way to elicit further information from respondents or to explain any ambiguity or divergence from the topics (BRYMAN, 2012; NAOUM, 2007). Using e-mail attachments or an embedded method, a questionnaire survey may be distributed to respondents via several means, including the post and the internet. According to BRYMAN (2012), there are several advantages to adopting online surveys, giving the researchers the flexibility in analysing the data.

While a questionnaire survey is a quick and easy approach to collect data from a big group of people, it is claimed to be most effective and profitable when combined with other data collection approaches. In this way, concerns like poor rate response rates can be improved by employing a variety of additional techniques (SAUNDERS *ET AL.,* 2012). In order to obtain data from a wide population in a timely way, this study will use a questionnaire survey that that will be delivered through the internet.

3.3.2. Instrument Development

How a survey is developed for sustainability performance study is intricate and depends on a conceptual framework that clarifies the study's objectives. Theory-testing is recognized as a rigorous method of survey research, it also permits the integration of measures, explanations, and findings from prior studies, facilitating continual enhancement of the survey tool. The procedural framework illustrated in Figure 18, is adopted. Chapter 2 of this thesis outlines the development and explanation of propositions and hypotheses for this research, denoted as Step 1: which is the Link to the theory level. Subsequent sections in this chapter delve into the remaining aspects of Step 1, along with those in Steps 2: which the Design phase, 3: the pilot test phase, and certain elements of Step 4: which is collecting data for testing of the theory for clarity and coherence. The research will proceed to the theory testing phase outlined in 16.

Chapter 4 will cover Steps 5 and 6, which involves analyzing the data, while and generating the report.

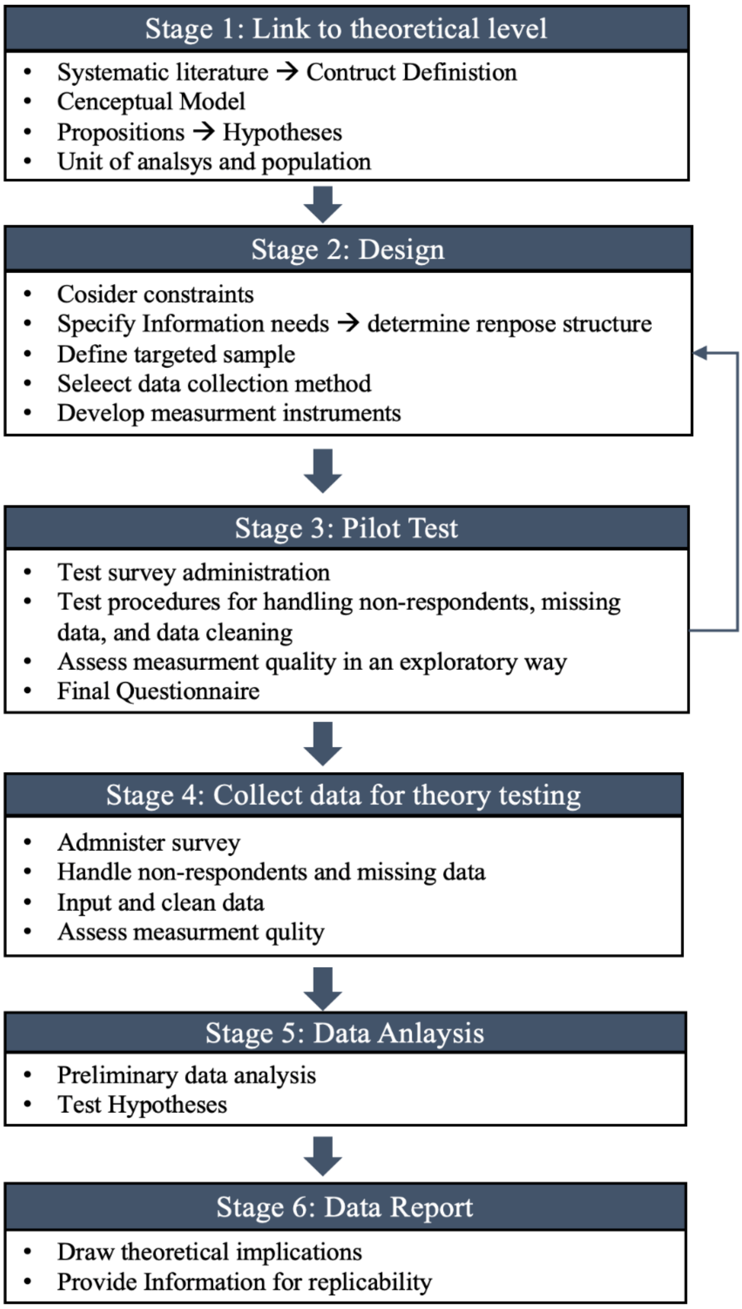

Figure 18: Survey research Process.

Source: Author's own collaboration.

The selection of the questions was also influenced by the literature review on sustainability and the application of sustainable development principles to the food industry's operations and the built environment general, and the generated sustainability assessment model (SAM) which provided different factors areas of each pillar of sustainability that might be impacted by implementing Industry 4.0 on food industry.

3.3.3. Sampling

The process of choosing a certain number of observations from a wider group is well-known as sampling. In research, sampling is essential since there is typically a broader population to whom sampling is the only logical choice for gathering trustworthy replies that represent the viewpoints of the broader and total population. Every researcher's first goal when starting a study is to collect enough information to undertake a meaningful analysis and get the best conclusion possible (MAY, 2011). However, the biggest issue that researchers have while doing such research is estimating the number of respondents needed to provide them with the data, as well as the methods that may provide enough information to accomplish their study aims. The targeted respondents to a survey should have certain traits in common. The goal of the study should guide the selection of samples from the entire population. It is necessary to accurately characterize the whole population from which samples will be drawn. As a result, selecting the appropriate demographic and sample is critical (DAWSON, 2002; COLLIS-HUSSEY, 2003).

Sampling techniques are classified into two groups: probability-based samples and non-probability-based samples. This allows researchers to select the best suitable sample for the given research. Each category has a variety of strategies for selecting the most appropriate sample in the context of the given research (SAUNDERS *ET AL.,* 2012; BRYMAN-BELL, 2011). According to SAUNDERS *ET AL.* 2012, various types of samples are emphasized in Figure 19.

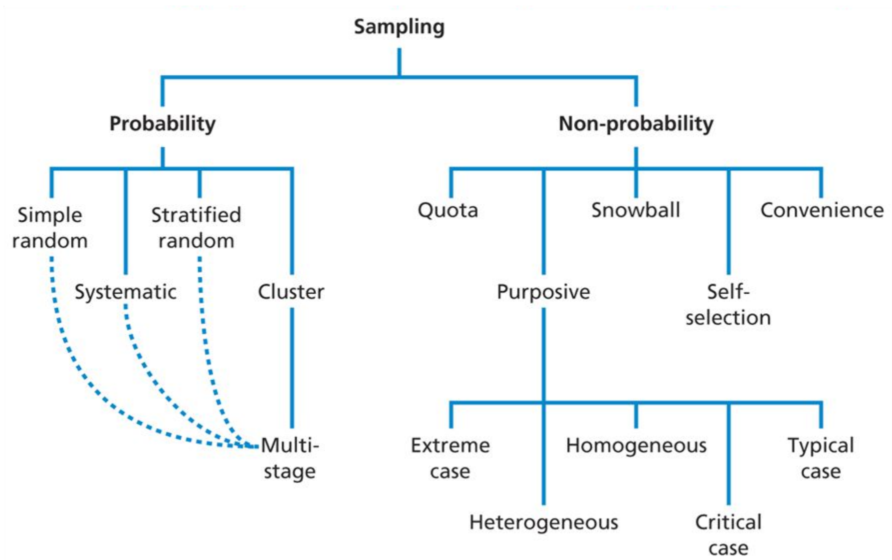

Figure 19: Sampling Methods.

Source: SAUNDERS *ET AL.,* (2012).

The study's population comprises of enterprises in the Jordan food sector, which includes food production, processing, wholesaling, and retailing businesses. The food and beverage industry in Jordan is the target population for data gathering. Industries are selected from the databases maintained by the Ministry of Industry and the Jordan Chamber of Industry. But not every targeted respondent's phone number or email address was accessible. The researcher had to utilise a non-probability purposive sample method as they could only depend on contacts who had phone numbers or email addresses that met the specified criteria.

Although non-probability sampling is not based on probability theories, it accurately represents the targeted population (EASTERBY-SMITH *ET AL.,* 2012; CRESWELL-CLARK, 2011). However, there is no way to control the probability of picking any particular sample, therefore not every unit in the population has an equal chance of being selected as a sample

Despite concerns about population representation, POLIT-BECK (2006) concluded that choosing a sample of individuals who are experts in the study context may be done effectively with purposive sampling.

3.3.4. Measurement Developments

This thesis then goes on to determine the measurements for every variable Considering how the research's constructs were discussed to test the hypotheses generated from the theoretical model. In summary, the theory testing survey approach is used in this study. Because of this, this specific survey approach makes it easier to reuse measures for the constructs from earlier empirical research (FORZA, 2009).

The constructs developed based on the theoretical model are translated abstract concepts into measurable variables. Identifying measurements for each construct can be derived from validated scales and instruments used in previous research studies. The goal is to select measurements that are reliable and valid for assessing the constructs of interest. Choosing the appropriate survey instruments or scales for collecting data on the identified measurements are vital for successful measurement.

This survey study utilizes multiple-item scales sourced from previous empirical research to assess the adoption of I4.0, as well as sustainability performance in food industries. These measurements, are employed to gauge the perceptions of respondents within the respective samples. Rensis Likert created the Likert scale in 1932, and it is the main tool used in survey research to measure attitudes and perceptions. It allows for a multi-item evaluation of the level of attitudes or emotions in the chosen study fields. Approaching five-point Likert scale, with "strongly agree" as the middle and "strongly disagree" as the opposite, respondents often express how much they agree or disagree (BRYMAN, 2012).

In order to obtain data from a wide population in a timely way, a questionnaire survey will be distributed online will be used in this research. Six elements made up the questionnaire survey: general information section, the level of Industry 4.0 and sustainability practices, I4.0 capabilities, sustainability performance and Industry 4.0 drivers and inhibitors of sustainability practices. A number of difficulties were discovered and deemed crucial during the questionnaire survey design process. Bearing in mind the research objectives and to ensure that the requirements were effectively satisfied, it was imperative that the questionnaire survey be well-designed. Table 11 presents the Construct, item codes, variable and number of questions corresponding to each variable, which are included to facilitate the data collection input process.

In Appendix B, the questionnaire with the measurement scales derived from the study are provided (with the English version included for reference). Before being distributed, the survey questionnaire was translated into Arabic, the original tongue, to allow for local study. Furthermore, researchers from partner universities/institutions contributed to refining the survey questionnaire in addition to the translation process.

3.3.5. Data Collection

The method of data collections is described in this section. It starts by describing the food sector in Jordan which is involved in this study. Then it outlines the methodology for participant selection. Finally, the section wraps up with an explanation of the methodology used to collect data from food industries in Jordan.

To compile an extensive list of Jordanian Food Industries, a conducted search across various internet platforms to pinpoint companies engaged in activities within the food sector, including:

- Chamber of Industry
- Invest Jordan and Ministry of Investment
- Ministry of Industry and Trade

Each company identified was further explored using their website links to uncover additional potential company for consideration. This method led to the identification of 20 companies. In order to determine which food industries were eligible for this research, a set of predetermined criteria was developed, and each company was evaluated based on these criteria: history, resources, core activities, involvement in large food chain activities, and involvement in food sustainability and organization structure. Subsequently, the involvement of each company in the food sector was analyzed through their respective websites. This systematic approach of identification and classification yielded a directory of 9 organizations.

Once the participants were identified, a combination of phone calls and analysis of both website content documents was employed to gather comprehensive information on each of the 9 organizations. The subsequent section elaborates on the various sources utilized for data collection.

To encourage participation, prospective participants received thorough information on the nature and goals of the research, clarifying their involvement. Ensuring anonymity and confidentiality was paramount, assuring participants that their personal identities would not be linked to any comments they made, thereby fostering openness and candid responses. Prior to engagement, all companies were informed that the research was self-funded through a PhD program. This transparency regarding the funding of the research aimed facilitates open dialogue. All 9 organizations have agreed to participate in the research.

Data were gathered via an online survey. A message was sent to industries' inboxes as presented in Appendix A, comprising an introduction to the research, a motivational letter and a link to the survey. The questionnaire was distributed in July 2021 over a -week period to minimize the likelihood of significant changes occurring in the estimated population. The survey distribution strategy focuses on reaching out to a subset of Jordanian food industry members who belong to particular special interest in adopting I4.0 practices.

3.4 Ethical Considerations

Ethical consideration is critical in research, from initiating the concepts to the final results (BRYMAN, 2012). To preserve moral guidelines, ethical permission has been provided by the Jordan Chamber of Industry. The Jordan Chamber of Industry database was used to acquire a list of food and drink industries and businesses in Jordan which were used for data collecting. The list includes company names, contact information, and email addresses. Google survey was used for data collection. To acquire the participants agreement, an email detailing the purpose of the research and the research methodology was given to them prior to providing the link/questionnaire. Participants received guarantees on the privacy and confidentiality of the data they submitted. The researcher and supervisors will use personal data strictly for research purposes and will not share it with any other parties.

Table 11: Instrument measures

Block	Description	Dimension	No of Items
1	**Profile of respondents**	Type of Business	1
		Number of Employees in the Company	1
		Capital of Company	1
2	**Level of I4.0 Implementation**	Stage of Industry 4.0 Implementation	1
		Activties	5
		Departments	5
		Skills	7
	Level of Sustainability	Stage of Sustainability	1
		Environmental measures of sustainability	1
		Economic measures of sustainability	1
		Social measures of sustainability	1
3	**Environmental Pillar**	Materials & Energy (ME)	3
		Environmental Management (EM)	3
		Emmision, waste & pollution (EWP)	3
	Economic Pillar	Production & Resourcing (PR)	3
		Technology & Innovation (TI)	3
		Macroeconomics (MA)	3
	Social Pillar	Community (COM)	3
		Individuals (IND)	3
4	**I4 Capabilities**	Organizational Capabilities (OC)	7
		Industrial Capabilities (IC)	5
5	**Drivers and challneges**	Drivers (DR)	13
		Challenges (CH)	10
6	**Performance (PER)**	Resource efficiency	1
		Energy efficinecy	1
		Renewable energy	1
		Redcued workload	1
		Competitiveness	1
		Improved decision making	1
		Well beimg and productivity	1
		Cost and flexibility improvement	1
		Service oriented and event-driven	1
		Information based models	1
		Product life cycle management	1
		Eco-design	1
		Product life extension	1
		Resource integration	1
		Transparency	1
		Traceability	1
	Total		**99**

Source: Author's own collaboration.

3.5 Pilot Study

The primary goal of developing data collection instruments is to make them straightforward and clear to the respondents for whom they are designed (MAY, 2011). After completing the study design, it is critical that the researcher verifies that the data collecting tools and methods used are, to a significant degree, effective, valid, and reliable for their intended aims (SARANTAKOS, 2013; BABBIE, 2004). Pilot testing is an essential component of questionnaire design, "*Through in-person administration of the pilot study, the researcher can ascertain whether systemic discrepancies exist between the researcher's and respondents' perspectives on certain variables"* (FLYNN *ET AL.*, 1990). The pilot research aids in the refinement and modification of the questions in order to maximize outputs of the responses (BEEBE, 2007).

Pilot tests allow researchers to examine the questionnaire for checking whether questions are intelligible to respondents and whether the items meet the planned measurement scales (THABANE *ET AL.*, 2010). In other words, determining if the questions achieve the research objectives is the main goal of the pilot study, and to evaluate the validity and reliability of the instrument, pilot tests were conducted. Instruments for the pilot study were created based on reviewing previous literature, and experts from academia and industry were contacted.

A number of checks and modifications were made before delivering the questionnaire to participants for a trial run. Following the original draft, opinions from experts and colleagues in academia were obtained, and initial revisions were made based on the responses. Academics were first concerned about the phrasing, technical terminologies and complexities of the sentences. Following adjustments, a second round of comments were gathered with industry professionals to identify any issues and improve the quality of questions. Concerns were made at this point regarding the time required to complete the questionnaire and the total number of questions.

From the Jordan Chamber of Industry database, a list of food business contacts was collected, including food products manufacturing and food products processing and preserving. The industry sector was within the Jordanian food sector. Nine companies were contacted through email and phone from the contact list, requesting a minimum of 10 workers to answer the questionnaire from each company. After one week, a follow-up email was sent to the company to remind them to complete the survey. The response rate was lower than predicted two weeks after the questionnaire was delivered. In all, 195 responses were received, the response rate was approximately 72.6% as it is shown in Table 12.

Table 12: The distribution and response rate of questionnaire surveys.

Organization Category	Questionnaire Distributed	Completed Questionnaire Received	Questionnaire Not Completed	Response Rate
Manufacturing Industry	270	195	75	72.2%
Total (N)	**270**	**195**	**75**	**72.2%**

Source: Author's own collaboration.

The sample for this study comprised employees working in manufacturing sector of the food industry in Jordan. A total of 195 participants were selected to ensure the inclusion of diverse job roles within the food industry. The sample included a wide range of ages and genders to accurately represent the workforce in this industry. The sample size was determined based on previous studies and industry reports to achieve a robust analysis of workplace conditions and employee well-being. Participants were recruited through workplace notices and professional networks, with all individuals providing informed consent. While the sample reflects the diversity of the food industry workforce, limitations include potential selection bias and the focus on a single geographic region, which may limit the generalizability of the results. Ethical considerations were addressed by guaranteeing confidentiality and voluntary participation throughout the research process.

3.6 Reliability Test

The term "reliability" has been explored extensively in the research field (SAUNDERS *ET AL.,* 2012). Reliability refers to the *"replicability of the research process as well as the accuracy or correctness of the methods and research procedures used"*. JOPPE (2000) has said, *"Reliability is defined as the degree to which findings are accurate in representing the whole population being studied throughout time and as well as the reproducibility of study outcomes when using a comparable methodology"*. It is apparent that both quantitative and qualitative researchers must show the reliability of their study (WILSON, 2010; BRYMAN, 2012; SAUNDERS *ET AL.,* 2012).

From the perspective of quantitative research, a reliability test offers an evaluation and details on the internal consistency of responses across survey measures in a questionnaire. Although there are a number of methods for assessing the data's reliability throughout the questionnaire survey, the most popular method for measuring a survey's internal consistency and inter-item reliability is the Cronbach's Alpha method (PALLANT, 2010).

When using Cronbach's Alpha to gauge the internal reliability of the survey's questions, the degree of acceptance varies from 0 to 1.0 (FELLOW-LIU, 2008), where "0" represents a result that is totally unreliable and "1.0" represents a result that is totally reliable. Cronbach's Alpha has a critical threshold of 0.7, which is typically considered sufficient for assessing internal reliability (PALLANT, 2010). Higher internal reliability and more acceptable results are produced by values exceeding 0.89.

In this study, reliability tests were performed on the entire questionnaire, but without the demographic characteristics. Table 13 presents the findings of the survey's reliability test. The questionnaire's extraordinarily excellent internal consistency reliability, as indicated by its Cronbach's Alpha score of 0.932, means that it may be deemed consistent and reliable to a great extent.

Table 13: Reliability test results.

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.932	.930	75

Source: Author’s own collaboration.

3.7 Data Analysis

This section provides an overview of the analysis conducted. Initially, the data from the online Google survey were transferred into Excel format. Subsequently, data coding and editing were conducted, involving the assignment of numerical values to participants' response variables and the verification of responses for logical consistency. In the case of Likert scale responses, which ranged from "strongly disagree" to "strongly agree," a 5-point coding system from 1 to 5 was applied in accordance with the specified order. After the data has been cleansed and prepared, the descriptive analysis step begins where data obtained from the questionnaire administered will be statistically analyzed using SPSS software. Various statistical methods can be utilized during the initial phases of empirical investigation, particularly in instances where there is a dearth of robust theoretical frameworks and the primary objective is exploratory in nature.

3.7.1. Instrument Assessment Methodology using factor analysis and reliability

Conventional approaches utilized for constructing and assessing measurement scales typically involve techniques such as, exploratory factor analysis (EFA), principal component analysis (PCA) and the estimation of reliability through Cronbach's alpha coefficient (KOUFTEROS, 1999). Utilizing factor analysis, groups of closely associated variables are identified as factors, delineating distinct dimensions within the dataset (HAIR *ET AL.,* 2010).

In this research, Exploratory Factor Analysis (EFA) is utilized to explore patterns among variables outlined in the theoretical framework. Unlike Confirmatory Factor Analysis, which requires a pre-established structure, EFA allows for an open-ended exploration without predetermined factors or variable groupings. The primary goals are achieving succinct illustrations of the connections between the variables that are being assessed. Hence, the EFA method of factor analysis can be considered more appropriate for the specified study objectives, as it facilitates a more flexible and exploratory approach to identifying underlying structures (FABRIGAR *ET AL.,* 1999). Once adequacy is confirmed, factor analysis proceeds using Principal Component Analysis (PCA), which involves both component analysis and common factor analysis to evaluate the validity of the instrument.. In summary, two evaluations of measurement quality, namely factor analysis and reliability analysis, are conducted on the collected data.

3.7.2. Descriptive Statistical Analysis.

Once factor analysis and reliability have been established, the suitability of the research data for regression analysis is evaluated by assessing different statistical techniques. Descriptive statistics demonstrate the easiest method for analysing quantitative data so that it provides a broad image and overview of the results (NAOUM, 2007). Mean, median, standard deviation, as well as percentages for the variables and other statistical information are usually provided using descriptive analysis (PALLANT, 2010). A descriptive study of food Industry practices, for example, will allow the researcher to explain and offer a vivid description of the sustainable activities of the organization. This will allow to both visually and mathematically describe and compare the data.

3.7.3. Normality, Correlation & Multicollinearity

The suitability of the research data for regression analysis is evaluated by assessing normality, correlation and multicollinearity. In the context of statistical analysis, assessing normality, correlation, and multicollinearity plays a crucial role in ensuring the validity and reliability of research findings. Normality examines whether the data follow a normal distribution, which is essential for the accurate application of certain statistical tests and models. Deviations from normality may necessitate data transformations or alternative analytical approaches (HAIR *ET AL.,* 2010). Correlation analysis explores the relationships between variables, revealing the strength and direction of relationships (TABACHNICK-FIDELL, 2014). This examination aids in identifying patterns and dependencies within the dataset, informing subsequent analyses and interpretations. Multicollinearity assessment focuses on detecting high correlations among predictor variables, which can undermine the accuracy and stability of regression models by inflating standard errors and obscuring true relationships (HAIR *ET AL.,* 2014). Identifying and addressing multicollinearity through techniques such as variance inflation factor (VIF) analysis are imperative for robust regression analyses and sound conclusions. Therefore, comprehensive scrutiny of normality, correlation, and multicollinearity ensures the integrity and reliability of statistical analyses in research endeavours.

3.7.4. Regression Analysis

Regression analysis was used to look at how Industry 4.0 capabilities affect performance, analyze the consequences of Industry 4.0 capabilities, and look at performance results across several pillars. Through the process of fitting a linear equation to the observed data, regression analysis aims to predict an outcome variable based on one or more predictor variables. According to Field (2005), R^2 and F statistics may be used to assess the model's overall fit. Whereas F statistics show the regression model's overall significance, R-squared shows the percentage of variation explained by the model. Furthermore, the significance of the link between the independent and dependent variables is shown by the Beta value, which is usually derived from the SPSS output, and is used to evaluate the relationship strength of respective variables.

4. RESULTS AND ANALYSIS

4.1 Introduction

The outcomes of the quantitative data analysis are summarized in this chapter. In addition, research hypotheses are tested, and the results are presented together with the conclusions about the relationships between the research variables that were previously described in the conceptual model. In order to provide insightful findings that respond to the research questions, the analysis comprises modifying, changing, and evaluating data using SPSS software.

After the survey distribution concluded, the findings were compiled and presented in section 4.2. Subsequently, in section 4.3, to evaluate the calibre of the gathered data, tests were carried out, employing exploratory factor analysis, principal component analysis and reliability analysis to ensure its meaningfulness regarding the assigned variables. Section 4.4 further details this study's statistical analysis, involving statistical descriptives, normality, linearity, analysis of spearman's rank correlation leading to multicollinearity. Section 4.5 elaborates on the hierarchical regression analysis, outlining the outcomes of testing the hypotheses of this research. Finally, section 4.6 presents the research findings and the discussion.

4.2 Results of Survey

The information for this research was gathered from participants holding different roles within their respective organizations in the food industry sector of the Jordan. The dataset underwent analysis utilizing the IBM SPSS software.

4.2.1. Profile Characteristics of Respondents

The research obtained 195 usable responses where all of them were collected from participants engaged in food manufacturing industries in Jordan. Table 14 shows the details of demographic characteristics of the survey respondents, which include the type of business, the number of employees in the company and the capital of the company. Data were collected from nine different food industries in Jordan, including: Hammoudeh Food Industries Co, Siniora Food Industries, Al Durra International, Tamam, AL-JUNEIDI Food Industries, Kasih Food Production Company, Al-Araj Meat Products Factory, Mudieb Haddad & Sons Co. And Al Raya Bakery. Respondent profiles are displayed in Table 14.

Some of the most important details of the demographic data used in this study are outlined below. It is important to note that all of the respondents have held their roles in the food manufacturing industries, suggesting a significant level of experience and awareness of manufacturing technologies.

Table 14: The study's respondents' demographic characteristics.

Characteristics	Category	Frequency	Percentage
Type of business	Food Manufacturing	195	100.00
	Food Processing	0	0.00
	Food Wholesaling	0	0.00
	Food Retailing	0	0.00
	Others	0	0.00
Number of Employees in the Company	Between 25-50	0	0.00
	Between 51-100	20	10.30
	Between 101-250	25	12.80
	Over 250	150	76.90
Capital of the company	500 thousand to 750 thousand (JOD)	20	10.30
	750 thousand to 1 million (JOD)	25	12.80
	1 million to 2 million (JOD)	25	12.80
	2 million and more (JOD)	125	64.10

Source: Author's own collaboration.

It should be noted that none of the participating organizations fall under the small business category with fewer than 50 employees. In contrast, more than 76% of participating organizations were classified as big, having more than 250 employees. Also, 64% of the organizations have a capital of over a 2 million Jordanian Dinar whereas 10% of the firms have less than 500,000 Jordanian Dinar.

4.2.2. Profile characteristics of Jordanian Food Industry

One of the aims of this study is to assess the extent of Industry 4.0 and sustainable practices within the food sector in Jordan. The investigation involved finding the extent of sustainability and Industry 4.0 integration among Jordan's food industries. This investigation encompassed aspects like adoption of sustainability measures (economic, environmental and social) Moreover, the study examined the stage of Industry 4.0 implementation of the food industries that were either being currently executed or are being planned to be adopted by these industries.

Table 15: Levels of Sustainability Practices and Industry 4.0 implementation in this Study.

Criteria	Percentage
Stage of Industry 4.0 Implementation	
No plan for adoption now and in future	12.8
Will adopt in future	56.4
Recent and on-going implementation	20.5
Made significant progress in implementation	10.3
Total	**100.0**
Stage of Sustainability Adoption	
No, not available	12.8
Yes, to some extent	64.1
Made significant progress in integration	23.1
Total	**100.0**
Availability of Economic measures of Sustainability	
No, not available	13.7
Yes, to some extent	51.3
Yes, completely	35.0
Total	**100.0**
Availability of Environmental measures of Sustainability	
No, not available	17.9
Yes, to some extent	53.8
Yes, completely	28.2
Total	**100.0**
Availability of Social measures of Sustainability	
No, not available	23.1
Yes, to some extent	46.2
Yes, completely	30.8
Total	**100.0**

Source: Author's own collaboration.

As demonstrated in Table 15, it is evident that 20.5% of the industries that participated in the survey are actively integrating Industry 4.0 in their business. Among the surveyed industries, 10.3% had made notable strides in integrating Industry 4.0. Around 56.4% of the responding firms expressed intentions to adopt Industry 4.0 in the future. Conversely, 12.8% of the industries indicated that they had no plans to adopt Industry 4.0, either presently or in the future. The results highlight that a substantial 87.2% of the surveyed industries had either currently integrated or were in the process of integrating sustainability practices. On the other hand, 12.8% of the industries were not presently engaged in sustainability efforts. This indicates a noteworthy level of sustainability and Industry 4.0 adoption within the Jordanian's food industry.

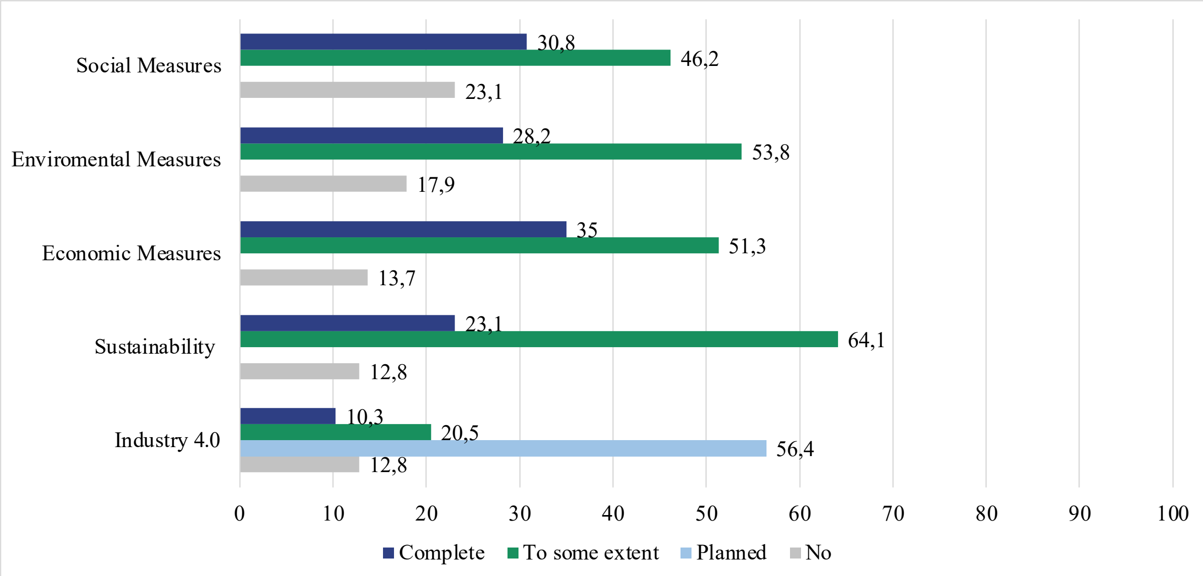

Figure 20: Levels of implementation

Source: Author's own contribution

The sustainability pillars associated with these industries were also explored. This emphasis on achieving sustainability objectives has been proposed to closely link with the mindset and actions embraced by industry practitioners. The economic principles are firmly ingrained within our local community. The outcomes of the survey questionnaire (as shown in Table 15) additionally indicated that more than 85% of industries either adopted economic measures completely or to some extent. In comparison, only 76.9% of respondents have either adopted social measures completely or to some extent. It is commonly held that fulfilling the societal, environmental and economic needs of a community stands as a primary method through which that society can genuinely thrive and maintain its sustainability. Figure 20 presents an overview of the distribution of respondents based on the levels of integrating Industry 4.0 and sustainability pillars of their respective organizations within the Jordanian food industry.

The major departments in industries that has invested in implementing Industry 4.0 also been analyzed. This step involved analyzing the extent to which different departments in an industry, which hold significant importance within an enterprise have invested in components of Industry 4.0. 195 respondents were surveyed with 5 questions related to the extent to which different departments within a company has implemented Industry 4.0. The findings derived from the questionnaire survey revealed the frequency pertaining to the specific departments of a company, as depicted in Table 16.

Table 16: Level of implementation of Industry 4.0 within different department of food Industry.

Department	Large	Medium	Small	None	Mean
Research & Development	30,8	41,0	10,3	17,9	2.85
Production/Manufacturing	63,6	21,0	11,3	4,1	3.44
Purchasing/sales	42,6	29,2	14,4	13,8	3.01
Logistics	46,7	33,3	14,9	5,1	3.22
IT	56,4	23,1	16,9	3,6	3.32

Source: Author's own collaboration.

Figure 21 illustrates the parentages of major departments adopting Industry 4.0 sustainability strategies. This adoption is expected to sustain their market dominance and leadership. The implementation of Industry 4.0 is poised to ensure continual enhancement of economic and environmental performance for large-scale industries. Results have shown that the manufacturing and IT departments are the most invested in adopting Industry 4.0 technologies within food industry in Jordan.

The food sector is adopting sector 4.0 technology at a rate that is mostly driven by the manufacturing and IT departments. Automation, data analytics, and Internet of Things sensors are examples of Industry 4.0 technologies that present chances to improve supply chain operations, guarantee product quality and compliance, and improve operational efficiency. Supply chain optimization and data-driven decision-making are made possible by the IT department's ability to manage and analyze the massive volumes of data produced by these technologies. Additionally, collaboration between manufacturing and IT departments fosters innovation, competitive advantage, and continuous improvement in product offerings and business processes. Overall, their investment in Industry 4.0 technologies positions food manufacturers to meet evolving consumer demands, navigate regulatory requirements, and stay ahead in a competitive market landscape.

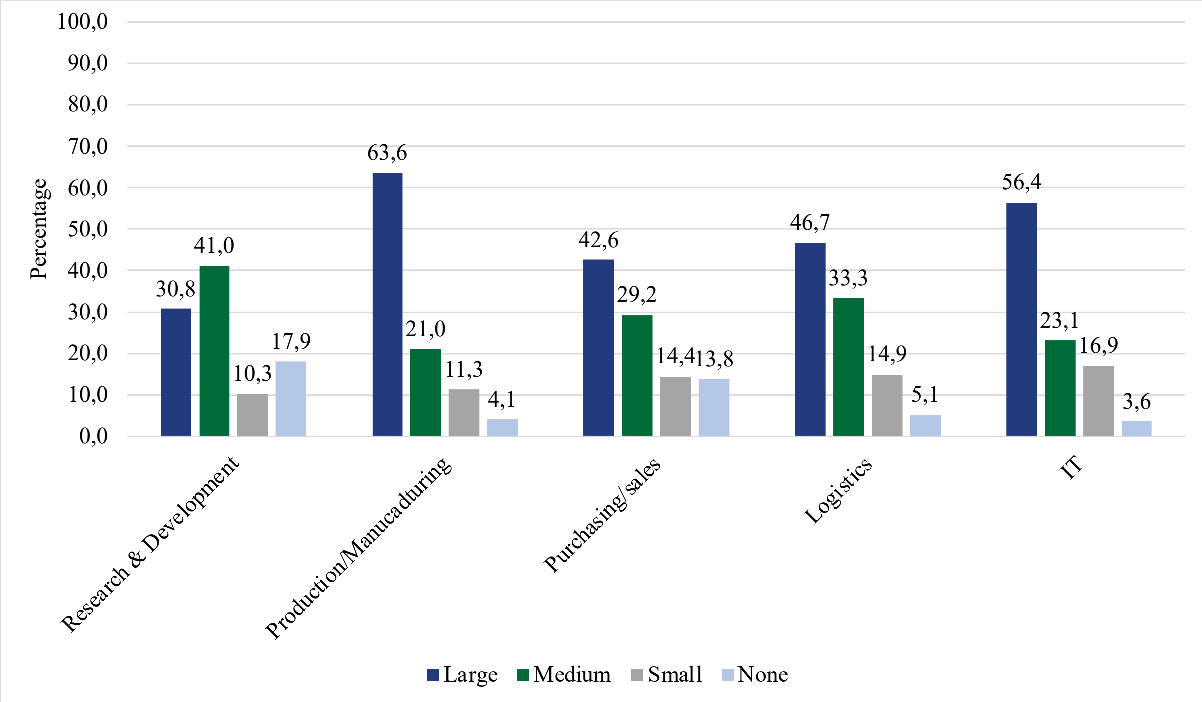

Figure 21: Level of Industry 4.0 implementation in several food industry departments.

Source: Author's own contribution

4.2.3. Adoption of industry 4.0 in the food industries

This section discusses the adoption of I4.0 in the food industry of Jordan. This includes the typical activities that firms had undertaken or plan to ensure that new Industry 4.0 technologies are adopted successfully and integrating them with the existing ones and employees' proficiency with regard to the competencies needed to meet Industry 4.0's future expectations. After surveying the Jordanian food industries, Table 17 presents the percentages of the main activities that firms had undertaken or plan to ensure that new Industry 4.0 technologies are adopted successfully and integrating them with the existing ones.

Findings in Table 17 are validated by 195 practitioners who have participated in this study. It can be observed that the effective routines for implementing and adopting new technologies might be an asset for a successful implementation of industry 4.0 in the Jordanian food industries. These routines that enhance the implementation of Industry 4.0 in the food industry involves a range of activities aimed at leveraging technology to enhance efficiency, quality, and innovation throughout the production and distribution processes.

It is vital to equip both corporations and individuals with digital skills to effectively navigate the significant wave of automation. Consequently, showcasing the level of digital proficiency within the food industries through the elements of Industry 4.0 holds importance.

Table 17: Activities undertaken or planned to ensure successful implementation of I4.0

Activity	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)	Mean
Effective routines to identify, value and import new systems and technologies	15.4	53.8	17.9	8.2	4.6	3.67
Employees are assigned to tasks that commensurate with their task relevant knowledge and skills.	23.1	46.2	20.5	5.4	4.9	3.78
Overall, the technology adoption activity is/will be well coordinated.	17.9	49.7	24.1	2.9	5.4	3.72
Management is effectively involved in technology adoption activities at the working level.	25.6	43.6	17.9	5.7	7.1	3.74
Evaluation of the suitability of new manufacturing technologies to existing processes before procurement.	33.3	35.9	20.5	2.6	7.7	3.85

Source: Author's own collaboration.

A retraining initiative ought to be established to ensure that older citizens in specific nations remain technologically current, with a primary emphasis on educational methods. For a more precise portrayal of the acquisition of digital experience and skills, it's crucial to measure adaptability over an extended period and track its evolution over time.

This research unequivocally investigated the employee's skills readiness concerning the requirements that Industry 4.0 will impose in the future, digital skills are vital for success and therefore must be given significant emphasis. The digital skills that were investigated are:

1. Automation Technology
2. Collaboration Software
3. Data Analytics
4. Data Security
5. Development or application of Assistance Systems
6. IT Infrastructure
7. Non-technical Skills

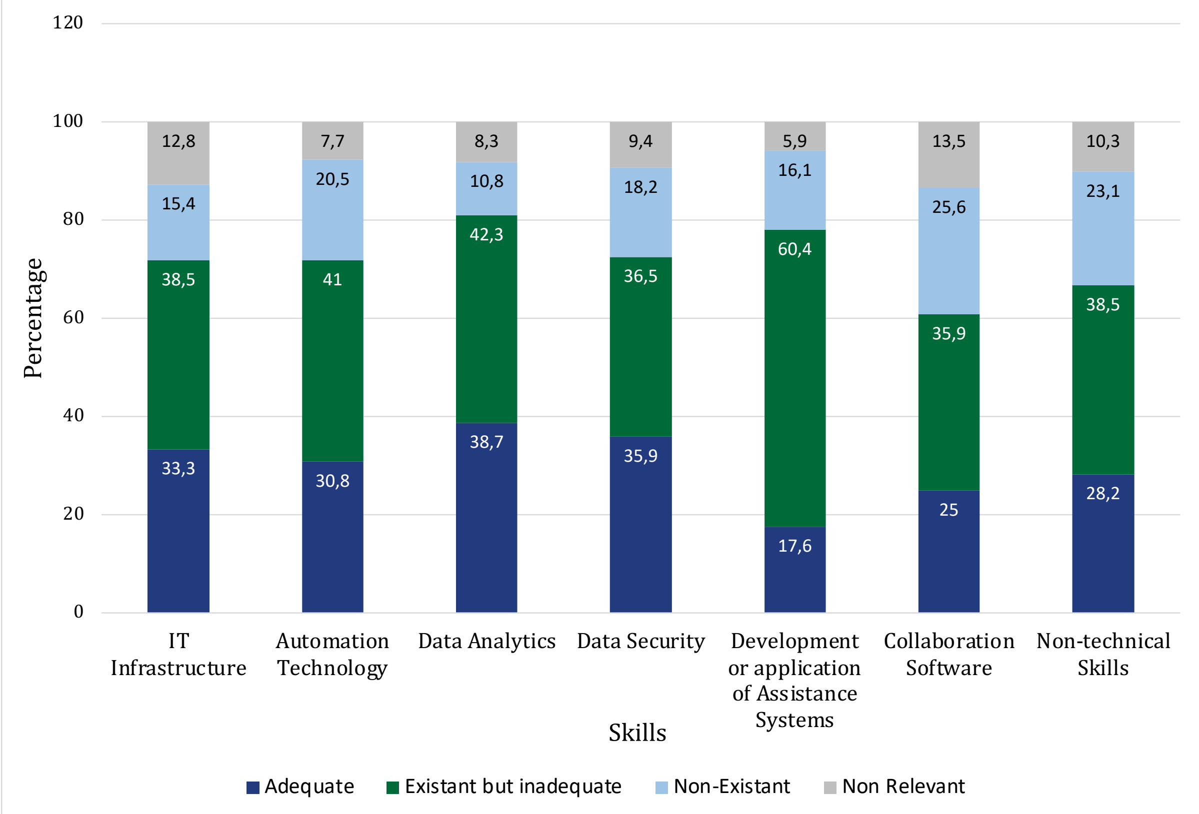

Figure 22: Employees' skills readiness concerning the requirements that Industry 4.0 will impose in the future

Source: Author's own contribution

In accordance with technological trends, Figure 22 indicates that employees are most proficient in data analytics with results (38.7% adequate) and (42.4%) existent but inadequate. Employees are more skilled in handling large volumes of data, utilizing analytics tools to derive meaningful insights, and translating these insights into actionable strategies that enhance efficiency, quality control, and customer satisfaction. Furthermore, collaboration and communication skills are essential for fostering cross-functional teamwork, enabling seamless integration of data analytics initiatives across various departments within food manufacturing, distribution, and retail operations. By cultivating a workforce that is well-prepared and enthusiastic about harnessing the power of data analytics, food industries can unlock new levels of efficiency, innovation, and competitiveness in the era of Industry 4.0.

Based on Figure 22 employees may lack proficiency in collaboration software with results (25% adequate) and (35.9%) existent but inadequate, which may lead to facing significant challenges in harnessing the full potential of technological advancements. Effective collaboration is paramount for seamless integration of data-driven processes across different facets of food production, distribution, and marketing. Employees not skilled in collaboration software may struggle to effectively communicate, share information, and coordinate tasks with colleagues and partners, hindering the efficiency and agility of operations. This deficiency can lead to disjointed workflows, delays in decision-making, and missed opportunities for innovation and optimization. As Industry 4.0 increasingly emphasizes interconnectedness and real-time data exchange, investing in training and upskilling programs to enhance employees' proficiency in collaboration software is essential for food industries to thrive in the digital age, fostering a culture of collaboration and innovation that drives sustainable growth and competitive advantage.

Moreover, fostering a culture of continuous learning and innovation is essential to empower employees to navigate the evolving landscape of different skills within Industry 4.0, driving sustainable growth and competitive advantage for food businesses.

4.2.4. Sustainability Dimensions

Sustainability is a broad term including aspects related to the economy, environment, and society. The main objective of corporate sustainability policies is to prevent future deterioration of the environment and social welfare. Table 18 illustrates the Industry 4.0's impact on environmental performance, the industries surveyed indicate positive direction of implementing sustainability strategies on the environment. By adopting environmentally friendly production processes through industry 4.0, these companies utilize new technologies that mitigate adverse environmental effects, leading to the creation of consumer-friendly products. This approach serves to protect the environment from further deterioration.

Table 18 demonstrates that only 16.9% of respondents suggested that I4.0 doesn’t minimize waste and emissions. Waste management initiatives aim to preserve landfills and prevent environmental decay caused by waste accumulation, thereby ensuring a high-quality environment for present and future generations. Moreover, 75.9% of respondents suggested that I4.0 employ environment friendly technologies which are used to save the environment, with efforts focused on reducing carbon emissions, a critical aspect of sustainability given their contribution to global warming and associated environmental and social issues. Implementing emission-free processes helps mitigate these problems, ensuring a healthier atmosphere and environment for current and future generations.

Additionally, 69.2% of respondents affirm that I4.0 enhances the production process that are designed to use Natural Resource/Renewable energy and 64.1% on production processes which are designed to reduce consumptions of resources in operations, underscoring the importance of sourcing materials sustainably to preserve environmental resources for future generations.

Table 18: Industry 4.0's impact on environmental performance.

Environmental sustainability Factors	Very extensively	Medium	Very little	Not at all
Production process is designed to use Natural Resource/Renewable Energy	73(37.4%)	62(31.8%)	47(24.1%)	13(6.7%)
Products and packaging are designed to be reusable and recyclable	67(34.4%)	48(24.6%)	55(28.2%)	25(12.8%)
Production process is designed to reduce consumptions of resources (materials & energy)	70(35.9%)	55(28.2%)	64(32.8%)	6(3.1%)
Conduction of environmental audits	51(26.1%)	75(38.5%)	46(23.6%)	20 (10.3%)
Environment friendly technologies are used to save the environment	83(42.6%)	65(33.3%)	37(18.9%)	10(5.1%)
Environmental training to the staff	33(16.9%)	56(28.1%)	76(39.0%)	30(15.4%)
Emission and waste free production	47(24.1%)	75(38.5%)	40(20.5%)	33 (16.9%)
There are positive impacts on environmental biodiversity	15(76.9%)	47(24.1%)	71(36.4%)	62(31.8%)
The use eco-friendly (e.g., fuel efficient) processes	19(9.7%)	30(15.4%)	48(24.6%)	98 (50.3%)

Source: Author's own collaboration.

It is imperative that companies utilize renewable resources in a manner that aligns with the rate of renewal to ensure long-term environmental preservation.

When it comes to the use of eco-friendly (e.g., fuel efficient) processes, only 25.1% of respondents agreed that I4.0 has a positive impact on this factor, while the rest incorporating ungreen methods. Similarly, 45% of respondents suggested that I4.0 provide environmental management training for their employees, while the rest suggested not. The absence of sustainability experts within respondent companies poses a significant obstacle to achieving sustainability goals. Providing environmental management training for employees serves as a mechanism to enhance their sustainability skills.

Table 19 illustrates the Industry 4.0's impact on economic performance. A significant portion, comprising 25.6% and 30.8%, perceive Industry 4.0 to have a substantial positive influence on production costs, ranging from very high to moderate impacts. Conversely, 12.8% believe the impact to be low. This perspective is associated with various practices adopted by companies in the industry, such as reducing carbon footprint through minimizing official travel and employing alternatives like teleconferencing. Additionally, energy-saving measures and resource conservation efforts, including water usage reduction and waste recycling, contribute to cost reduction. These initiatives effectively curtail waste across the supply chain, resulting in cost savings for companies.

Furthermore, Table 19 indicates that 17.9% and 42.6% of respondents perceive a high or very high increase in production and efficiency, with 16.4% noting a no. This increase is closely tied to the speed of operations within companies, as faster processes lead to enhanced delivery rates. Innovation and technology are used interchangeably in this study, considering that technology often drives innovation. The data shows that only 18% of respondents recognize a significant impact of inventory and new product development had been/will be improved.

Moreover, 60.5% of respondents report a high or very high increase in proactivity resulting from transparency between companies, reflecting the link between innovation and proactive behavior in industries. Business Models product and process quality supply chain integration improvements are also evident, with 55.9% strongly agree or agree in quality due to Industry 4.0 implementations. This is attributed to the correlation between innovation and quality enhancement, as innovative companies tend to produce higher-quality goods and services. In the Jordanian food industry, 46.2% perceive Industry 4.0 to have a significant positive impact on their market share. The data shows that 81.5% of respondents recognize a significant impact of innovation on labor cost, with 10.3% acknowledging no impact.

Table 19: Industry 4.0's impact on economic performance

Economic sustainability Factors	**Strongly Agree**	**Agree**	**Neither agree or disagree**	**Disagree**	**Strongly Disagree**
Profit and cost savings had been/will be increased	50(25.6%)	60(30.8%)	50(25.6%)	10(5.1%)	25(12.8%)
Overall production and efficiency had been/will be increased	35(17.9%)	83(42.6%)	32(16.4%)	22 (11.3%)	23(11.7%)
Product longevity & durability had been/will be increased	56(28.7%)	75(38.5%)	38(19.5%)	14(7.2%)	12(6.2%)
Transparency between companies had been/will be increased	35(17.9%)	80(41.0%)	37(18.9%)	25(12.8%)	18 (9.2%)
Reliability of Data had been/will be Increased	48(24.6%)	70(35.9%)	64(32.8%)	9 (4.6%)	4(2.1%)
Business Models product and process quality supply chain integration had been/will be improved	19(9.7%)	90(46.2%)	36(18.5%)	13(6.7%)	37(18.9%)
Market share & performance relative to competitors had been/will be improved	20 (10.3%)	70(35.9%)	85(43.6%)	17(8.7%)	3(1.5%)
Inventory & new product development had been/will be improved	5(2.6%)	30(15.4%)	33 (16.9%)	85(43.6%)	45(23.1%)
Savings on labor cost have been/will be increased	120(61.5%)	39(20.0%)	20(10.3%)	9(4.6%)	7(3.6%)

Source: Author's own collaboration.

This trend is linked to Industry 4.0 influence on sustainability, which, over time, is expected to translate into higher sales turnover. This correlation is tied to Industry 4.0 role in fostering lean and efficient production and distribution, ultimately leading to increased sales turnover and, consequently, higher net profits. Additionally, innovation plays a role in enhancing customer loyalty and, consequently, the firm's share value.

Table 20: Industry 4.0's impact on social performance.

Social sustainability Factors	**Positive Effect**	**No Effect**	**Negative Effect**
The standard of living	144(73.8%)	36(18.5%)	15(7.7%)
The community security/wellbeing	110(56.4%)	65(33.3%)	20 (10.3%)
The locally sourced products	130(66.7%)	50(25.6%)	15(7.7%)
Job opportunities	15(7.7%)	64(32.8%)	116(59.5%)
The socially responsible practices	32(16.4%)	141(72.3%)	22 (11.3%)
Employees' skills, knowledge and competencies are aligned with job performance	19(9.7%)	161(82.6%)	15(7.7%)
The customer satisfaction	140(71.8%)	35(17.9%)	20 (10.3%)
The employees' welfare	38(19.5%)	47(24.1%)	110(56.4%)
The health and safety environment for the staff	145(74.4%)	44(22.6%)	6(3.1%)
The working environment of the organisation has been improved	125(64.1%)	55(28.2%)	15(7.7%)
Employee job satisfaction	103(52.8%)	80(41.0%)	12(6.2%)

Source: Author's own collaboration.

Table 20 demonstrates Industry 4.0's impact on social performance., showing a positive direction of implementing industry 4.0 strategies on the social pillar of sustainability. Table 20 illustrates that a significant portion, comprising 73.8%, perceive Industry 4.0 to have a substantial positive influence on the standard of living, ranging from very high to moderate impacts..

Similarly, Table 20 indicates that only 7.7% of respondents report fair employment opportunities, with 32.8% remaining neutral and 59.5% not considering such opportunities. This highlights the crucial effect of Industry 4.0 on workforce, with technological advancements like automation and robots are more likely to replace many jobs performed by labor and lead to massive job losses. Moreover, 74.4% of respondents agree that Industry 4.0 offer positive impact on the health and safety environment for the staff, with 3.1% failing to do so. Providing such amenities not only serves as a motivational strategy but also aligns with the principles of social sustainability, aiming to enhance worker productivity and reduce issues like absenteeism and strikes. In terms of customer and employee satisfaction, 71.8% and 52.8% of respondents respectively affirm the positive effect on.

4.2.5. Drivers and challenges for implementing I4.0

The adoption of Industry 4.0 (I4.0) is powered by several sustainability factors. These include the need for resource efficiency, where I4.0 technologies streamline processes to reduce waste and resource usage. Additionally, I4.0 enables companies to lower their environmental impact by optimizing energy usage and embracing eco-friendly practices. Furthermore, I4.0 supports the shift towards a circular economy by facilitating product lifecycle management and resource reuse. Improved supply chain transparency is another benefit, allowing companies to monitor the environmental impact of their products and ensure responsible sourcing. I4.0 also promotes innovation in sustainable products and services. Compliance with regulations and corporate social responsibility efforts further drive the adoption of I4.0, alongside the competitive advantages it offers in terms of efficiency and product quality. These factors collectively underline the importance of sustainability in I4.0 technology installation.

The sustainability drivers were diverse and intricate, with ecological and economic concerns at their core. Key aspects such as energy conservation, resource conservation, and waste reduction were pivotal considerations in sustainability implementation (GOPALAKRISHNAN *ET AL.,* 2012; WALKER-JONES, 2012; CARTER-EASTON, 2011; MANN *ET AL.,* 2010). Two primary drivers, namely energy and resource conservation, focus on processes and decisions at the input stage of production systems, while waste reduction and pollution control address issues at the output stage. Additionally, economic motivations played a significant role, as firms were driven by the potential for cost savings and revenue growth (STEAD-STEAD, 2005). Table 21 illustrates that the main sustainability drivers for implementing Industry 4.0 within the food industries, which are achieving competitive advantage and increasing market share each at 69,2% respectively. Energy conserving follows at 66.7% Other drivers include the desire to reduce carbon footprint, pollution, and enhance revenue.

Table 21: Drivers for Industry 4.0 Implementation in the Food Sector.

Driver	Large	Medium	Small	None
Desire to reduce cost	56,4	30,8	10,3	2,6
Desire to enhance revenues/profits	64,1	28,2	5,1	2,6
To achieve competitive advantages	69,2	15,4	12,8	2,6
Desire to conserve energy	59	37,8	3,3	0
Desire to conserve resources/resources pressures	66,7	20,5	7,7	5,1
Desire to reduce pollution	48,7	38,5	12,8	0
Desire to reduce waste	53,8	30,8	15,4	0
Legal/regulatory pressures	41	43,6	12,8	2,6
Marketing pressures	48,7	35,9	12,8	2,6
Environmental advocacy pressures	41	45,2	13,7	0
Desire to enter new markets	61,5	23,1	10,3	5,1
To increase market share	69,2	17,9	10,3	2,6
Carbon foot print reduction	56,4	32,2	9,8	1,6

Source: Author's own collaboration.

Analysis of the sustainability drivers depicted in Table 21 reveals a blend of environmental and economic factors. This suggests that businesses implementing sustainability want to increase their competitiveness while simultaneously enhancing their environmental performance.

The economic drivers empirically found in this research were: desire to reduce cost, desire to enhance profits, marketing pressures, desire to enter new markets and desire to increase market share respectively whilst the environmental drivers discovered were: desire to conserve energy, desire to conserve resources, desire to reduce pollution, desire to reduce waste, environmental advocacy pressures, reduction of carbon foot print. This implies that the food industry enhances their environmental performance in tandem with achieving their economic goals. According to SVENSSON *ET AL.* (2018), this demonstrates how social norms and environmental preservation may provide economic advantages through the successful integration of TBL. There is a direct correlation between a firm's competitiveness and its environmental consciousness since organizational strategy and competitive advantage are based on the ability to support ecologically sustainable economic activities (HART, 1995; LEAL *ET AL,* 2003).

The drivers of sustainability in the Jordanian food sectors included legal/regulatory driver that are regarded to place the most pressure on organizations. This demonstrates that although the food sectors in Jordan were compelled to embrace sustainability due to legal or regulatory pressure, they did so voluntarily since doing so would improve their performance both environmentally and economically. Through the voluntary adoption of Industry 4.0, the food industry may more effectively and efficiently implement sustainability than when forced to do so.

Even though several sustainability strategies have been developed, the risks associated with industries activities remain significant due to numerous challenges faced in implementing Industry 4.0. The primary challenges are identified in Table 22.

Table 22: Challenges for Industry 4.0 Implementation in the Food Sector.

Challenge	**Exist**	**Slightly exist**	**Non-Existent**
Higher cost of adaption (take up)/higher running costs	41	43,6	15,4
Problems of other stakeholders' pressures	30,8	48,7	20,5
Lack of relevant information	23,1	53,8	23,1
Inappropriate infrastructures	32,8	47,7	19,5
Decline of profit level	35,9	35,9	28,2
Lack of expertise/unskilled employees on Industry 4.0 practices	25,6	55,8	18,5
Difficulties of implementing Industry 4.0 (new concept) in the firm	38,5	51,3	10,3
Lack of funding/Financial support	38,8	46,2	15,1
Conflicts with organization business objectives	23,1	43,6	33,3
Conflict with stakeholder interest	24,7	39,4	35,9

Source: Author's own collaboration.

The most challenges which might face the food industry when implementing Industry 4.0 technologies are high cost of adoption, Lack of funding/Financial support and difficulties of implementing a new concept in the firm, which account for 41%, 38.8% and 38.5%

respectively, followed by the decline of profit level at 35.9% and inappropriate Infrastructure at 32.8%.

These challenges align with those identified in financial constraints pose challenges for many Small and Medium-sized Enterprises (SMEs) in conducting diverse sustainability initiatives with Industry 4.0 and providing environmental training for employees. This underscores the substantial funds required to support infrastructure, innovation, information, and manpower needs for sustainability.

Table 22 outlines the challenges of sustainability applicable to both SMEs and large-scale industries. In industries, problems such as inadequate infrastructure, lack of relevant information, adoption costs, unskilled employees on Industry 4.0 practices, and higher running costs are exacerbated by financial deficiencies. Highly educated employees are crucial for understanding sustainability issues and implementing effective Industry 4.0 operations.

Due to the nature of their business, companies, especially those in the food industry, may have issues with improper infrastructure, greater adoption costs, inexperienced staff, and lower operating expenses.

4.3 Goodness of measures

Using both the anticipated relationships between factors and the theoretical framework created especially for this research, we analyze the questionnaire data to ascertain their significance based on the applied criteria. Through factor analysis, groups of closely linked variables when factors are generated, representing dimensionality in the data (HAIR *ET AL.,* 2010). The gathered data are subjected to factor analysis and reliability analysis, two evaluations of measurement quality.

4.3.1. Exploratory Factor Analysis (EFA)

A measure of interdependence aimed at uncovering the latent structure among the measurement variables in an analysis is called the factor analysis, aiming to summarize patterns of correlations between the variables that are being examined, or to test hypotheses on the characteristics of underlying processes (HAIR *ET AL.,* 2010; TABACHNICK-FIDEL, 2014). This technique can be approached either confirmatory or exploratorily. EFA, which stands for Exploratory Factor Analysis, is utilized to explore structure among variables or as a means of data reduction, allowing for the identification of factors without imposing any predetermined structure (HAIR *ET AL.,* 2010). On the other hand, Confirmatory Factor Analysis (CFA) evaluates the extent to which data conform to an anticipated structure derived from theoretical underpinnings or previous studies (HAIR *ET AL.,* 2010). That is to say, CFA is appropriate if a researcher has predefined notions regarding factors number or the grouping of variables onto factors. In this study, EFA is employed to explore the structure between the variables that the theoretical model indicated. The researcher's goal, lacking a predefined framework, is to ascertain how many factors there really are and which variables the factor analysis process will group together. EFA is seen to be better appropriate for this research since factor analysis's goal is to produce a succinct representation of relationships between measured variables (FABRIGAR *ET AL.,* 1999).

The sphericity of the Bartlett's test and the Kaiser-Meyer-Olkin (KMO) test are utilized to determine whether or not EFA is suitable for the intended purpose of this study. While the Bartlett's test determines whether there are any non-zero correlations, patterns and correlations between variables are evaluated using the KMO test (HAIR *ET AL.,* 2010).

The Kaiser-Meyer-Olkin (KMO) statistic evaluates the sampling adequacy by examining the relationship between variables, shown as the squared partial correlation between items divided by the squared correlation between items. It has a range of 0 to 1, with values closer to 0 signifying that the total of partial correlations is greater than the total of correlations, indicating unsuitability for factor analysis (FIELD, 2009). Conversely, values closer to 1 signify tight correlation patterns, suggesting that factor analysis would generate unique and trustworthy factors. FIELD (2009) suggests thresholds for interpretation: a score of 0.5 is barely acceptable, a value between 0.5 and 0.7 is decent, a value between 0.7 and 0.8 is good, a value between 0.8 and 0.9 is wonderful, and a value over 0.9 is exceptional. Table 23 presents the outcomes of both the KMO test and Bartlett's test of sphericity. BLAIKIE (2003) mentioned that if KMO test yielded an overall sampling adequacy value of 0.886, it will indicate a high level of adequacy. This value, nearing 1, suggests that factor analysis can effectively produce reliable elements of the dataset being examined. Additionally, Bartlett's test of sphericity demonstrated high significance ($p < 0.001$), affirming the existence of a structure of relationships between elements, thus justifying the application of factor analysis.

EFA plays a crucial role in uncovering the underlying structure of variable relationships, necessitating the determination of correlation patterns. In this process, the choice between Principal Components Analysis (PCA) and Common Factor Analysis (CoFA) for factor extraction becomes pivotal.

Table 23: KMO and Bartlett's tests Results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.886
Bartlett's Test of Sphericity	Approx. Chi-Square	27193.731
	df	1953
	Sig.	.000

Source: Author's own collaboration.

CoFA primarily aims to unveil common factors shared among variables, whereas PCA is employed to condense a vast number of variables into a smaller set of components. To clarify, CoFA yields factors, whereas PCA yields components. Since the goal of this study is to identify latent constructs that are represented in terms of factors within the original variables, CoFA is chosen as the best factor extraction technique.

Principal Axis Factoring (PAF) is an alternative term for CoFA, which aids in comprehending latent variables explaining relationships among measured variables. PAF allows for successive extraction of factors until a significant variance is accounted for in the correlation matrix, purportedly resulting in more stable loadings, therefore, exhibits superior performance in overextraction. The SPSS output shows factor loadings reflecting each variable's correlation with each factor after Principal Axis Factoring (PAF) was selected as the factor analysis extraction method in this study. However, these factor loadings need to be rotated in order to provide a more straightforward and theoretically valid factor solution (HAIR *ET AL.,* 2010). With the goal of maximizing high correlations and minimizing low correlations between factors and variables, rotation reallocates variance from earlier factors to subsequent factor outputs (TABACHNICK-FIDEL, 2014).

There are two different kinds of rotations: oblique factor rotations and orthogonal factor rotations. Both varieties seek to make the factor matrix more readable by to aid interpretation (HAIR *ET AL.,* 2010). However, oblique factor rotation, unlike its orthogonal counterpart, permits correlated factors, aligning with the assumption of intercorrelation among constructs in this research. Hence, the study employs Promax rotation, an option for oblique rotations in SPSS. Oblique rotations such as Promax are reputed for their flexibility and ability to generate theoretically meaningful factors (HAIR *ET AL.,* 2010). Based on the survey data, the factor loading matrix is produced via the extraction procedure (using Principal Axis Factoring) and variable rotation (using Promax). This matrix basically consists of correlations between variables and factors, where variables with large loadings on a factor are used to interpret that factor (TABACHNICK-FIDEL, 2014).

From the initial dataset of 99 factors, an examination was conducted to derive eigenvalues for each component within the dataset. Eigenvalues represent the cumulative variance associated with each factor. The EFA revealed eleven factors meeting Kaiser's criterion of 1 or higher, collectively explaining 87.06% of the variance, as it can be seen in Table 24. However, in accordance with the principle of interpretability, which dictates that smaller factors should only be retained if they hold significant meaning, and considering the slightly ambiguous nature of the scree plot with some inflections, a decision was made to retain ten factors for subsequent analysis. A cumulative variance nearing 100% suggests a high level of interrelation among the variables (HAIR *ET AL.,* 2010). SPSS calculates these factor loadings based on eigenvalues greater than 1.0. An eigenvalue cutoff at 1.0 signifies an adequate amount of information captured by a factor, indicating that a sufficient number of factors have been extracted (HAIR *ET AL.,* 2010).

The eleven factors identified through the factor analysis require careful examination of their loading patterns. Items demonstrating loadings exceeding 0.4 within each factor are retained (HAIR *ET AL.,* 2010). Moreover, each factor should comprise a minimum of three items. These criteria for factor loadings align with the standards (SWAMIDASS-KOTHA, 1998). Adhering to these guidelines, examining factor loadings closely might highlight problems like weak or inconsequential loadings for certain variables and cross-loadings (HAIR *ET AL.,* 2010).

Table 24: Total Variance

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	20.639	32.761	32.761	20.639	32.761	32.761	17.234
2	10.569	16.775	49.536	10.569	16.775	49.536	10.586
3	7.095	11.261	60.798	7.095	11.261	60.798	9.894
4	3.742	5.939	66.737	3.742	5.939	66.737	8.239
5	2.757	4.376	71.113	2.757	4.376	71.113	8.078
6	2.458	3.902	75.015	2.458	3.902	75.015	5.008
7	2.000	3.175	78.190	2.000	3.175	78.190	2.767
8	1.768	2.806	80.996	1.768	2.806	80.996	1.929
9	1.455	2.310	83.306	1.455	2.310	83.306	1.785
10	1.279	2.031	85.336	1.279	2.031	85.336	1.533
11	1.090	1.730	87.066	1.090	1.730	87.066	1.451
12	.923	1.465	88.531				

Extraction Method: Principal Axis Factoring.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Source: Author’s own collaboration.

After examining factor loading issues, only seven factors remain, each consisting of at least three items. No factor contains only one item. Meanwhile, weak loadings are observed for eight items, DR9, D12, CH10, CH11, PER6, PER9, PER12 and PER 15, representing marketing pressures (DR9), to increase market share (DR12), Conflicts with organization business objectives (CH10), conflict with stakeholder interest (CH11), improved decision making (PER6), service oriented and event-driven (PER9), product life extension (PER12), traceability (PER 15) respectively. Specifically, showing loadings on two factors, indicating ambiguity in its attribution to any single factor. Consequently, they are excluded from further analysis. The factor loadings acquired during ten iterations using Promax rotation and Principal Axis Factoring, with values eliminated shown in bold are provided in Appendix C, showing extensive matrix of factor loadings.

Communality represents the proportion of variation explained by the factors that were extracted, showing how much of the variance of an original item is shared by other research items (HAIR *ET AL.,* 2014). Evaluating communality assists in identifying variables that are not adequately explained by the factor solution, falling below acceptable levels of explanation. The variance in a variable that is explained by the factor solution is shown by the communality value. Higher communalities indicate that a significant portion of the variable's variance has been captured by the factors, while lower communalities suggest that a considerable portion of the variable's variance remains unexplained.

Generally speaking, a threshold of 0.4 is advised, and the factor solution should explain at least half of the variation for each item. Accordingly, variables having communalities less than 0.4 are seen to provide insufficient justification (FIELD, 2009). Appendix C displays the extracted communality and initial loadings for the study items. All communalities have surpassed the 40% mark, according to the results, with communality extraction ranging from 96.1% for ECO_PR1 to 75.3% for both SOC_COM1 & CH1.

According to the findings from the exploratory factor analysis (EFA), the first 29 elements of sustainability pillars including environmental pillar (ENV), economic pillar (ECO) and social pillar (SOC) exhibited strong associations with the two factors, factors 1 and 3, surpassing the significant factor threshold of 0.4 as outlined by HAIR *ET AL*. (2010). Consequently, PCA was performed on the sustainability pillars in the next section.

Based on the results of the EFA, all 15 items in sustainability performance (PER) are loaded into factor 2. Meanwhile, Factor 4 comprises 11 drivers (DR) for implanting Industry 4.0. Those highlights the Desire to reduce cost, desire to enhance revenues/profits, to achieve competitive advantages, desire to conserve energy, desire to conserve resources/resources pressures, desire to reduce pollution, desire to reduce waste, Legal/regulatory pressures, environmental advocacy pressures, desire to enter new markets and carbon foot print reduction, these re-designated into new category called “Drivers”.

In the case of the rest of the factors, a similar restructuring approach is applied to factors 5, 6 and 7. Factor 5 encompasses challenges for implementing industry 4.0 (CH), which included 9 items; Higher cost of adaption (take up)/higher running costs, Problems of other stakeholder's pressures, Lack of relevant information, Inappropriate infrastructures, Decline of profit level

Lack of expertise/unskilled employees on Industry 4.0 practices, Difficulties of implementing Industry 4.0 (new concept) in the firm, Lack of funding/Financial support. These challenges constitute essential for information exchange and tracking how industry 4,0 might affect sustainability outputs. Hence, they are recategorized as "Challenges".

As anticipated, I4.0 capabilities dimensions are consolidated into two factors, 6 and 7. In Factor 6, seven organizational I4.0 capabilities are loaded: Data-Driven Decision Making (OC1), Agility and Flexibility (OC2), Operational Efficiency and Productivity (OC3), Innovation and Product Development (OC4), Visibility and Resilience (OC5), Centricity and Personalization (OC6), Connectivity and Collaboration (OC7), with loading factors exceeding 0.40. Consequently, this group is designated under "organizational capabilities".

Furthermore, Factor 7 comprises of I4.0 technologies undertaken by the food industry including: IoT/Food Safety Management Systems (IC1), Blockchain Technology (IC2), Big Data Analytics (IC3), Automation and Food Traceability Systems (IC4), AI & ML (IC5). Consequently, this group is designated under "Industrial capabilities".

4.3.2. Principal Component Analysis (PCA)

Component analysis and common factor analysis are the two basic concepts of factor analysis. This method investigates the connections between various variables and clarifies them in terms of common underlying causes (HAIR *ET AL.,* 2014). Condensing a large number of related things into a smaller set of factors while preserving as much information as possible is the main goal of factor analysis (HAIR *ET AL.,* 2014). By evaluating the underlying structure of multiple items related to research variables, factor analysis identifies groups of items that commonly align with a factor. This empirical estimation of variable structure provides a basis for creating objective summated scales (HAIR *ET AL.,* 2014). Therefore, in this study, principal component analysis (PCA) was conducted to uncover the underlying structure of research variable items and determine the minimum number of common factors that adequately explain the correlations among observed variables. Consequently, PCA is employed to unveil the principal patterns of factors underlying each research construct, including sustainability factor resulted from the EFA serving as an intermediate step for subsequent regression and association analyses.

To find out the underlying structure of the research variable items, a principal component analysis (PCA) was performed on the 29 sustainability items, which represent independent research constructs. Initially, criteria including item size, the Kaiser-Meyer-Olkin (KMO) measure, communalities, and total variance explained were used to evaluate the sample's eligibility and sufficiency for factor analysis.

The sustainability construct comprises three variables: Environmental performance (ENV), economic performance (ECO), and social performance (SOC). Measurement of the sustainability pillars involved a total of 29 items. Table 25 presents the statistical assessments, including the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (0.948) and Bartlett's test of sphericity ($p < .001$), confirmed the suitability of the data for factor analysis of PCA. Specifically, Bartlett's test indicated strong correlations among the items, supporting the use of Principal Component Analysis (PCA).

Table 25: KMO and Bartlett's tests Results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.948
Bartlett's Test of Sphericity	Approx. Chi-Square	13342.501
	df.	378
	Sig.	.000

Source: Author's own collaboration.

To find components with eigenvalues larger than 1, Principal Component Analysis (PCA) with Promax rotation and Kaiser normalization was utilized. Table 26 reveals the results that nine factors were derived for the sustainability construct variables. After examining weak factor loading issues, only eight factors remain. Weak loadings are observed for one item only, ENV_EWP2. The first factor, termed "Individuals" exhibits explaining 24.47% of the total variance. The cumulative variance explained by these factors is 73.07%, considered adequate for subsequent statistical analyses. The eight factors were named according to the environmental, economic and social factors, resulting sustainability construct comprises of eight variables: Material and Energy (ME), Environmental Management (EM), Emissions, waste and pollution (EWP), Production and Resourcing (PR), Technology and Innovation (TI), Macroeconomics (MA), Community (COM) and Individuals (IND).

Table 26 provides a comprehensive overview of the construct of loadings, providing a matrix of their loading pattern, a list of items, instrument questions, and communality scores. Loadings range from 1.090 for SOC_IND2 to 0.611 for SOC_COM5, all surpassing the threshold of 0.4.

Similarly, communalities range between 83% to 94.9%, all surpassing the 0.4 minimally specified level.

To summarize, the factor analysis using the EFA identifies five significant factors whose loading ranges are larger than the 0.40 limit, indicating a high degree of variable convergence within each factor. According to the factor solution obtained from the EFA, 5 factors were obtained which are: Performance (PER), Drivers (DR), Challenges (CH), Organizational capabilities (OC) and Industrial capabilities (IC). The choice of these labels is determined by their suitability in accurately representing the underlying dimensions of the newly identified factors, as advised by HAIR *ET AL.* (2010).

Table 26: Factors Pattern matrix and communalities of PCA

Variable	Component									Communalities	
	1	2	3	4	5	6	7	8	9	Initial	Extraction
ENV_ME1			.616							1.000	.925
ENV_ME2			.886							1.000	.944
ENV_ME3			.938							1.000	.934
ENV_EM1				.866						1.000	.926
ENV_EM2				.904						1.000	.905
ENV_EM3				.880						1.000	.931
ENV_EWP1					.866					1.000	.921
ENV_EWP2					.777				.493	1.000	.951
ENV_EWP3					.813					1.000	.940
ECO_PR1						.990				1.000	.932
ECO_PR2						.887				1.000	.943
ECO_PR3						.920				1.000	.935
ECO_TI1							.806			1.000	.949
ECO_TI2							.950			1.000	.900
ECO_TI3							.687			1.000	.901
ECO_MA1								.860		1.000	.905
ECO_MA2								.830		1.000	.900
ECO_MA3								.957		1.000	.949
SOC_COM1		.685								1.000	.945
SOC_COM2		.799								1.000	.880
SOC_COM3		1.046								1.000	.928
SOC_COM4		.791								1.000	.888
SOC_COM5		.611								1.000	.892
SOC_IND1	.804									1.000	.900
SOC_IND2	1.090									1.000	.932
SOC_IND3	.812									1.000	.941
SOC_IND4	.998									1.000	.865
SOC_IND5	.960									1.000	.919
SOC_IND6	.761									1.000	.830
% of Variance	25.47%	19.36%	9.57%	6.22%	4.35%	2.51%	2.25%	1.92%	1.42%	Cumulative: 73.07%	
Extraction Method: Principal Component Analysis.											
Rotation Method: Promax with Kaiser Normalization.											
Rotation converged in 8 iterations.[a]											

Source: Author's own collaboration.

To illustrate the transformations of the sustainability variables from their original forms based on the theoretical model of this study to their revised forms, a PCA was performed, resulting sustainability construct comprises of eight variables: Material and Energy (ME), Environmental Management (EM), Emissions, waste and pollution (EWP), Production and Resourcing (PR), Technology and Innovation (TI), Macroeconomics (MA), Community (COM) and Individuals (IND).

4.3.3. Reliability Analysis

Reliability refers to the evaluation of the consistency and uniformity of scale measures, determining how well multiple measurements of a variable align with one another (HAIR *ET AL.,* 2014). Put differently, it involves gauging whether questionnaire items consistently capture the underlying constructs they aim to measure. Additionally, a robust reliability of the research instrument strengthens the validity of research findings when generalizing them. Researchers employ various methods to establish instrument reliability. The most prevalent method involves evaluating the overall scale consistency using Cronbach's alpha. Cronbach's alpha measures the extent to which participants consistently respond across all items representing a scale or variable (HAIR *ET AL*., 2014). Analyzing the reliability of a measurement instrument is crucial to ensure consistent results (FLYNN *ET AL.,* 1994). Internal consistency is commonly used to assess reliability, suggesting that items within a scale should correlate strongly since they measure the same construct (HAIR *ET AL*., 2010).

Following the factor analysis results in the preceding section, Cronbach's alpha is employed to evaluate the internal consistency of the entire scale used in this research. Cronbach's alpha provides a reliability coefficient that indicates the degree of item interrelatedness within a factor. The widely accepted lower threshold for Cronbach's alpha is 0.70 (HAIR *ET AL.,* 2010). In this research, all variables exhibit reliability coefficients exceeding the suggested value of 0.70, which denotes a good degree of internal consistency. All variables have Cronbach's alpha values that are higher than the 0.70 cutoff, which suggests little measurement error and strong reliability on all scales.

The reliability of a scale is measured by Cronbach's alpha, which ranges from 0 to 1, with values typically between 0.60 and 0.70 considered minimally acceptable (HAIR *ET AL.,* 2014). Table 27 displays the Cronbach's alpha values for the research variables. The results show a highest value of 0.982 observed for the production and resourcing variable (PR) variable and the lowest value of 0.725 for the community (COM) variable. Despite the community variable's marginal value slightly above the 0.6 threshold, it still falls within an acceptable range. These results indicate good internal consistency among the scales, confirming the reliability of the research instrument.

Despite the substantial reliability of measurements utilized in this study, inaccuracies in responses may arise due to respondent misinterpretation or doubts, potentially increasing measurement error. In such cases, quantifying measurement error becomes necessary. However, given the sample size of this research, this approach is deemed unsuitable and falls beyond the study's scope (HAIR *ET AL.,* 2010).

Table 27: Reliability Test Results

Construct	Variable	No of Items	Cronbach's alpha (α)
Environmental Pillar (ENV)	Materials & Energy (ME)	3	0.819
	Environmental Management (EM)	3	0.825
	Emissions, waste & Pollution (EWP)	2	0.827
Economic Pillar (ECO)	Production & Resourcing (PR)	3	0.982
	Technology & Innovayion (TI)	3	0.898
	Macroeconomics (MA)	3	0.731
Social Pillar (SOC)	Community (COM)	5	0.725
	Individuals (IND)	6	0.890
Drivers & Challenges	Drivers (DR)	11	0.794
	Challenges (CH)	8	0.753
I4.0 Capabilities	Organizational Capabilities (OC)	7	0.787
	Industrial Capabilities (IC)	5	0.821
Performance (PER)		11	0.931

Source: Author's own collaboration.

4.4 Appropriateness of Regression Analysis

Prior to performing a regression analysis to evaluate the anticipated relationships posited by the research, it is recommended to scrutinize certain assumptions to assess the suitability of regression analysis for the gathered data. The subsequent segment will explore these statistical factors, including normality, multicollinearity, and homoscedasticity (HAIR *ET AL.,* 2014)

4.4.1. Descriptive Statistics and Normality

One of the key methods in quantitative data analysis involves utilizing descriptive statistics to gain insights into the data (HAIR *ET AL.,* 2014). The output of descriptive statistics shows the distribution of answers for every variable that is assessed. Finding significant differences or correlations is facilitated by characterizing data in terms of variables and their combinations (TABACHNICK-FIDELL, 2014). Typically, statistical explanations of variables concentrate on illustrating dispersion and central tendency. While dispersion sheds light on how values are distributed around the central tendency, central tendency gives a general overview of common or average values (SAUNDERS *ET AL.,* 2012). Table 28 shows the mean values for all items with N = 195 in order to show the dispersion and central tendency. In addition, the standard deviation shows how individual answers vary from the mean, indicating how far apart the observations are (HAIR *ET AL.,* 2010). Table 28 displays the remaining descriptive statistics, which provide information about the variables' lowest (Min) and maximum (Max) values.

The degree to which the sample data distribution resembles a normal distribution is referred to as normality, which is a fundamental assumption for many statistical methods. If the departure from normality is substantial, it can invalidate the results of statistical tests reliant on normality, such as F and t statistics (HAIR *ET AL.,* 2014).

Table 28: Normality test.

Construct	Variable	N	Min	Max	Mean	SD	Skewness	Kurtosis
Environmental Pillar (ENV)	Materials & Energy (ME)	195	1	4	2.97	.942	-.230	-.936
	Environmental Management (EM)	195	1	4	2.47	.949	-.424	-.874
	Emissions, waste & Pollution (EWP)	195	1	4	2.68	1.014	-.315	-.948
Economic Pillar (ECO)	Production & Resourcing (PR)	195	1	5	3.51	1.243	-.795	-.364
	Technology & Innovayion (TI)	195	1	5	3.76	1.194	-.767	-.249
	Macroeconomics (MA)	195	1	5	3.45	1.059	-.886	.092
Social Pillar (SOC)	Community (COM)	195	1	3	2.05	.631	-.926	.637
	Individuals (IND)	195	1	3	2.56	.634	-.934	1.099
Drivers & Challenges	Drivers (DR)	195	1	4	3.41	.777	-.923	.768
	Challenges (CH)	195	1	3	2.05	.713	-.117	-.606
I4.0 Capabilities	Organizational Capabilities (IC)	195	1	5	3.67	1.029	-.997	.866
	Industrial Capabilities (OC)	195	1	4	2.95	.962	-.510	-.416
Performance (PER)		195	1	5	3.99	.833	-.827	-.357

Source: Author's own collaboration.

Particularly for small sample sizes (e.g., fewer than 30), testing for normality is strongly recommended. Therefore, researchers are advised, per HAIR *ET AL.* (2014), to examine both graphical plots and statistical tests to accurately assess the degree of departure from normality. It's also crucial to determine the significance level of deviations from normality to ensure the suitability of the data for specific analysis methods.

The dataset utilized in this study underwent normality testing through examination of skewness and kurtosis, alongside a visual assessment via normal probability plots of the constructs. Skewness and kurtosis values serve to describe the distribution characteristics of the observations, interpreting the symmetry and peakedness or flatness of the distribution (Hair *et al.,* 2010). A distribution that is moderately skewed is indicated by skewness values close to ±1, and the existence of outliers may be indicated by kurtosis values larger than or less than 3 (TABACHNICK-FIDELL, 2014). With Table 28, the researcher may move forward with further parametric tests, including regression analysis, on the survey data because the skewness and kurtosis values of the study variables show acceptance. Upon visual review of SPSS normal probability plots, no more evidence of dramatic departures from the assumptions of normalcy was found. The results of the normality tests showed that the study's data had a normal distribution. Appendix D contains the histogram that shows normality based on the study's data.

In testing the normality of research data, analyses of skewness and kurtosis are typically conducted. Examination involves assessing skewness and kurtosis values to gauge the distribution's shape and symmetry. Skewness indicates the balance of the distribution, while kurtosis reflects its peakedness or flatness compared to a normal distribution (HAIR *ET AL.,* 2014). Table 28 presents the skewness and kurtosis Z values for the research variables. By applying the ±2.58 critical value rule (HAIR *ET AL.,* 2014), the results fall within an acceptable range, suggesting conformity to normality assumptions.

4.4.2. Linearity and Pearson correlation analysis

A dataset following a normal distribution suggests that there are linear relationships between pairs of variables (TABACHNICK-FIDELL, 2014). However, since correlations only capture linear relationships, any non-linear effects might lead to an underestimation of the true strength of these relationships (HAIR *ET AL.,* 2010). The linearity between pairs of variables can be evaluated by visually examining scatterplots. The assumption of linearity is satisfied when there is no discernible pattern in the scatterplot. The scatterplot provided in Appendix D for this study shows no apparent pattern.

4.4.3. Multicollinearity

Multicollinearity refers to the extent to which variables in a study may be used to explain one another (HAIR *ET AL.,* 2014). It appears when two or more predictors in a regression model have a significant correlation with one another. The principle underlying the evaluation of multicollinearity is that there should not be a perfect linear relationship between predictors, and they should not exhibit excessively high correlations (FIELD, 2009). Complete collinearity or multicollinearity occurs in rare instances of singularity, where one independent variable is perfectly predicted at a level of 1.0 by another independent variable.

Assessing multicollinearity is crucial because a high association between independent variables diminishes their ability to predict the dependent variable effectively (HAIR *ET AL.,* 2014). Therefore, to optimize the predictive power of a set of independent variables, it's essential for them to exhibit low multicollinearity among each other. One straightforward approach to gauge collinearity is by examining the correlation matrix for independent variables, with correlations above 0.8 or 0.9 considered as indicators of high collinearity (HAIR *ET AL.,* 2014). However, collinearity may arise due to the combined effect of multiple independent variables, necessitating researchers to diagnose multicollinearity before conducting regression analysis.

Effective assessment of multicollinearity involves evaluating how much each independent variable is explained by the other independent variables in the set (HAIR *ET AL.,* 2014).

A nonparametric correlation analysis was conducted using spearman's correlation to assess the relationship between the main constructs variables, with Performance (PER) serving as the dependent variable. The findings in Table 29 revealed that no correlation exceeded the 0.8 collinearity indicator between independent variable, indicating the absence of multicollinearity. The highest correlations observed were between community (COM) with Individuals (IND), where ρ = 0.775 *, and between materials and energy (ME) and environmental management (EM) where ρ = 0.755. However, none of these correlations surpassed the 0.8 multicollinearity threshold.

Table 29: Nonparametric correlation (Spearman's Correlation coefficient)

	Spearman's rank correlation coefficient												
	ME	**EM**	**EWP**	**PR**	**TI**	**MA**	**COM**	**IND**	**DR**	**CH**	**IC**	**OC**	**PER**
ME													
EM	.755**												
EWP	.750**	.701**											
PR	-.277**	-.002	.016										
TI	-.210**	-.092	-.108	.742**									
MA	-.239**	-.107	-.153*	.683**	.713**								
COM	-.210**	-.178*	-.281**	.672**	.731**	.691**							
IND	.028	-.005	.013	.679**	.744**	.668**	.775**						
DR	.242**	.129	.179*	.079	.214**	.114	.192**	.187**					
CH	-.058	-.159*	-.115	-.351**	-.372**	-.361**	-.237**	-.325**	.323**				
IC	.230**	.136**	.069*	.691**	.691**	.621**	.581**	.764**	.045*	-.476**			
OC	-.082	-.053	.067	.573**	.582**	.589**	.585**	.664**	-.206**	-.416**	.652**		
PER	.244**	.291**	.239**	.756**	.822**	.736**	.712**	.797**	.454**	-.163*	.717**	.598**	

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Source: Author's own collaboration.

Variance inflation factor (VIF) and tolerance are the two approaches for multicollinearity assessment that are most frequently used. VIF is the reciprocal of the tolerance value, where tolerance is the variability of an independent variable that is not explained by other independent variables. According to HAIR ET AL. (2014), a tolerance value threshold of 0.10, or a VIF value less than 10, is advised. The findings of VIF and tolerance are shown in Table 30. Values above the tolerance cutoff of 0.1 and below the variance inflation factor (VIF) threshold of 10 were found by the tolerance and VIF tests for the study constructs. The findings supported the lack of multicollinearity, ranging from a minimum tolerance of 0.146 with a VIF of 6.855 for the environmental management variable to a maximum tolerance of 0.739 with a VIF of 1.353 for the macroeconomics variable.

Table 30: Multicollinearity Test Results

Collinearity Statistics		
Model	Tolerance	VIF
ME	.174	5.752
EM	.146	6.855
EWP	.224	4.459
PR	.632	1.659
TI	.563	1.979
MA	.739	1.353
COM	.398	2.691
IND	.443	2.259
DR	.680	1.470
CH	.583	1.717
IC	.257	3.898
OC	.342	2.928
PER	Dependent Variable	

Source: Author's own collaboration.

The lack of multicollinearity was further supported by tolerance and VIF tests for these variables, which had values above the tolerance cutoff of 0.1 and below the VIF threshold of 10. Moreover, no correlation greater than the 0.8 collinearity indicator was discovered in the prediction relationships between the variables, suggesting the lack of multicollinearity.

4.5 Hierarchical Regression Analysis

While correlation quantifies the relationship between variables, regression is employed to forecast one variable based on others (TABACHNICK-FIDELL, 2014). Although the previous analysis of the spearman's coefficient correlation revealed noteworthy patterns of correlations between the variables, it was unable to clarify the strength of these relationships or the effect the variables had on one another; for this reason, regression analysis was carried out.

The method utilized to examine the five primary hypotheses of this study is hierarchical regression. This method is widely used to analyze the effects of sets of variables in a methodical, controlled, and step-by-step systematic way (TABACHNICK-FIDELL, 2014). The evaluation of each component's contribution to the model is also made possible via hierarchical regression analysis (MEYER *ET AL.,* 2002).

In the initial stage, the direct influence of the I.40 capabilities on the sustainability performance of food industries was evaluated. Subsequently, in the second stage, the direct impact of I.40

capabilities alongside drivers and challenges of adoption on industries performance was calculated. In order to identify moderating effects, the third step involves examining the interaction effects of barriers and drivers of I4.0 adoption on the link between I.40 capabilities and sustainable performance of the food industry.

In the second stage, the direct impact of each sustainability factor on the industry's performance was evaluated, then the interaction effects of I4.0 Capabilities on the relationship between factors of sustainability and industrial sustainability performance to determine moderating effects of I4.0 capabilities on each factor of three pillars of sustainability.

The outcomes of the hierarchical regression analysis yield five distinct direct models, each of which is examined separately in the subsequent sections.

4.5.1. Relationship between I.4 Capabilities and Performance

In this initial model, the regression analysis reveals the direct impact of organizational and industrial Capabilities on Performance (PER). According to the theoretical framework of this study, I4.0 capabilities can affect the performance directly, this corresponds to Hypothesis 1, which posits a direct and positive relationship between I4.0 capabilities and performance. Also, it is conceptualized as a moderator that could influence the relationships between each factor of sustainability pillars and performance, this corresponds to Hypothesis 3,4 and 5.

The beta coefficient (β) values are utilized to evaluate the significance of various independent variables. Due to their consideration of the heterogeneity within each independent variable, these β values permit direct comparison (HAIR *ET AL.,* 2010). In other words, each change in the standard deviation of an independent variable reflects that variable's proportional influence on the dependent variable, PER. This is accomplished by using standardized regression coefficients, which allow one to compare β values directly and determine the independent contribution of each variable to the variance in Performance (BUCKINGHAM, 2004).

Table 31: Analysis of Regression Model and I4.0 Capabilities Coefficients.

Coefficients											
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	F change	R	R Square	Adjusted R Square	R Square change
1	(Constant)	113.947	4.970		22.928	.000	114.096	.737[a]	.543	.538	.543
	IC	2.799	.317	.568	8.827	.000					
	OC	.973	.274	.228	3.547	.000					

a. Predictors: (Constant), IC, OC

b. Dependent Variable: PER

Source: Author's own collaboration.

The β values of industrial capabilities and organizational capabilities of 0.568 and 0.228 respectively (p<0.001), found in Table 31, shows that there is a significant positive direct relationship between I4.0 Capabilities and PER. The R-square change value of 0.543 indicates that I4.0 Capabilities account for 54.3% of the total variance in sustainability performance of food industries.. Moreover, this model's F change statistics are significant at p<0.001, with a value of 114.096, indicating a significant and positive impact that I4.0 Capabilities have on performance. This finding is not surprising, given that the I4.0 capabilities required by food industries play a crucial role in determining their ability to engage in sustainability performance of food industries.

The regression model depicted in Figure 23 also illustrates the change in R-square value concerning sustainability performance. R-square serves as one of the metrics utilized to evaluate the adequacy of the model's fit. Figure 23 indicates that I4.0 industrial capabilities has a notably beneficial effect on sustainability performance compared to I4.0 organizational capabilities within the surveyed food industries.

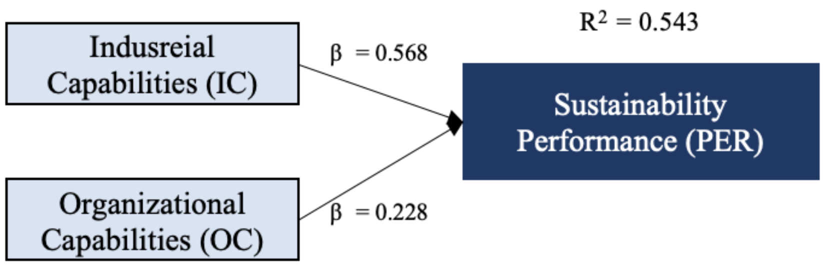

Figure 23: Effects of I4.0 capabilities on sustainability performance.

Source: Author's own contribution

4.5.2. Relationship between drivers and challenges with Performance

In the second model, the regression analysis was conducted to examine the relationship between drivers and challenges of implementing I4.0 predictors on Performance (PER). According to Table 32, while drivers exhibit a significant positive relationship with performance, challenges demonstrate a negative relationship with performance, with β values of drivers and challenges of implementing of 0.547 and -0.288 (p<0.001), respectively. Additionally, the ANOVA analysis found in Table 32 reveals an F statistic of 37.400 with a significance level of p < 0.000, suggesting the adequacy of the overall model. Figure 24 illustrates the effect of drivers and challenges on the performance of food Industries.

Table 32: Regression analysis Model Summary and coefficients of drivers and challenges

Coefficients												
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	F change	R	R Square	Adjusted R Square	R Square change
		B	Std. Error	Beta							
1	(Constant)	141.934	8.440		16.816	.000	37.400	.529a	.280	.273	.280
	DR	1.567	.185	.547	8.456	.000					
	CH	-1.207	.271	-.288	-4.450	.000					

a. Predictors: (Constant), CH, DR

b. Dependent Variable: PER

Source: Author's own collaboration.

The R-square change value of 0.280 is less than the previous model. The small R- square change value shows that drivers and challenges explain only 28% of the total variance of performance. To further examine the predictors and adjusted R square, a stepwise regression analysis was conducted (refer to Table 31).

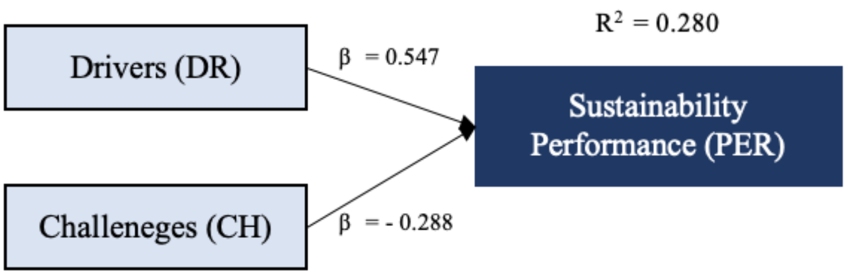

Figure 24: Effects of drivers and challenges on sustainability performance.

Source: Author's own contribution

4.5.3. Interaction Effects of drivers and challenges of adoption I4.0 on I4.0 Capabilities

The aim of this analysis is to examine whether the interaction effects of drivers and challenges of adoption I4.0 positively influence I4.0 capabilities, as suggested by Hypothesis 2, which proposes that "drivers and challenges of I4.0 adoption moderate the relationship between I4.0 capabilities and industry's sustainability performance." Table 33 presents the results of regression analysis.

According to Table 33, in the case of the I4.0 industrial capabilities, the drivers and challenges exhibit a positive β value of 0.868 ($p < 0.001$), indicating a significant interaction effect. However, with I4.0 organizational capabilities, the drivers and challenges show a negative β value of -0.223 (at $p < 0.01$), signifying a negative significant interaction effect.

Table 33: Regression analysis Model Summary and coefficients of interaction effects

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	F change	R	R Square	Adjusted R Square	R Square change
1	(Constant)	77.073	14.904		5.171	.000	183.278	0.924	.854	.849	.854
	DRI	.941	.144	.328	6.553	.000					
	CHA	-.551	.373	-.132	-2.478	.001					
	IC	4.282	.345	.868	6.634	.000					
	OC	-.949	.314	-.223	-1.547	.004					
	INTER_OC.DR.CH	-.002	.001	-.491	-3.037	.003					
	INTER_IC.DR.CH	.003	.001	.849	4.706	.000					

a. Predictors: (Constant), DR, CH, OC, IC, INTER_OC.DR.CH, INTER_IC.DR.CH

b. Dependent Variable: PER

Source: Author's own contribution

The β values depicted in Figure 25 suggest that drivers and challenges of I4.0 adoption have positive moderating effects on the relationship between I4.0 industrial capabilities and negative moderating effects on the organizational capabilities with sustainability performance. Consequently, the adoption of I4.0 would positively impact food industries' performance as a whole but might affect the employees negatively.

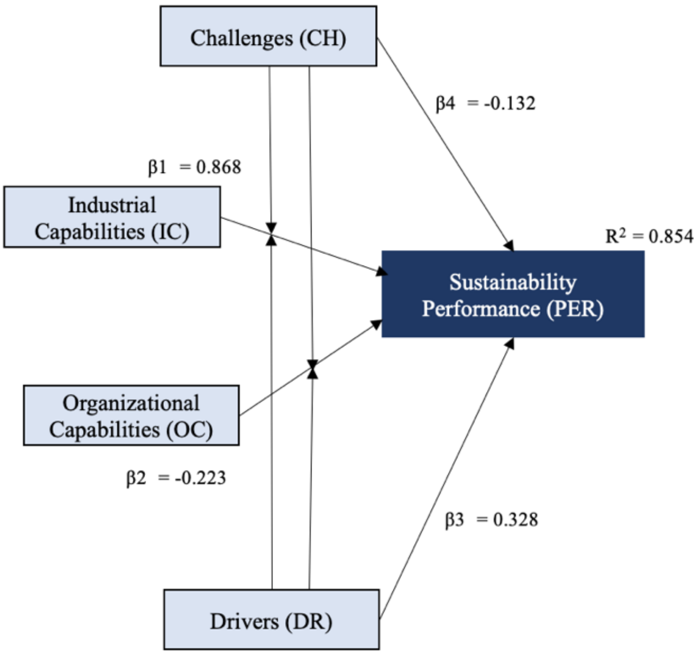

Figure 25: Interaction effects of drivers and challenges on the relationship between I4.0 capabilities and sustainability performance.

Source: Author's own contribution

The R-square change value of 0.854 indicates that the moderating effects of drivers and challenges on I4.0 capabilities account for 85.4% of the total variance Performance. In the regression model presented in Figure 25, the interaction effect of drivers and challenges on

I4.0 Capabilities positively influences food industries performance. Figure 25 illustrates these interaction effects between drivers and challenges of I4.0 adoption and I4.0 organizational and industrial capabilities

4.5.4. Interaction Effects of I4.0 Capabilities on Sustainability factors and Performance

The purpose of this analysis is to determine if I4.0 capabilities' moderating effects positively influence sustainability, as suggested by hypotheses 3,4 and 5. In the second stage the first model derived from regression analysis illustrates the connections between the factors of the three pillars of sustainability-Environmental, Economic, Social-and Performance. Table 34 presents the results of regression analysis between sustainability factors and the performance before and after implementing I4.0. It appears that I4.0 capabilities have significant effects on some factors but not all of them.

As depicted in Table 34, after adding the moderating effects of I4.0 capabilities, the economic pillar stands out as with the most influenced factors, with β values of -1.189 ($p > 0.05$) for Production and Resourcing, 0.971 for technology and Innovation in relation to its effect on Performance (PER). The positive signs indicate positive direct relationships, where an increase in the I.4.0 adoption will affect the production and resourcing negatively. Hence, they are considered significant in terms of their effects on industry's performance. The macroeconomics factor of the economic pillar had no significant relationship with the performance of industries before I4.0 capabilities adoption. I4.0 capabilities have a significant positive moderating effect on the macroeconomic part of industries with β change value from 0.082 to 0.543 after I4.0 capabilities adoption.

In the case of the environmental pillar, I4.0 capabilities exhibit a significant positive moderating effect on Materials and energy with β value of 1.110, indicating a significant interaction effect. Also, with Environmental management, I4.0 Capabilities show β value of -0.424 , which indicates that I4.0 will affect the environmental management negatively, signifying significant interaction effects. However, for emissions waste and pollution the β value equals -0.052 ($p > 0.05$) which suggests that insignificant interaction effect with I4.0 capabilities. For the social pillar, I4.0 capabilities have a negative moderating effect on the individual factor, β value has decreased from 0.338 to -0.352 after I4.0 adoption. I4.0 capabilities have no significant moderating effect on the community ($p > 0.05$).

Table 34: Regression analysis Model Summary and coefficients of interaction effects of sustainability factors

Model			Standardized Coefficients Beta	t	Sig.	F change	R	R Square	Adjusted R Square	R Square change
1 (Without I4.0)		(Constant)		14.458	.000	97.388	.898a	.807	.799	.807
	ENV	ME	.165	2.192	.030					
		EM	-.202	-3.740	.002					
		EWP	.168	2.821	.005					
	ECO	PR	.172	2.564	.019					
		TI	.284	3.154	.003					
		MA	.082	.989	.324					
	SOC	COM	.119	1.575	.117					
		IND	.338	4.343	.000					
2 (with I4.0)		(Constant)		3.273	.001	59.559	.927a	.859	.845	.859
	ENV	ME	1.110	4.190	.000					
		EM	-.424	-2.629	.004					
		EWP	-.052	-.275	.783					
	ECO	PR	-1.189	-2.800	.003					
		TI	.971	3.624	.004					
		MA	.543	2.240	.026					
	SOC	COM	.325	1.525	.129					
		IND	-.352	-3.195	.000					
	INTER_ME.OC.IC		-1.919	-3.845	.000					
	INTER_EM.OC.IC		1.245	2.347	.020					
	INTER_EWP.OC.IC		.248	.684	.495					
	INTER_PR.OC.IC		2.374	1.943	.044					
	INTER_TI.OC.IC		-1.582	-2.544	.024					
	INTER_MA.OC.IC		-.944	-2.636	.004					
	INTER_COM.OC.IC		-1.428	-1.885	.061					
	INTER_IND.OC.IC		2.263	2.837	.005					
	OC									
	IC									

a. Predictors: (Constant), IND, EM, MA, EWP, ME, COM, PR, TI
b. Predictors: (Constant), I4IC, EWP, PR, COM, I4OC, ME, MA, EM, IND, INTER_TI.OC.IC, TI, INTER_EWP.OC.IC, INTER_COM.OC.IC, INTER_ME.OC.IC, INTER_EM.OC.IC, INTER_MA.OC.IC, INTER_IND.OC.IC, INTER_PR.OC.IC
c. Dependent Variable: PER

Source: Author's own contribution

The regression model depicted in Table 34 also presents the R-square change value for performance, which is one of the metrics used to evaluate model fit. While a value closer to 1 is preferable, it's important to note that a high R-square value doesn't necessarily signify a better fit (HAIR *ET AL.,* 2010). The R-square change value of 0.807 for performance in the first model indicates that 80.7% of the total variance in performance is accounted for by the entire model, indicating that the three pillars have a noteworthy positive influence on performance among the surveyed food industries. The R-square change value of 0.859 indicates that the moderating effects of I4.0 Capabilities on the sustainability factors account for 85.9% of the total variance performance, which is slightly higher. The adoption of I4.0 will positively impact some factors of food industries' sustainability while harming others. Consequently, the adoption of I4.0 would positively impact food industries' performance regardless of a firm's existing capabilities.

Figure 26 illustrates these interaction effects between each factor of sustainability before and after I4.0 adoption. Figure 26 presents the regression the interaction effect of I4.0 Capabilities on the affected sustainability factors However, I4.0 capabilities do not exhibit a significant interaction effect on the emissions waste and pollution factor and the community factor.

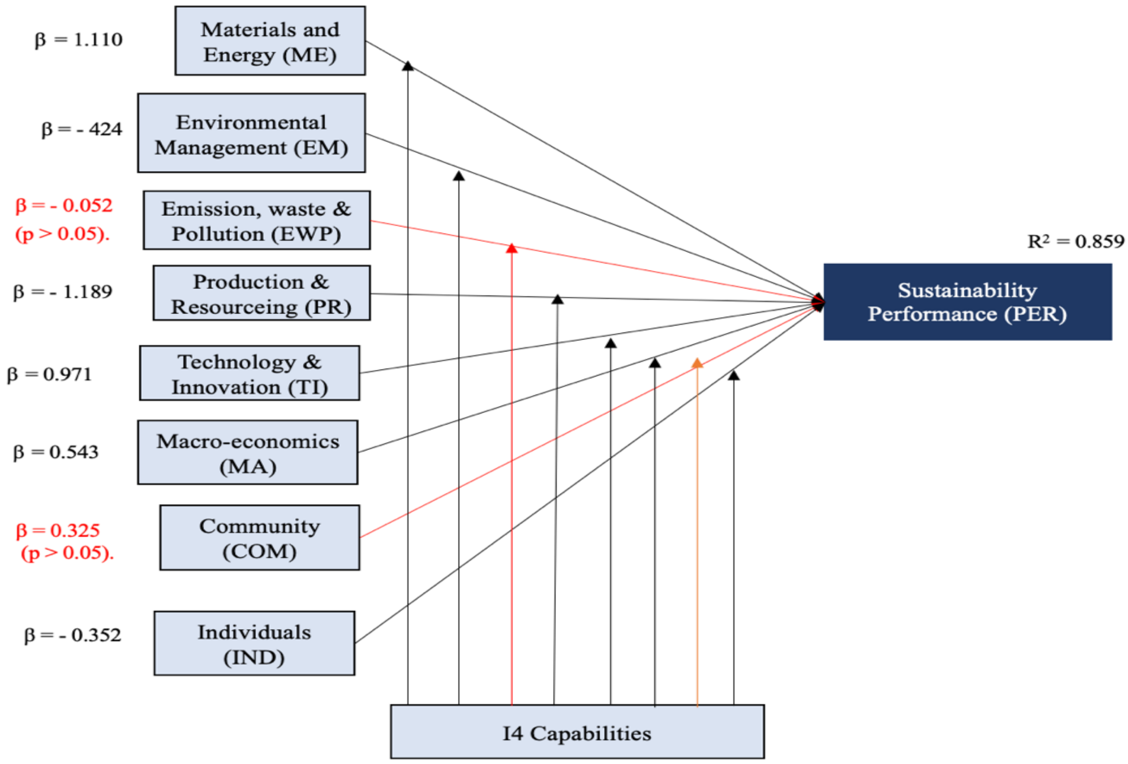

Figure 26: Interaction effects of I4.0 capabilities and on sustainability factors.

Source: Author's own contribution

I4.0 Capabilities, drivers and challenges and sustainability can have a high moderating impact on the industry performance as captured by these models. This outcome is consistent with correlation analysis, which showed a strong correlation between all predictor factors and performance at the p=0.000 level (see Table 29)..

4.5.5. Hypotheses Results Summary

The hierarchical regression findings suggest full support for hypothesis 1 (H1) and partial support for hypotheses (H2), (H3), (H4) and (H5). This conclusion is drawn from the analysis of twelve subsidiary hypotheses, with five fully supported, one partially supported, and five not supported.

Concerning the subsidiary hypotheses related to (H1), both I4.0 organizational and industrial capabilities backs the assertion that "There is a direct relationship between Industry 4.0

capabilities and sustainability performance of food industries", as indicated in Table 35, both *H1a* and *H1b* are supported.

While the supporting hypotheses for (H2) reveal that drivers and challenges effectively positively moderates the relationship Industry 4.0 Industrial capabilities and sustainability performance of food industries, as shown in *H2a* of Table 33, it didn't support that drivers and challenges similarly enhance the relationships between Industry 4.0 organizational capabilities and sustainability performance as indicated in *H2b*.

Regarding the subsidiary hypotheses associated with the three pillars of sustainability (environmental, economic and social) (H3), (H4) and (H5) respectively Industry 4.0 capabilities positively impact some sustainability factors, including Materials and energy, technology and Innovation, and macro-economics. But I4.0 capabilities won't improve environmental management, production and resourcing, and individuals factors of sustainability. Furthermore, there is no differentiation observed in the influential effects of Emissions, waste and pollution and community factors. Table 35 display the updated theoretical model's list of along with corresponding annotations indicating whether they are "Supported," "Partially Supported," or "Not Supported."

Table 35: Hypotheses Results

Items	Hypothesis Statements	Results
H1	There is a direct relationship between Industry 4.0 capabilities and sustainability performance of food industries	***Supported***
H1a	There is a direct relationship between Industry 4.0 Industrial capabilities and sustainability performance of food industries	***Supported***
H1b	There is a direct relationship between Industry 4.0 Organizational capabilities and sustainability performance of food industries	***Supported***
H2	Drivers and Challenges postively moderates the relationship Industry 4.0 capabilities and sustainability performance of food industries	*Partially Supported*
H2a	Drivers and Challenges postively moderates the relationship Industry 4.0 Industrial capabilities and sustainability performance of food industries	***Supported***
H2b	Drivers and Challenges postively moderates the relationship Industry 4.0 Organizational capabilities and sustainability performance of food industries	*Not Supported*
H3	Industry 4.0 capabilities positively impact the environmental pillar of sustainability in food indsutry	*Partially Supported*
32a	Industry 4.0 capabilities positively impact the materials and energy in food industry	***Supported***
H3b	Industry 4.0 capabilities positively impact the enviromental management in food industry	*Not Supported*
H3c	Industry 4.0 capabilities positively impact the emissions, waste and pollution in food industry	*Not Supported*
H4	Industry 4.0 capabilities positively impact the economic pillar of sustainability in food indsutry	*Partially Supported*
H4a	Industry 4.0 capabilities positively impact the production and resourcing in food industry	*Not Supported*
H4b	Industry 4.0 capabilities positively impact the technlogy and Innovation in food indsutry	***Supported***
H4c	Industry 4.0 capabilities positively impact the macro-economics in food indsutry	*Partially Supported*
H5	Industry 4.0 capabilities positively impact the social pillar of sustainability in food indsutry	*Not Supported*
H5a	Industry 4.0 capabilities positively impact the community in food industry	*Not Supported*
H5b	Industry 4.0 capabilities positively impact the individuals in food indsutry	*Not Supported*

Source: Author's own contribution

4.6 Research Findings and Discussion

This section examines the research findings concerning the research objectives and theoretical model hypotheses formulated for this study. The results of the survey are analyzed according to the sustainability factors identified in the earlier systematic literature, along with an exploration of the role of I4.0 capabilities effects on each factor. The aim of this study was to expand our understanding of how I4.0 implementation technology impacts the sustainability performance of food industries by exploring the I4.0 capabilities and what drivers and challenges might arise when implementing I4.0.

To facilitate this inquiry, the empirical research has not only assessed whether the pursuit of I4.0 practices influences sustainability performance of food industries, but has also investigated the impact of specific contingency factors on the relationship between sustainability practices and industry's performance. In essence, this research has sought to determine whether industry 4.0 adoption can enhance overall industry's sustainability performance, and what drivers and challenges this adoption might face.

To fulfill the objectives of the study, we initially constructed a conceptual model and formulated hypotheses based on existing literature, delineating the causal connections between the various constructs. Employing a quantitative methodology, we aimed to substantiate the validity of the conceptual model, test the hypotheses, and facilitate the interpretation of the findings.

4.6.1. Influences of Industry 4.0 and sustainability dimensions

This section pertains to the first research query of this thesis, aiming to investigate how collaborative knowledge influences food sustainability outcomes. This study aimed to find whether I4.0 capabilities implemented by food industries exerted a significant influence on their sustainability performance. Additionally, it investigated the main factors of the three pillars of sustainability that might get affected by I4.0 integration. This analysis aims to answer the first two research questions as illustrated in Figure 27.

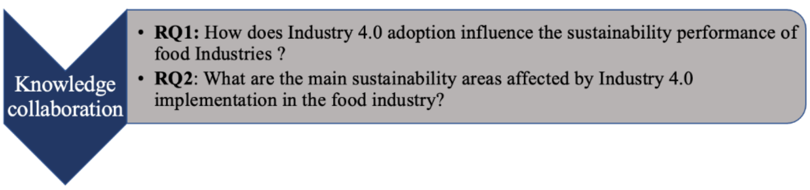

Figure 27: Concept analysis for knowledge collaboration

Source: Author's own contribution

As food industries increasingly prioritize corporate sustainability performance to enhance their competitive edge (BRACCINI-MARGHERITA, 2018), there is a growing necessity for deeper insights into the I4.0 implementation and performance outcomes of sustainability practices. This quest for knowledge is essential for comprehending how industries can effectively execute I4.0 strategies to their advantage. Given the multifaceted aspect of industries sustainability, an expanding literature base encompasses a diverse array of I4.0 implementation influences on sustainability practices being adopted by industries (KHAN *ET AL.,* 2021).

From a broad perspective, examining the average scores for responses indicate that the research metrics exhibited a higher average than the median of 2.5 (Refer to Table 28). This suggests several conclusions about how the research participants perceive each measured variable within their respective categories. For instance, in terms of the I4.0 capabilities construct, the high average response scores of 3.67 and 2.95 indicate that employees in food industries perceive a significant benefit from integrating I4.0 technologies in the food industry. Likewise, the sustainability performance factor yielded an average score of 3.99, suggesting that respondents are quite positive about the sustainability gained from I4.0 technologies.

This study demonstrated the impact of Industry 4.0 implementation on the sustainability performance of the food business. It is not unexpected that I4.0 Capabilities has been shown to have a direct and positive influence on sustainability performance in the food manufacturing sector (JAMWAL *ET AL.,* 2021). Industry 4.0 affects positively the sustainability performance and practices of food through IoT integration, data analytics, automation, and optimization. These technologies enable supply chain integration, information sharing and transparency, and process digitization and automation, leading to significant improvements in sustainability performance. This outcome highlighted two significant effects on the connection between I4.0 capabilities and sustainability performance. Furthermore, the implementation of Industry 4.0 strategies in food industries has the potential to reduce resource consumption, minimize waste generation, and enhance energy efficiency, thus contributing to a more sustainable and environmentally friendly production processes (OLÁH *ET AL.,* 2020). The findings from the empirical study validate the theoretical ideas that there are two interconnected elements of Industry 4.0: Organizational capabilities (OC) and Industrial capabilities (ID). The results indicate. The results indicate that Industry 4.0 implementation positively influences sustainability practices in food industries.

The research has focused on the key findings and insights obtained from the reviewed systematic literature. It has highlighted the various aspects of sustainability pillars that industry 4.0 implementation contribute to sustainability performance in food industries. There is a scarcity of research examining the areas within sustainability affected by Industry 4.0 implementation. Findings has outlined various sustainability implications of the digital transformation associated with Industry 4.0 on food industries (BAI *ET AL.,* 2020). It underscores that the integration of Industry 4.0 in food industry with sustainability is an area that requires further exploration in academic literature. The adoption of standardized and sustainable Industry 4.0 models within food industries could contribute to a better future and enhance individuals' quality of life. This hinges on the extent to which academic research contributes new insights to this domain. Several projects emphasizing sustainability, such as "agri-food 4.0/agriculture 4.0," "Taiwan Productivity 4.0," "Making Indonesia 4.0," and "Made in China 2025," have been analyzed. This review identifies specific approaches for addressing sustainability concerns, emphasizing the importance of a systematic approach.

Following the classification of sustainability factors influenced by Industry 4.0 and supply chain management, it becomes evident that I4.0 impacts various aspects of each sustainability pillar. Through synthesis and analysis, sub-goals or subthemes of sustainability have been identified, including Production & Resourcing, Technology and Innovation, Macro-economics, Materials & Energy, Environmental Management, Emission, Waste and Pollution Prevention, and Community, Individuals. These subthemes provide a framework for understanding how sustainability is affected during the adoption of digital technologies. Figure 9 offers a thematic analysis synthesis organized by each dimension and subtheme of sustainability, highlighting the significant sustainability factors resulting from the integration of Industry 4.0 into supply chain management practices.

The analysis initially focuses on the environmental dimension of sustainability. The utilization of advanced industry and technology is expected to drive energy conservation and environmental preservation (MÜLLER *ET AL.,*2018). Recent literature on Supply Chain 4.0 has concentrated on enhancing productivity and process efficiency through the adoption of Industry 4.0 pillars such as big data, 3D printing, and IoT. These technologies have demonstrated flexibility and efficiency, facilitated mass customization and contributed to energy and environmental efficiency. Various studies have highlighted the importance of addressing environmental concerns within the context of sustainability. For instance, TSAI-LU (2018) proposed a mathematical model to address green issues, particularly emphasizing the role of IoT technology in improving energy efficiency. Figure 12 provides an overview of environmental sustainability factors affected by Industry 4.0 in food industries.

This study reinforces previous findings in the literature addressing the connection between renewable energy and resource efficiency and Industry 4.0 implementation. For example, research by BILDIRICI *ET AL.* (2023) indicates that Industry 4.0 adoption is a significant driver of renewable energy production in both high and middle-human development countries, as well as across the entire sample. Similarly, BELTRAMI *ET AL.* (2021) support this relationship.

Moving on to economic sustainability, the challenge lies in balancing cost control with sustainability objectives, which has necessitated an evolution in economic logic. Rather than solely focusing on cost reduction, efforts should also target efficiency improvements and cost reduction. This can be achieved by leveraging real-time data and machine learning algorithms to analyze consumer behavior and market trends (CHAUDHARY *ET AL.,* 2021). Automation of repetitive tasks not only increases the speed and accuracy of production but also reduces the reliance on manual labor, leading to potential cost savings and improved safety for workers. Standardization of processes has been identified as a means to enhance efficiency, often achieved through the implementation of protocols and standards in service delivery (CHAUDHARY *ET AL.,* 2021). Circular economy business models, such as waste recycling aligned with Industry 4.0 principles, have also been explored in recent research. Financial performance, especially in the context of green and eco-friendly practices within supply chain 4.0, has received considerable attention. Figure 12 outlines economic sustainability factors and their implications within the integration of I4.0 in food industries framework.

In terms of social sustainability, a literature review by STOCK *ET AL.,* (2018) emphasizes the creation of value through a focus on social and environmental aspects within the context of Industry 4.0. Various studies have examined the social implications of Industry 4.0, including its effects on work conditions and job opportunities. The integration of Industry 4.0 for measuring sustainability outcomes in virtual learning environments has been proposed as a means to address social issues. Challenges in this domain are often associated with the potential substitution of jobs by technological systems. Figure 12 highlights factors influencing social sustainability within the Supply Chain 4.0 landscape.

The research highlights the potential of Industry 4.0 to address environmental concerns, enhance economic efficiency, and promote social well-being within the food supply chain. By synthesizing and analyzing data, the study identifies key subthemes of sustainability affected by the adoption of digital technologies, providing a comprehensive framework for understanding the multifaceted impacts of Industry 4.0 on sustainability practices. This gap However, despite these significant findings, there remains a gap in research exploring the broader implications of Industry 4.0 implementation on sustainability across various dimensions. This underscores the importance of continued academic exploration in this domain to inform sustainable practices and policies within the food industry

In conclusion, the research contributes valuable insights into the complex interplay between Industry 4.0 implementation and sustainability outcomes in the food industry. By elucidating the mechanisms through which I4.0 capabilities influence sustainability performance and identifying areas for further exploration, the study lays the groundwork for future research and informs strategies for achieving sustainable development within the food sector.

4.6.2. Effects of Industry 5.0 on sustainability dimensions

This section offers an in-depth analysis of the research findings concerning the collaborative generation and exchange of knowledge within platforms focused on Industry 4.0 in the context of sustainability within the food industry. Addressing the third, fourth, and fifth research questions of the thesis, this section explores the impact of knowledge, as depicted in Figure 28. All types of knowledge emerging from collaborative platforms centered on Industry 4.0 capabilities and sustainability dimensions within food industries result from collaborative learning and knowledge sharing processes, as discussed in section 4.6.1 and referred to as knowledge collaboration. This study posits that the integration of Industry 4.0 technologies by food industries will lead to noticeable improvements in sustainability performance only when influenced by the firm's internal capabilities. Hence, all types of knowledge emerging from collaborative platforms centered on I4.0 capabilities and sustainability dimensions within food industries are outcomes of collaborative learning and knowledge sharing processes, as elucidated in section 4.6.1 and termed as knowledge collaboration.

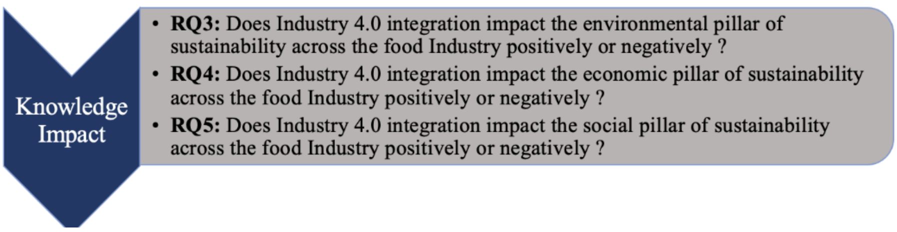

Figure 28: Concept analysis for knowledge impact

Source: Author's own contribution

This study proposed the idea that the integration of Industry 4.0 technologies by food industries will lead to noticeable improvements in sustainability performance only when influenced by the firm's internal capabilities. Drawing from the diverse categorization of sustainability and the comprehensive literature review outlined in Chapter 2, this study has defined sustainability through 8 variables: Material and Energy (ME), Environmental Management (EM), Emissions, waste and pollution (EWP), Production and Resourcing (PR), Technology and Innovation (TI), Macroeconomics (MA), Community (COM) and Individuals (IND).

The analysis of survey data presented in this chapter has suggested that all 29 constructs identified for the three pillars of sustainability can be grouped into two factors, therefore a PCA was performed on the factors of sustainability which resulted into 8 factors . Furthermore, it indicates that categories of sustainability need to coexist within a company in their combined forms to impact the success of I4.0 adoption in food industries. This study does not suggest that I4.0 capabilities, in all of their manifestations, directly impact every aspect of sustainability. Nonetheless, the survey findings of this study indicate that I4.0 capabilities directly impact the food industry' sustainable performance.

Several studies explore the impact of Industry 4.0 adoption on sustainability performance, such as resource efficiency, energy efficiency, the use of renewable energy, competitiveness, productivity and efficiency, workload, job opportunities and work safety (BAG *ET AL.,* 2021; KHAN *ET AL.,* 2021; GHOBAKHLOO, 2020; BAI *ET AL.,* 2020; BRACCINI-MARGHERITA, 2018).

The primary distinction lies in the incomplete alignment between empirical evidence and the theoretical framework of the sub-constructs. The survey analysis findings presented in Chapter 4 reveal that I4.0 capabilities have direct positive influences on materials and energy, technology and innovation and macroeconomic part of the food Industry. However, findings have revealed that there is no direct impact of I4.0 capabilities on the community and emission, waste and pollution reduction in food industries. The findings also revealed that Industry 4.0 capabilities might harm the individuals, production and resourcing and environmental factors of food Industries. Therefore, it is crucial for food industries to carefully consider the potential impacts and ensure the integration of sustainable practices into their Industry 4.0 strategies to maximize the positive outcomes and minimize any negative impacts on sustainability.

The integration of Industry 4.0 capabilities with sustainability practices can contribute to a more sustainable and environmentally friendly production process in the food industry (OLÁH *ET AL.,* 2020). Overall, Industry 4.0 holds promise for enhancing sustainability practices in the food industry, but careful consideration and integration of sustainable practices are necessary to mitigate any potential negative impacts (BONILLA *ET AL.,* 2018).

The analysis may have overlooked important variables that could influence the relationship between Industry 4.0 capabilities and sustainability outcomes. Future research should consider additional factors such as organizational culture, regulatory environment, and market dynamics. The findings of the study may not be generalizable beyond the specific context of the food industry or the geographical region in which the research was conducted. Future studies should replicate the research in diverse settings to enhance the generalizability of the results.

4.6.3. Drivers and Challenges of Implementing I4.0 on food industries' sustainability

This section addresses the sixth and seventh research questions of this thesis, focusing on investigating the outputs on food sustainability resulting from knowledge impact. In the analytical framework of this research thesis, this section pertains to the knowledge output as shown by Figure 29, and follows sequentially from the preceding sections.

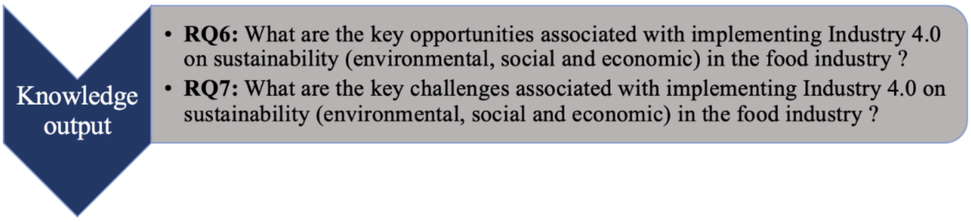

Figure 29: Concept analysis for knowledge output

Source: Author's own contribution

The advent of Industry 4.0 has ushered in a new era of transformative supply chains, driven by smart technologies and digitalization. Across industries worldwide, there is a gradual shift towards embracing these advanced tools to navigate through uncertain, complex, and rapidly evolving times (FATORACHIAN-KAZEMI, 2020). Industry 4.0 promises to enhance production processes, offering greater flexibility and efficiency, enabling both mass production and customized outputs within the supply chain network. By integrating green practices throughout the product lifecycle, it holds the potential to create energy-efficient and environmentally sustainable industries (AGRAWAL *ET AL.,* 2021).

However, the implementation phases of Industry 4.0, both before and after deployment, carry certain challenges that could impact the sustainability of food industries (OLÁH *ET AL.,* 2020). These challenges include concerns about job displacement and the necessity to adapt educational systems to align with the demands of this emerging technological revolution. Such issues may introduce vulnerabilities and heighten risks, potentially leading to unsustainable outcomes in the adoption of Industry 4.0. Addressing these challenges requires a focus on sustainability factors affected by the digitization of the food manufacturing.

The findings highlighted the critical role of sustainability drivers in integrating Industry 4.0 (I4.0) technologies as presented in Table 21. The high mean of drivers on sustainability have suggests that sustainability considerations are pivotal in the successful deployment and operation of I4.0 technologies. Such drivers may include environmental impact assessments, resource efficiency, renewable energy usage, and waste reduction strategies. By prioritizing sustainability, organizations can not only enhance their environmental performance but also improve operational efficiency and long-term viability in the era of digital transformation.

The drivers for sustainability were multifaceted and complex, with ecological and economic considerations forming their core. Essential elements like energy preservation, resource management, and waste reduction were crucial factors in sustainability integration (GUERRERO *ET AL.*, 2018). Two primary drivers, energy and resource conservation, primarily address processes and decisions during the input phase of production systems, while waste reduction and pollution control focus on issues at the output phase (MÜLLER *ET AL.,* 2018). Additionally, economic incentives played a significant role, as companies were motivated by the potential for revenue growth and cost minimization The analysis of sustainability drivers illustrated in Table 21 indicates a blend of economic and environmental motivations. This suggests that companies embracing sustainability aim to enhance competitiveness while simultaneously improving ecological performance.

The economic drivers identified empirically in this study were: the desire to cut costs, the drive to boost profits, marketing pressures, the aspiration to enter new markets, and the aim to increase market share, respectively. Meanwhile, the environmental drivers discovered were: the desire to conserve energy, the aspiration to preserve resources, the drive to reduce pollution, the aim to minimize waste, environmental advocacy pressures, and the reduction of carbon footprint. This implies that while achieving their economic goals, food industries simultaneously enhance their environmental performance. It demonstrates that by successfully integrating Triple Bottom Line (TBL) principles, economic benefits can be achieved through social responsibility and environmental preservation for future generations (SVENSSON *ET AL.,* 2018).

Among the drivers of sustainability in Jordanian food industries, legal and regulatory pressures exerted the most perceived influence on business organizations. This indicates that food industries in Jordan may be compelled to adopt sustainability practices due to legal and regulatory mandates but are also driven to voluntarily adopt sustainability in order to improve their performance on both the environmental and economic fronts. By willingly embracing Industry 4.0, food industries can efficiently and effectively implement sustainability measures compared to being compelled to do so.

Despite the formulation of diverse sustainability strategies, the risks linked with industrial activities persist significantly due to several challenges encountered in the implementation of Industry 4.0. The main challenges are outlined in Table 22. The primary challenges that the food industry might encounter when implementing Industry 4.0 technologies include the high cost of adoption, lack of funding or financial support, and difficulties in integrating a new concept into existing operations, this is followed by concerns regarding declining profit levels and inadequate infrastructure. The challenges include the need for significant investment in technologies and infrastructure, the requirement for upskilling and training of existing workforce, and the potential disruption to traditional supply chain systems (MÜLLER *ET AL.,* 2018).

Industry 4.0 in the food industry sustainability also offers opportunities for improved efficiency, traceability, and quality control (BONILLA *ET AL.,* 2018). By implementing Industry 4. 0 technologies, food industries can better manage and optimize their production processes, reducing waste and ensuring the safety and quality of their products (MÜLLER *ET AL.,* 2018). Furthermore, Industry 4.0 can enable greater transparency throughout the supply chain, allowing consumers to make more informed choices about the sustainability and ethical aspects of the food they consume. Overall, implementing Industry 4.0 in the food industry sustainability is a complex endeavor that comes with its own set of challenges and opportunities.

Understanding and addressing these challenges while leveraging the opportunities can lead to a more sustainable and efficient food industry (BONILLA *ET AL.,* 2018). To address these challenges and harness the opportunities of implementing Industry 4.0 in the food industry sustainability, collaboration among stakeholders is crucial. Collaboration among stakeholders, including industry leaders, policymakers, and technology providers, is crucial to overcome the challenges and fully harness the opportunities of implementing Industry 4.0 in the food industry sustainability (MÜLLER *ET AL.,* 2018). These stakeholders may collaborate to create creative solutions that tackle the difficulties of integrating Industry 4.0 in the sustainability of the food business by sharing their knowledge, resources, and skills. Collaborative efforts can help in developing strategies to overcome hurdles such as investment requirements, upskilling of the workforce, and potential disruptions to supply chains. Additionally, collaboration can facilitate the exchange of best practices and lessons learned, enabling stakeholders to make informed decisions and avoid common pitfalls. By fostering collaboration among stakeholders, the food industry can collectively navigate the complexities of implementing Industry 4.0 in a sustainable manner, leading to improved productivity, reduced environmental impact, and enhanced social responsibility. Overall, collaboration among stakeholders is crucial for successfully implementing Industry 4.0 in the food industry sustainability and realizing its full potential for sustainable development.

In analyzing the impact of Industry 4.0 on sustainability in the food industry, it is insightful to compare the experiences of different regions. In Europe, the implementation of Industry 4.0 technologies is closely aligned with stringent environmental regulations and sustainability goals. European countries, such as Germany and the Netherlands, have embraced smart technologies—like precision agriculture, IoT-driven supply chain optimization, and advanced waste management systems—to achieve significant sustainability milestones (BAI *ET AL.*, 2020).

It is insightful to compare the experiences of Germany, a leading adopter of advanced industrial technologies, with those of regions such as Jordan. Germany, with its robust infrastructure and high technological adoption, has leveraged Industry 4.0 to significantly enhance resource efficiency and reduce waste in its food sector. Smart manufacturing processes, IoT-enabled supply chain management, and AI-driven predictive maintenance have collectively contributed to minimizing environmental footprints and optimizing energy use (BAG *ET AL.,* 2021).

In North America, the integration of Industry 4.0 technologies, such as automation, big data analytics, and advanced robotics, has led to substantial improvements in the sustainability of food production. This region benefits from high levels of investment in technology and infrastructure, resulting in optimized supply chains, reduced food waste, and more efficient energy use (BAG *ET AL.,* 2021).

In contrast, regions like middle east, while increasingly incorporating Industry 4.0 technologies, face challenges such as limited infrastructure and varying levels of technological readiness, which can affect the pace and extent of sustainability gains. Here, the integration of advanced technologies is often met with incremental improvements in resource management and waste reduction, reflecting a more gradual transition. Jordan, on the other hand, experiences the ones of the most significant hurdles, including economic constraints and infrastructural deficits, which limit the deployment of Industry 4.0 solutions. Consequently, the potential sustainability benefits of Industry 4.0 are less pronounced, with improvements in sustainability often constrained to localized and smaller-scale innovations rather than widespread systemic changes. Thus, while Industry 4.0 holds transformative potential for enhancing sustainability across the food industry globally, the degree of impact is heavily influenced by regional factors such as technological infrastructure, economic capacity, and the pace of adoption.

The discussion delves into the following key aspects:

1. Complexity of Sustainability Integration

- Deep Dive into Sustainability Drivers: Further exploration of the multifaceted and complex nature of sustainability drivers can unveil the interplay between economic incentives and environmental motivations. This could involve a qualitative analysis to uncover underlying attitudes, values, and organizational cultures driving sustainability initiatives within food industries.
- Triple Bottom Line (TBL) Integration: While the study touches upon the integration of TBL principles, a deeper exploration of how economic benefits align with social responsibility and environmental preservation can provide insights into the mechanisms through which companies balance competing interests and achieve sustainable outcomes.

2. Challenges and Opportunities of Industry 4.0 Implementation

- Risk Management Strategies: In addition to outlining the challenges associated with Industry 4.0 implementation, examining risk management strategies adopted by food industries can shed light on how companies navigate uncertainty and mitigate potential negative impacts. This could involve case studies or comparative analyses of different risk management approaches.
- Opportunities for Innovation: Expanding on the opportunities presented by Industry 4.0, such as improved efficiency, traceability, and quality control, can highlight the transformative potential of these technologies. Identifying specific examples of innovation enabled by Industry 4.0 in the food industry and their implications for sustainability could provide actionable insights for industry stakeholders.

3. Collaboration for Sustainable Development

- Stakeholder Engagement Strategies: Investigating effective strategies for stakeholder engagement and collaboration in the context of Industry 4.0 implementation can offer practical guidance for fostering collaboration among industry leaders, policymakers, and technology providers. This could involve participatory action research or stakeholder mapping exercises to identify key actors and their roles in sustainable development initiatives.

- Knowledge Sharing and Capacity Building: Exploring mechanisms for knowledge sharing and capacity building among stakeholders can facilitate collective learning and problem-solving. This could include the development of collaborative platforms or communities of practice focused on sustainability and Industry 4.0 integration, where stakeholders can exchange best practices, lessons learned, and innovative ideas.

4. Potential Risks

- Data Privacy and Security: The extensive data collection required for Industry 4.0 (I4.0) technologies raises concerns about how personal and sensitive information is handled. Increased connectivity and data sharing can make systems more vulnerable to cyberattacks, potentially compromising sensitive information and disrupting operations. Additionally, there is a risk of data being used unethically, such as in price manipulation, unfair targeting of vulnerable consumer groups, or unauthorized surveillance. These issues highlight the importance of robust data protection measures and ethical guidelines to ensure the responsible use of data in the food industry.
- Supply Chain Vulnerabilities: The integration of Industry 4.0 (I4.0) technologies into supply chains adds a layer of complexity that can introduce new vulnerabilities and points of failure. This increased complexity makes the supply chain more susceptible to disruptions such as technical failures or cyberattacks, which can have widespread impacts, potentially leading to food shortages or quality issues. Additionally, an over-reliance on technology can heighten the food industry's exposure to systemic risks, as failures in critical systems could have cascading effects throughout the supply chain.
- Health and Safety and Concerns: Health and safety concerns are critical when implementing Industry 4.0 technologies in the food industry. Ensuring that automated systems uphold high standards of food safety and quality can be challenging, particularly during the transition period. The introduction of new food production technologies may pose health risks if they are not thoroughly tested and regulated. Additionally, it is crucial to maintain rigorous safety protocols to prevent accidents and contamination in highly automated environments, ensuring that the integrity and safety of food products are consistently upheld.

5. Ethical Considerations

- Equity and inclusion: Equity and inclusion are essential considerations in the implementation of Industry 4.0 technologies. It is crucial to ensure that all stakeholders, including small and medium-sized enterprises (SMEs), have access to I4.0 technologies and the benefits they offer. This approach helps to prevent the creation of new divides between those who can leverage technological advancements and those who cannot. Additionally, promoting diversity and inclusion in the development and implementation of new technologies is vital for fostering innovation and ensuring that technological progress benefits a broad range of individuals and organizations. By addressing these aspects, the industry can support a more equitable distribution of technological advancements and opportunities.

- Ethical Use of AI and Automation: Ethical use of AI and automation is paramount to ensure that these technologies operate fairly and transparently. It is essential to ensure that AI and automated systems are free from biases that could lead to discrimination or unfair treatment of certain groups, promoting fairness across all applications. Transparency in the decision-making processes of AI systems is crucial, as it allows stakeholders to understand how decisions are made and ensures that these processes are open to scrutiny. Additionally, establishing clear accountability for the actions and decisions made by automated systems is necessary to address any potential issues and maintain trust in the technology. By focusing on these aspects, the industry can foster ethical practices and mitigate the risks associated with AI and automation.
- Consumer rights and trust: Consumer rights and trust are crucial in the context of Industry 4.0 technologies. Providing clear and accurate information about how products are made, including the role of I4.0 technologies, is essential for product transparency. This transparency helps consumers make informed decisions and understand the impact of technological advancements on their products. Additionally, respecting consumer privacy is vital; personal data should be handled with care and not misused or sold without explicit consent. Building trust with consumers involves engaging with them transparently and ethically, ensuring that the implementation of new technologies aligns with their expectations and values. By prioritizing these aspects, companies can foster a positive relationship with consumers and uphold their rights in the evolving technological landscape.
- Ethical Governance: Ethical governance is essential in the implementation of new technologies within the industry 4.0 framework. It is crucial to ensure that these technologies comply with existing laws and regulations, maintaining adherence to legal standards and industry guidelines. Effective stakeholder engagement is also key; involving a diverse range of stakeholders—including employees, consumers, regulators, and communities—in decision-making processes ensures that various perspectives are considered and that decisions are made transparently. Additionally, demonstrating corporate responsibility involves acknowledging and addressing the

broader social and environmental impacts of technological changes. By integrating these practices, companies can uphold high standards of ethical governance and contribute positively to the wider society.

5. CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the research's contributions, limitations, and potential recommendations for further research. Section 5.1 examines how this research impacts the evolution of Industry 4.0 manufacturing technologies adoption effects on sustainability, as well as the drivers and challenges for this implementation. In Section 5.2, the research limitations are pinpointed, alongside recommendations for refining the research methodology. Moreover, future research prospects are highlighted within this section. Section 5.3 presents the concluding remarks for this thesis.

5.1 Research Contribution

The objective of this research was to examine the integration of I4.0 technologies and its potential impact on the sustainability performance of food industries. Specifically, the study aimed to explore how Jordanian food manufacturers can enhance their sustainability performance through the adoption of I4.0 technologies, considering the industry's reliance on I4.0 capabilities. Industry 4.0 capabilities are deemed essential for firms operating within the food industry value chain, as the industry places great importance on certifications of capabilities and sustainability value by industry regulators.

This research has developed theoretical framework and delved into two critical domains within the field of food industries: the sustainability performance and Industry 4.0 capabilities. These concepts, thoroughly operationalized through this research, serving as foundational theories for numerous empirical studies on the adoption of Industry 4.0 and its effects on sustainability within food industries. On the other hand, the drivers and challenges of implementing Industry 4.0 on food industries' sustainability was also examined.

The integration of Industry 4.0 technologies within the food industry represents a significant advancement with far-reaching implications for sustainability (JAMWAL *ET AL.,* 2021). Industry 4.0, characterized by the convergence of digital technologies and physical systems, offers unprecedented opportunities to enhance efficiency, productivity, and innovation across the food supply chain (FATORACHIAN-KAZEMI, 2020). However, alongside these promising prospects come a host of challenges and considerations related to sustainability. As the food industry navigates the adoption of Industry 4.0, it must carefully weigh the potential drivers and implications for sustainability, balancing technological advancement with environmental, social, and economic considerations (COCCIA, 2019). In this dynamic landscape, understanding the interplay between Industry 4.0 implementation and sustainability becomes imperative for shaping the future of the food industry.

This study revealed extensive research within sustainability literature regarding the adoption of Industry 4.0 technologies in smart factories, empirical findings regarding various technology types are utilized to demonstrate the evolution of manufacturing technologies, given the trajectory of technological progress within Industry 4.0, which is poised to fundamentally transform manufacturing activities.

Despite the fact that Industry 4.0 and sustainability are hot topics in science, a preliminary literature analysis found that there are very few accessible sustainability evaluations for Industry 4.0. This gap in the literature emphasized the need for further research and analysis on the sustainability implications of Industry 4.0 in food industries. Furthermore, the research explored the different methodologies and evaluation approaches used to assess sustainability in the context of Industry 4. 0. The overall assessment of sustainability potential in Industry 4.0 is often based on three stages and a qualitative evaluation approach. The review of literature on Industry 4.0 and sustainability in food industries has also examined the concept of interoperability, a critical issue in implementing Industry 4.0 practices. Overall, this thesis aimed to provide a comprehensive understanding of the current state of research on the relationship between Industry 4.0 and sustainability in food industries, highlighting key findings, gaps, challenges, and opportunities for further research.

The progress in sustainability literature has facilitated the categorization of sustainability factors based on their attributes of environmental, economic and social features. Through an investigation into the utilization and efficacy of industry 4.0 implementation, this study confirmed that Industry 4.0 will enhance the overall sustainability performance, this study revises the classification of sustainability factors within the scope of this research. The findings from PCA indicate that the revised categorization of sustainability pillars is rooted in their functional attributes. Consequently, this research reorganizes the three pillars of sustainability into the following categories: Material and Energy (ME), Environmental Management (EM), Emissions, waste and pollution (EWP), Production and Resourcing (PR), Technology and Innovation (TI), Macroeconomics (MA), Community (COM) and Individuals (IND).

In doing so, this research has improved the understanding of the accompanying impacts and effect, thus help stakeholders and governments to adopt policies that are best suited to the ideal reflected in the adoption of Industry 4.0 technologies. The research conducted a comprehensive analysis of the existing activities on the implementation of Industry 4.0 in food industries and its impact on sustainability performance, which will contribute to the current knowledge by mapping and summarizing existing research efforts, identifying research agendas, examining gaps, and highlighting opportunities for further research in the field.

Coincidentally, as sustainability pillars are recognized as pivotal elements of Industry 4.0 implementation, scientific journals often prioritize topics like evaluating the newest Industry 4.0 technologies and assessing their integration into current manufacturing practices (KAMBLE *ET AL.,* 2018). However, many of these discussions may not directly tackle the drivers and challenges associated with Industry 4.0 adoption, in order enhancing sustainability performance (BAG *ET AL.,* 2021). Consequently, there seemed to be a lack of connection to the adoption of advanced manufacturing technologies in Industry 4.0 research. This study bridges this gap by referencing sustainability literature, demonstrating how Industry 4.0 capabilities are enriching sustainability performance discourse by broadening the scope of Industry 4.0 adoption to serve food industries sustainability.

Derived from the research propositions and corresponding hypotheses formulated for this study, this thesis delves into three theoretical implications. Firstly, it examines the link between Industry 4.0 capabilities (CAP) and sustainability performance of food industries (PER) as representatives of the progression in food manufacturing industries. It also explores how the drivers (DR) and challenges (CH) serve as necessitates in the adoption of these technologies to enhance firm sustainability performance. It has investigated the extent of influence exerted by I4.0 capabilities on the three pillars of sustainability and each factor of this pillar, and whether this influence is substantial enough to significantly impact food industries' sustainability performance.

In this study, the conceptualization of Industry 4.0 capabilities (CAP) adoption incorporates all the sustainability factors and considerations previously discussed regarding the industry 4.0 capabilities adoption and its effects on sustainability factors. Industry 4.0 capabilities designated as an independent variable within the theoretical model, signifies the overall uptake of manufacturing technologies within a firm. This research thus broadens the spectrum of Industry 4.0 adoption previously categorized under organizational and industrial capabilities to encompass the domain of sustainability performance.

The research aimed to explore the relationship between Industry 4.0 and sustainability in the context of food industries. It investigated the current state of Industry 4.0 integration, evaluated the existing methodologies used to assess sustainability in Industry 4.0, and identifying key gaps and future research directions. In doing so, this research provided valuable insights into how food industries can effectively implement Industry 4.0 strategies to promote corporate sustainability performance and enhance their competitive edge (KAMBLE *ET AL.,* 2018). In addition, this thesis addressed the drivers and challenges for future research on Industry 4.0 and contribute to the development of a sustainable Industry 4.0 framework for food industries

(MÜLLER *ET AL.,* 2018). This research aimed to evaluate the current state of research and provide a comprehensive understanding of the relationship between Industry 4.0 and sustainability in food industries

Theoretical implications of this research regarding the role of Industry 4.0 capabilities in literature can be delineated in terms of organizational capabilities and industrial capabilities (HOFMANN- RÜSCH, 2017). Organizational capabilities encompass various facets such as Data-Driven Decision Making (OC1), Agility and Flexibility (OC2), Operational Efficiency and Productivity (OC3), Innovation and Product Development (OC4), Visibility and Resilience (OC5), Centricity and Personalization (OC6), Connectivity and Collaboration (OC7). This research adopts the term "organizational capabilities" to denote a firm's capacity to carry out its routine manufacturing activities. Industrial capability I4.0 technologies undertaken by the food industry including: IoT/Food Safety Management Systems (IC1), Blockchain Technology (IC2), Big Data Analytics (IC3), Automation and Food Traceability Systems (IC4), AI & ML (IC5). Empirical applications of Industry 4.0 capabilities include its relationship with sustainability` performance, as well as moderating the relationship between sustainability factors and overall sustainability performance of food industries (JAMWAL *ET AL.,* 2021).

Additionally, this study reveals that drivers and challenges of Industry 4.0 implementation on in food industries hinge on a firm's existing capabilities to impact sustainability performance (BAG *ET AL.,* 2021). Drivers and challenges of implementation can enhance or harm the effectiveness of Industry 4.0 adoption, leading to impacts on sustainability performance of food industries (KAMBLE. *ET AL.,* 2018). Empirical research indicates that drivers and challenges can directly influence performance when combined with Industry 4.0 Industrial capabilities. However, findings of this research suggest that indicates that drivers and challenges may not directly impact Industry 4.0 organizational capabilities Instead, these studies suggest that operational capabilities might bolster a firm's supply chain integration, subsequently enhancing performance.

Studies on Industry 4.0 adoption in manufacturing indicate that capabilities tend to evolve gradually as technologies are integrated into existing processes or through the enhancement and expansion of existing systems and functions (TORTORELLA *ET AL.,* 2020). This observation holds particular relevance in food industries, where technology adoption is commonly viewed as a norm rather than an exception. These procedures impose requirements concerning opportunities regarding this integration, including desire to reduce cost, enhance revenues/profits, achieve competitive advantages, conserve energy, conserve resources/resources pressures, reduce pollution, reduce waste, legal/regulatory pressures, marketing pressures, environmental advocacy pressures to enter new markets, increase market share and carbon foot print reduction (MÜLLER *ET AL.,* 2018).

Despite the development of various sustainability strategies, the risks associated with industries activities remain significant due to numerous challenges faced in implementing Industry 4.0., including higher cost of adaption (take up)/higher running costs, problems of other stakeholders pressures, Lack of relevant information, Inappropriate infrastructures, decline of profit level, lack of expertise/unskilled employees on Industry 4.0 practices, difficulties of implementing Industry 4.0 (new concept) in the firm, lack of funding/Financial support, conflicts with organization business objectives, conflict with stakeholder interest (MÜLLER *ET AL.,* 2018). Consequently, this research underscores that drivers and challenges cultivated through Industry 4.0 adoption can significantly impact a firm's sustainability performance within the food industry. By considering I4.0 capabilities alongside opportunities and challenges, managers can adopt a more informed approach to decision-making.

The adoption of Industry 4.0 capabilities, how it shapes sustainability performance, and what drivers and challenges might arise through this adoption in food industries, as evidenced by this study, is highly encouraging. With high levels of capabilities, expanding the opportunities of adoption of Industry 4.0 technologies can positively impact sustainability performance. Conversely, firms should consider the challenges of Industry 4.0, adoption as they are likely to lead to significant performance improvements of sustainability.

5.2 Limitations and Future Research

When assessing limitations and outlining future research directions, our study underscores several research opportunities that have not received sufficient attention thus far.

Primarily, this study serves as an explanatory aimed at understanding the effects of Industry 4.0 adoption within the realm of food industries' sustainability. While the measurement scales utilized in this study are derived from an extensive literature review, there remains a necessity for future research to refine and develop consistent metrics for assessing corporate sustainability comprehensively. Therefore, forthcoming studies should take into account the insights garnered from this research and engage in the revalidation of measurement scales to bolster the generalizability of measurement instruments.

Secondly, while the survey respondents in this study were employees in food manufacturing, who presumably possess sufficient knowledge and are capable of adopting a holistic organizational perspective, biases can still arise due to the reliance on a single source of information. To mitigate this issue, future research endeavors could enhance the study by involving various positions within different sectors of food industries including the governmental sector. By incorporating multiple respondents from each organization, future studies aim to bolster reliability and diminish common method bias. Thus, enhancing the robustness of the findings.

Thirdly, the cross-sectional design of this study poses a limitation on the interpretation of empirical results. This limitation opens up opportunities for future research to delve into specific industrial sectors. Additionally, the challenge of demonstrating the causal relationship between sustainability practices and realized performance benefits presents a fertile ground for future investigation.

Future research could explore the performance implications of varying levels of Industry 4.0 practices by integrating several pertinent control variables, such as industry type, size, and age. Additionally, institutional isomorphism, highlighted by self-regulatory and voluntary initiatives like environmental management systems (EMS) and quality management approaches, could serve as a valuable theoretical framework for examining the orientation of sustainability practices.

Fifth, while limitations in the sample sizes of data subsets may constrain the generalizability of the findings, we contend that our research offers valuable insights into considering the effects of country of origin. Nevertheless, future research has the opportunity to expand upon or replicate the study to improve its generalizability. This research also indicates the need for further investigation into broader study domains, including additional regions like: Europe, Africa, and other economic zones.

The significance of this study lies in its potential to inform policymakers about the importance of prioritizing Industrial development from an economic growth standpoint. By addressing issues of Industry 4.0 implementation and sustainability for large food industries, this research aids in mitigating micro-level impacts on specific sustainability factors. Conducting more comprehensive and unbiased research at the microeconomic level helps to understand the sector-level consequences on the economy more effectively.

Given the relatively favorable transformation into smart factories, there is a call for increased investment in industrial manufacturing. This investment would ultimately boost food industries performance. Furthermore, I4.0 emerges as a superior alternative to traditional manufacturing, offering environmental benefits such as reduced pollution. This not only lowers environmental protection costs but also fosters economic growth opportunities.

Policy recommendations should prioritize making I4.0 technologies more accessible by lowering their costs. Supporting sector policies is crucial for global commerce and capital development, potentially stimulating economic growth by expanding the industrial and energy sectors.

Maintaining tax policies supportive of the food industry is essential. National governments can encourage I4.0 adoption by offering tax breaks to companies involved in food processing. Ultimately, this research underscores the importance of policymakers' efforts in fostering sustainable economic development through supportive policies.

5.3 Conclusion

This research initially hypothesized that a food industries' adoption of Industry 4.0 technologies would significantly impact sustainability performance, and can be influenced by drivers and challenges to this adoption. However, statistical tests in Chapter 4 reveal that the influence of drivers and challenges is positive only for the Industrial capabilities, on the other hand it may have a negative impact on the organizational capabilities.

The most striking discovery of this research is that the adoption of I4.0 technologies can affect each pillar of sustainability at different levels.

Drawing conclusions from both Industry 4.0 effects on sustainability and industrial perspectives, it becomes evident that food industries may adopt varied approaches to manage the interplay between opportunities and challenges. Essentially, the findings of this thesis enhance our understanding of how organizations can implement Industry 4.0 practices, thereby positively impacting sustainability performance.

6. MAIN CONCLUSIONS AND FINDINGS

The research aims to investigate the integration of Industry 4.0 (I4.0) technologies and their potential impact on sustainability performance within Jordanian food industries. It explores how food manufacturers in Jordan can enhance sustainability through I4.0 adoption, considering the industry's reliance on these capabilities. Taking into account the objectives, research questions and hypotheses of this study, the upcoming section outlines the novel discoveries and contributions:

1. The first novel finding: The study revealed that Industry 4.0 represents a positive impact on sustainability, offering opportunities to enhance efficiency, productivity, and innovation across the food supply chain. Understanding the interplay between I4.0 and sustainability is crucial for shaping the future of the food industry. Theoretical implications highlight organizational and industrial capabilities in I4.0 adoption, including data-driven decision making, agility, and innovation. Empirical applications of the study demonstrate a positive relationship between the capabilities provided by I4.0 and overall sustainability performance. This means that as food industry players adopt and utilize I4.0 technologies, they are likely to see improvements in their sustainability metrics, including environmental, economic, and social factors. The study, therefore, underscores the potential benefits of I4.0 for promoting sustainable practices in the food supply chain and highlights the importance of adopting these advanced technologies to achieve sustainability goals.

2. The second novel finding: The study explores methodologies for sustainability assessment within the context of Industry 4.0 (I4.0), including interoperability. It aims to provide a comprehensive understanding of the relationship between I4.0 and sustainability in food industries. Methodologies in previous studies were looked through a literature review. This process illuminates existing knowledge, disparities among various papers, and current gaps in the research domain. employing this method facilitates the interpretation and evaluation of the strength of both past and present research, thereby guiding future research endeavors effectively. Sustainability factors are categorized based on environmental, economic, and social attributes, providing insights into I4.0's impact on sustainability performance. The study reorganizes sustainability pillars into functional factored categories, this reorganization aims to provide clearer insights into the specific impacts of I4.0 and to facilitate the adoption and development of policies that promote sustainable practices in the industry.

3. The third novel finding: In terms of the environmental aspect, the study investigated that integration of Industry 4.0 capabilities demonstrates a notable positive moderating impact on

Materials and energy, indicating a significant interaction effect. Conversely, with Environmental management, Industry 4.0 Capabilities exhibit a negative influence. However, for emissions waste and pollution the study indicated an insignificant interaction effect with Industry 4.0 capabilities.

4. The fourth novel finding: In the realm of the economic pillar, study explored that certain factors stand out as the most influenced, which includes negative impact on Production and Resourcing, and a positive impact on Technology and Innovation in relation to their impact on Performance (PER). Implying that an increase in Industry 4.0 adoption positively affects technology and innovation but negatively impacts production and resourcing. Therefore, these factors are deemed significant in terms of their influence on industry performance. Before the adoption of Industry 4.0 capabilities, the macroeconomics factor within the economic pillar did not exhibit a significant relationship with industry performance. However, Industry 4.0 capabilities have a notable positive moderating effect on the macroeconomic aspect of industries.

5. The fifth novel finding: The research found that, when looking at the social aspect of sustainability, the adoption of Industry 4.0 (I4.0) technologies has a negative impact at the individual level. This means that the implementation of I4.0 capabilities, such as automation and data analytics, may lead to adverse effects for individual workers. For instance, workers might face job displacement, increased stress due to new technology demands, or a reduction in job satisfaction. This negative impact suggests that I4.0 technologies can act as a negative moderating factor at the individual level, potentially exacerbating challenges faced by workers rather than alleviating them. However, the study also found that there is no significant moderating effect of I4.0 capabilities on the community as a whole. This indicates that, while individual workers might experience negative consequences, these effects do not translate into a broader negative impact on the larger community.

6. The sixth novel finding: Based on the research work, drivers and challenges associated with I4.0 implementation have a significant impact on sustainability performance within organizations, with operational capabilities playing a significant role. Technology adoption evolves gradually, facing opportunities and challenges, including cost, stakeholder pressures, and expertise.

The adoption of I4.0 technologies is not instantaneous but rather evolves gradually over time. This evolution is influenced by various factors such as cost considerations, pressures from stakeholders (including customers, regulators, and investors), and the availability of expertise within the organization. Initially, organizations may face challenges related to the high initial investment required for implementing I4.0 technologies, as well as uncertainties about their long-term benefits. However, as technology evolves and becomes more accessible, opportunities for cost savings, improved productivity, and competitive advantage may outweigh these challenges, driving further adoption.

Conclusion indicates that I4.0 adoption positively impacts sustainability performance, with varying effects on different pillars of sustainability. Organizations must manage opportunities and challenges to implement I4.0 practices effectively and enhance sustainability performance in the food industry.

SUMMARY

This research has developed and validated a framework that provides an overview of the impact of integrating Industry 4.0 within food industries, with a particular focus on investigating sustainability from economic, social, and environmental perspectives. Furthermore, it illustrated how the integration of Industry 4.0 will enhance the efficiency and effectiveness of the food industry. Additionally, this study examined the challenges and opportunities associated with the implementation, assessing the relevance of Industry 4.0-related opportunities and challenges as catalysts for Industry 4.0 adoption within the context of sustainability.

This dissertation contained six comprehensive chapters meticulously crafted to delve into both theoretical underpinnings and analytical aspects of the research, culminating in the presentation of key findings and conclusive insights. The first chapter serves as a gateway, ushering readers into the research realm by meticulously introducing the research topic. Furthermore, it offers a insightful background, shedding light on the intricacies of the subject matter. Within this introductory narrative, paramount emphasis is placed on highlighting the research problem and defining the gaps that the study seeks to address. These gaps are subsequently translated into meticulously delineated aims, objectives, and research questions. These facets collectively form the foundational framework that not only underpins subsequent phases of the research but also serves as a guiding beacon, facilitating a holistic evaluation of research outcomes and fostering a profound understanding of the research landscape.

Chapter two was dedicated to conducting a thorough technical literature review. Its objective was to offer a comprehensive understanding of the research topic and previous contributions in the literature. This involved discussing the emergence of Industry 4.0 science, its research trajectory, and its distinctive impacts. Furthermore, it, explored literature on sustainability pillars, outlined sustainability into eight constructs. Additionally, the chapter introduced various I4.0 adoption models and previous research on I4.0 technologies, which directly informed the present study. Later through the chapter, it has developed the research conceptual framework, visually representing the research constructs and hypothesized relationships between the variables. It also defined the research variables, reviewed their appearances in prior literature, and examined their predictive roles in explaining the phenomenon of I4.0 adoption and its relationship with sustainability. Finally, the research hypotheses were comprehensively presented and elucidated based on the introduced framework.

Chapter three provides an in-depth exploration of the research materials and methodologies utilized throughout the study. It initiates with a comprehensive introduction to the research

methodology, explaining the philosophical foundations and approach adopted. Subsequently, the chapter meticulously outlines the research design, encompassing the research strategy, time horizon, data collection method, research instruments, sample design, and measurement tools employed. The research was specifically conducted within the food industries of Jordan, employing an online questionnaire as the primary data collection method. A robust dataset comprising 195 valid responses was meticulously gathered and subjected to rigorous analysis, forming the basis for the subsequent analysis, discussions and conclusions drawn in the study.

Chapter four provides a detailed exploration of data analysis and research findings, employing a variety of quantitative techniques facilitated by SPSS software. The process encompasses intricate steps of data manipulation, transformation, and evaluation aimed at deriving meaningful insights that directly address the research questions. Initially, the chapter introduces the demographic profile of the sample, furnishing valuable context regarding its composition and characteristics. After that, in-depth evaluations are carried out to evaluate the research instrument's validity and reliability. This entails using methods like Principal Component Analysis (PCA) and Exploratory Factor Analysis (EFA) to determine the underlying structure of study variables and computing alpha values to assess reliability.

Moreover, the suitability of the data for regression analysis is scrutinized through a battery of tests for normality, linearity, and multicollinearity. Subsequently, the research hypotheses are put to the test using Hierarchical Regression Analysis, with the resultant findings meticulously presented and discussed. Through a comprehensive synthesis of these findings with existing literature, the chapter endeavors to foster a deeper understanding and facilitate the drawing of insightful conclusions.

Furthermore, the latter part of the chapter is dedicated to the interpretation of research findings, aiming to provide nuanced insights that directly address the research objectives and offer substantive answers to the overarching research question. This section serves as a critical juncture where the implications of the study are carefully dissected and contextualized, thereby contributing to the broader scholarly discourse within the field.

The fifth chapter provided a comprehensive overview of the principal conclusions and novel insights derived from the dissertation. Furthermore, it extended valuable recommendations tailored for researchers, organizations, and policymakers, drawing from the nuanced interpretation of these findings. Additionally, it presented insightful suggestions for prospective avenues of research to advance understanding in the field.

The final chapter of the dissertation provides an in-depth analysis of the novel findings. It emphasizes the unique contributions of the study, showcasing how these discoveries can influence and advance the current understanding of Industry 4.0 integration within the food industry.

The findings of this study provide strong encouragement regarding the integration of Industry 4.0 capabilities within the food industry, shedding light on its influence on sustainability performance and the accompanying drivers and challenges. Elevated levels of capabilities in this domain present promising avenues for fostering the adoption of Industry 4.0 technologies, thereby bolstering sustainability performance. However, it is imperative for firms to conscientiously weigh the challenges associated with Industry 4.0 adoption, recognizing their potential to precipitate substantial enhancements in sustainability performance.

LIST OF TABLES

LIST OF FIGURES

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APPENDIX – A: PREVIEW EMAIL FOR THE SURVEY RESEARCH LAUNCH

Dear Sir/Madam,

I hope this email finds you well. You are invited to participate in a short survey focused on the integration of Industry 4.0 within the food industry sector.

I'm delighted to introduce our research project tailored specifically for PhD studies, aimed at gathering valuable insights on the challenges and opportunities of Industry 4.0 on food industry's sustainability. At University of Debrecen, we hold a strong commitment to advancing the frontier of knowledge and promoting deeper understanding within our academic community. To guarantee our research efforts are both relevant and impactful, we are initiating this survey to collect diverse perspectives and feedback from individuals like you, who are immersed in the world of food industry.

Background: Industry 4.0 is here. The food industry is both a contributor and user of advanced I4.0 manufacturing technologies. In collaboration with University of Debrecen, we are keen to collect feedback regarding the extent of utilization and effectiveness of Industry 4.0 adoption within the food industries of Jordan.

Objectives of survey: Our primary aim is to identify the factors driving and challenging the adoption of Industry 4.0 within Jordan's food industries, and to evaluate its influence on sustainability performance.

Your participation is vital to the success of this research. By sharing your perspectives and experiences through this survey, you'll play a crucial role in helping us gain a deeper understanding of Industry 4.0 implementation and its implications for sustainability.

The survey will take approximately 10 minutes to complete, and I assure you that all responses will be kept strictly confidential. We genuinely appreciate your time and contribution to this important project. Survey Link: *The Challenges and Opportunities of Industry 4.0 on food industry's sustainability.*

Should you have any questions or require further information, please do not hesitate to contact me directly, (Ms.) Luma Qudah (Institute of Economics, Faculty of Economics and Business, University of Debrecen, 4032 Debrecen, Hungary) at email: luma.qudah@econ.unideb.hu

Thank you in advance for your participation and support.

APPENDIX – B : SAMPLE QUESTIONNAIRE SURVEY

The purpose of this survey is to gather your feedback on the extent of use and the effectiveness of Industry 4.0 technologies in food Industry's sustainability. Your response will help provide an insight into how Industry 4.0 technologies will contribute to the sustainability development in the food industry.

Thank you for participating in this survey.

SECTION -A: General information

A1. Company Name:					
A2. What is the business Area of your company	Food Manufacturing ☐	Food Processing ☐	Food Wholesaling ☐	Food Retailing ☐	Other ☐ (Please Specify………..)
A3. Number of employees in your company	Between 25-50 ☐	Between 51-100 ☐	Between 101-250 ☐	Over 250 ☐	
A4. Approximate capital of your company (JOD)	500 thousands to 750 thousands (JOD) ☐	750 thousands to 1 Million (JOD) ☐	Between 1M and less than 2M (JOD) ☐	Over 2M (JOD) ☐	

SECTION -B: General Company information

B1. Identify the stage of Industry 4.0 implementation of your company

Stage of Industry 4.0 Implementation	Tick
No plan for adoption now and in future	

Will adopt in future	
Recent and on-going implementation	
Made significant progress in implementation	

B2. Identify the stage of sustainability implementation of your company

Stage of Sustainability Adoption	Tick
No, Not available	
Yes, to some extent	
Made signifcant progress in integration	
Availability of Economic measures of Sustainability	Tick
No, Not available	
Yes, to some extent	
Made signifcant progress in integration	
Availability of Environmental measures of Sustainability	Tick
No, Not available	
Yes, to some extent	
Made signifcant progress in integration	
Availability of Social measures of Sustainability	Tick
No, Not available	
Yes, to some extent	
Made signifcant progress in integration	

B3. In which parts of your company have been invested in the implementation of Industry 4.0 *Please tick the appropriate box that represents your views.* 4- Large, 3- Medium 2- Small. 1- None.

Department	**Level**			
	1	**2**	**3**	**4**
Research & Development				
Production/Manucadturing				
Purchasing/sales				

Logistics				
IT				

B4. Please kindly indicate the extent to which you agree or disagree on the activities that your firm had undertaken or plan to ensure that new Industry 4.0 technologies are adopted successfully and integrating them with the existing ones.
Please tick the appropriate box that represents your views. 5- Strongly agree, 4- Some degree of agreement, 3- Neither agree or disagree, 2- Some degree of disagreement 1- Strongly disagree.

Activities	**Agreement level**				
	1	**2**	**3**	**4**	**5**
Effective routines to identify, value and import new systems and technologies.					
Employees are assigned to tasks that commensurate with their task-relevant knowledge and skills.					
Overall, our technology adoption activity is/will be well coordinated.					
Management is/can effectively involved in technology adoption activities at the working level.					
Evaluation of the suitability of new manufacturing technologies to existing processes before we procure.					

B5. How do you assess the skills of your company's employees when it comes to the future requirements under Industry 4.0.
Please tick the appropriate box that represents your views., 4- Adequate, 3- Existant but inadeqaute, 2- Non-Existant, 1- Nonrelevant.

Employees' skills readiness	**Level**			
	1	**2**	**3**	**4**
IT Infrastructure				
Automation Technology				
Data Analytics				
Data Security				
Development or application of Assistance Systems				

Collaboration Software				
Non-technical Skills				

SECTION -C: Sustainability

C1. Please kindly indicate the extent to which you agree or disagree on the sustainability measures of Industry 4.0 adopted for improving this company's environmental performance.
Please tick the appropriate box that represents your views. 1- Not at all, 2- Very little, 3- Medium, 4- Very extensively.

Environment sustainability performance	**Impact level**			
	1	**2**	**3**	**4**
Production process is designed to use Natural Resource/Renewable Energy				
Products and packaging are designed to be reusable and recyclable				
Production process is designed to reduce consumptions of resources (materials & energy)				
Conduction of environmental audits				
Environment friendly technologies are used to save the environment				
Environmental training to the staff				
Emission and waste free production				
There are positive impacts on environmental biodiversity				
The use eco-friendly (e.g. fuel efficient) processes				

C2. Please kindly indicate the extent to which you agree or disagree on the sustainability measures of Industry 4.0 adopted for improving this company's economic performance.
Please tick the appropriate box that represents your views. 5- Strongly agree, 4- Some degree of agreement, 3- Neither agree or disagree, 2- Some degree of disagreement 1- Strongly disagree.

Economic sustainability performance	**Agreement level**				
	1	**2**	**3**	**4**	**5**
Profit and cost savings had been/will be increased					

Overall production and efficiency had been/will be increased					
Product longevity & durability had been/will be increased					
Transparency between companies had been/will be increased					
Reliability of Data had been/will be Increased					
Bsuiness Models product and process quality supply chain integration had been/will be improved					
Market share & performance relative to competitors had been/will be improved					
Inventory & new product development had been/will be improved					
Savings on labour cost have been/will be increased					

C3. Please kindly indicate the extent to which you think on how Industry 4.0 technology adoption will affect your company's social performance.
Please tick the appropriate box that represents your views. 1- Negative effect, 2- No effect, 3- Postitive effect.

Social sustainability performance	**Impact level**		
	1	**2**	**3**
The standard of living			
The community security/wellbeing			
The locally sourced products			
Job opportunities			
The socially responsible practices			
Employees' skills, knowledge and competencies are aligned with job performance			
The customer satisfaction			
The employees' welfare			
The health and safety environment for the staff			
The working environment of the organisation has been improved			
Employee job satisfaction			

SECTION -D: Impact level of Industry 4.0 Practices

D1. Please kindly rate the importance of the following Industry 4.0 organizational capabilities used to enable and support the sustainability progress in your firm?
Please rate by ticking the appropriate box that represents your views. 5- Very important, 4- Important, 3- Moderately important, 2- Slightly important, 1- Not important at all

Industry 4.0 Organizational capabilities	**Impact level**				
	1	**2**	**3**	**4**	**5**
Data-Driven Decision Making					
Agility and Flexibility					
Operational Efficiency and Productivity					
Innovation and Product Development					
Visibility and Resilience					
Centricity and Personalization					
Connectivity and Collaboration					

D2. Please kindly indicate the extent are the following Industry 4.0 industrial capabilities used to enable and support the sustainability progress in your firm?
Please tick the appropriate box that represents your views. 1- Not at all, 2- Very little, 3- Medium, 4- Very extensively.

Industry 4.0 Organizational capabilities	**Impact level**			
	1	**2**	**3**	**4**
IoT/Food Safety management				
Blockchan technology				
Big Data Analytics				
Automation and Food Traceability Systems				
Artificial Intelligence (AI) and Machine Learning (ML)				

SECTION -E: Opportunities and Inhibitors of Sustainability Practices within Industry 4.0

E1. Please kindly identify the extent of primary drivers/motives for your company's choice of the industry 4.0 strategies you have implemented.

Please tick the appropriate box that represents your views. 1- None, 2- Small, 3- Medium, 4- Large.

Driver/Motive	Level			
	1	2	3	4
Desire to reduce cost				
Desire to enhance revenues/profits				
To achieve competitive advantages				
Desire to conserve energy				
Desire to conserve resources/resources pressures				
Desire to reduce pollution				
Desire to reduce waste				
Legal/regulatory pressures				
Marketing pressures				
Environmental advocacy pressures				
Desire to enter new markets				
To increase market share				
Carbon foot print reduction				

E2. Please kindly identify the extent of difficulties your organizations encounter in adopting /practising new technologies of Industry 4.0?

Please tick the appropriate box that represents your views. 1- Non-existent, 2- slightly exist, 3- Exist.

Challenge	Availability		
	1	2	3
Higher cost of adaption (take up)/higher running costs			

Problems of other stakeholders pressures			
Lack of relevant information			
Inappropriate infrastructures			
Decline of profit level			
Lack of expertise/unskilled employees on Industry 4.0 practices			
Difficulties of implementing Industry 4.0 (new concept) in the firm			
Lack of funding/Financial support			
Conflicts with organisation business objectives			
Conflict with stakeholder interest			
Higher cost of adaption (take up)/higher running costs			

SECTION -F: Performance

E2. Please kindly indicate your opinion about how integretating Indsutry 4.0 will affect you company's performance.

Please tick the appropriate box that represents your views. 5- Strongly agree, 4- Some degree of agreement, 3- Neither agree or disagree, 2- Some degree of disagreement 1- Strongly disagree.

Performance	**Agreement level**				
	1	**2**	**3**	**4**	**5**
Resource efficiency					
Energy efficinecy					
Renewable energy					
redcued workload					
Competitiveness					
improved decision making					
well beimg and productivity					
cost and flexibility improvement					
service oriented and event-driven					
information based models					

product life cycle management					
eco-design					
product life extension					
resource integration					
Transparency					
Traceability					

SECTION -G: The End

Additional insights/ comments:	

Thank you for taking the time to complete this questionnaire.

<u>APPENDIX - C :</u> FACTORS PATTERN MATRIX AND COMMUNALITIES OF EFA

Variable	Component											Communalities	
	1	2	3	4	5	6	7	8	9	10	11	Initial	Extraction
ENV_ME1			.936									1.000	.808
ENV_ME2			.921									1.000	.897
ENV_ME3			.890									1.000	.926
ENV_EM1			.939									1.000	.830
ENV_EM2			.935									1.000	.880
ENV_EM3			.850									1.000	.855
ENV_EWP1			.936									1.000	.899
ENV_EWP2			.645									1.000	.856
ENV_EWP3			.686									1.000	.865
ECO_PR1	.955											1.000	.961
ECO_PR2	.973											1.000	.858
ECO_PR3	.965											1.000	.927
ECO_TI1	.972											1.000	.951
ECO_TI2	.912											1.000	.922
ECO_TI3	.948											1.000	.874
ECO_MA1	.845											1.000	.910
ECO_MA2	.796											1.000	.912
ECO_MA3	.973											1.000	.875
SOC_COM1	.931											1.000	.753
SOC_COM2	.936											1.000	.782
SOC_COM3	.956											1.000	.808
SOC_COM4	.631											1.000	.915
SOC_COM5	.749											1.000	.860
SOC_IND1	.653											1.000	.882
SOC_IND2	.940											1.000	.866
SOC_IND3	.667											1.000	.802
SOC_IND4	.896											1.000	.882
SOC_IND5	.957											1.000	.850
SOC_IND6	.878											1.000	.863
DR1				.624								1.000	.905
DR2				.580								1.000	.894
DR3				.897								1.000	.923
DR4				.698								1.000	.885
DR5				.884								1.000	.892
DR6				.967								1.000	.883
DR7				.946								1.000	.941
DR8				.755								1.000	.898
DR9				.796				**.439**				1.000	.835
DR10				.784								1.000	.898
DR11				.922								1.000	.874
DR12				.866				**.573**				1.000	.945
DR13				.831								1.000	.838
CH1					.674							1.000	.753
CH2					.794							1.000	.891
CH3					.824							1.000	.882
CH4					.901							1.000	.822
CH5					.692							1.000	.738
Ch6					.742							1.000	.857
CH7					.789							1.000	.755
CH8					.835							1.000	.894
CH9					.591				**.404**			1.000	.845
CH10					.800				**.516**			1.000	.827
IC1							.828					1.000	.931
IC2							.713					1.000	.937
IC3							.599					1.000	.886
IC4							.870					1.000	.934
IC5							.822					1.000	.917
OC1						.789						1.000	.921
OC2						.881						1.000	.866
OC3						.733						1.000	.745
OC4						.957						1.000	.886
OC5						.638						1.000	.760
OC6						.881						1.000	.861
OC7						.873						1.000	.893
PER1		.789										1.000	.957
PER2		.982										1.000	.834
PER3		.996										1.000	.931
PER4		.761										1.000	.784
PER5		.984										1.000	.934
PER6		.967								**.412**		1.000	.924
PER7		.935										1.000	.948
PER8		.954										1.000	.962
PER9		.878								**.423**		1.000	.832
PER10		.784										1.000	.896
PER11		.948									**.501**	1.000	.799
PER12		.923										1.000	.768
PER13		.867										1.000	.948
PER14		.972										1.000	.935
PER15		.832									**.435**	1.000	.788

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.
Rotation converged in 10 iterations.[a]

APPENDIX – D : STATISTICAL FIGURES

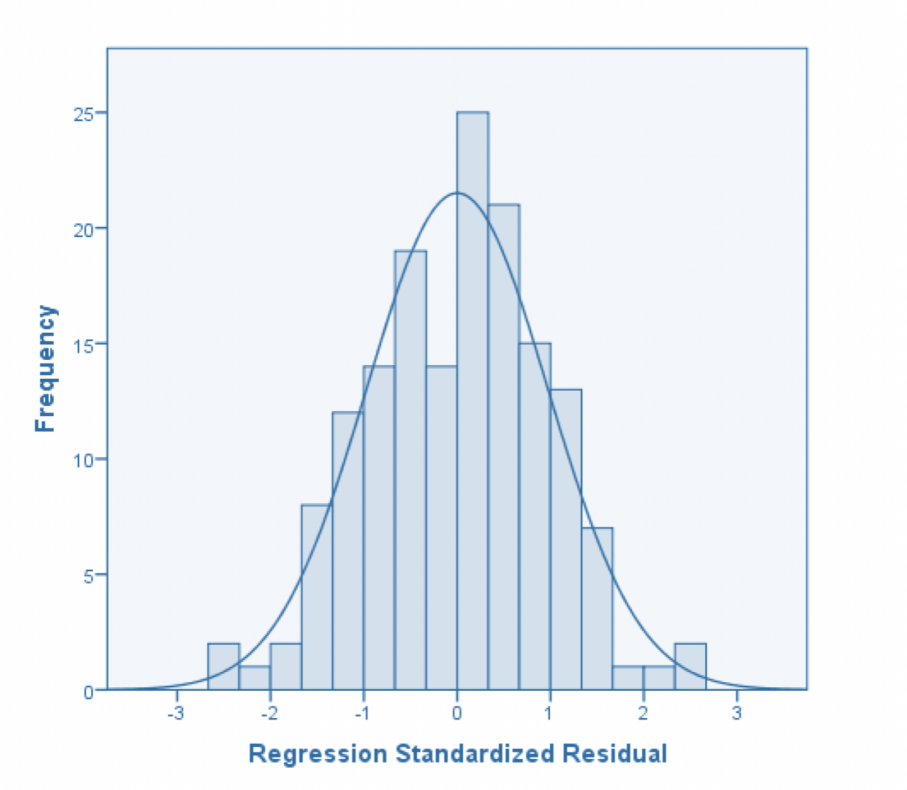

Figure D.1: Histogram with Performance as dependent variable (N=195).

Source: Author's own contribution

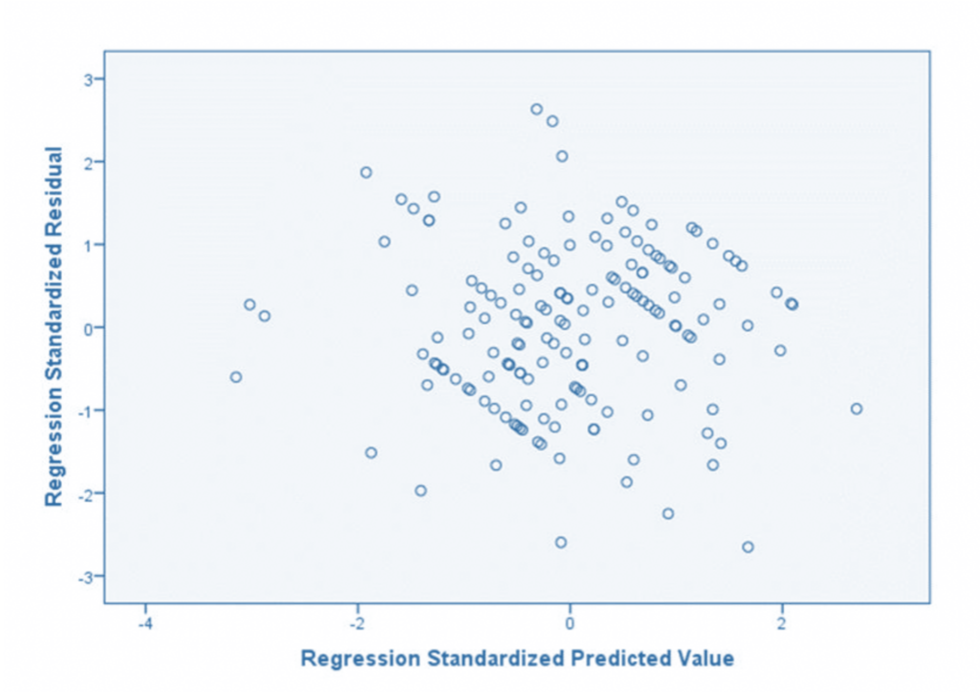

Figure D.2: Scatter Plot.

Source: Author's own contribution

LIST OF PUBLICATIONS

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Subject: PhD Publication List

Candidate: Luma AlQudah
Doctoral School: Károly Ihrig Doctoral School of Management and Business
MTMT ID: 10076918

List of publications related to the dissertation

Articles, studies (4)

1. Haddad, H., Albawab, A., **AlQudah, L.**: The effect of intellectual and social capital on banks profitability.
   Journal of Governance and Regulation. 12 (1), 359-366, 2023. ISSN: 2220-9352.
   DOI: http://dx.doi.org/10.22495/jgrv12i1siart14
2. Haddad, H., **AlQudah, L.**, Almansour, B. Y., Rumman, N. A.: Bank Specific and Macroeconomic Determinants of Commercial Bank Profitability: in Jordan from 2009 -2019.
   Montenegrin Journal of Economics. 18 (4), 155-166, 2022. ISSN: 1800-5845.
   DOI: http://dx.doi.org/10.14254/1800-5845/2022.18-4.13
   IF: 1.5
3. **AlQudah, L.**, Piontek, B., Oláh, J.: Economic Growth and Foreign Direct Investment in the Context of Financial Development: Evidence from Jordan.
   European Research Studies Journal. 24 (2B), 762-782, 2021. ISSN: 1108-2976.
   DOI: http://dx.doi.org/10.35808/ersj/2263
4. **AlQudah, L.**: The perception of implementing industry 4.0 on Supply Chain: A Review on sustainability pillars.
   Cross-Cultural Management Journal. 23 (1), 57-69, 2021. ISSN: 2286-0452.

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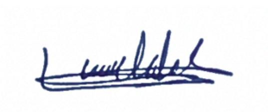
DECLARATION

I undersigned (name: **Luma AlQudah**, date of birth: 10/3/1993) declare under penalty of perjury and certify with my signature that the dissertation I submitted in order to obtain doctoral (PhD) degree is entirely my own work.

Furthermore, I declare the following:

- I examined the Code of the Károly Ihrig Doctoral School of Management and Business Administration and I acknowledge the points laid down in the code as mandatory;
- I handled the technical literature sources used in my dissertation fairly and I conformed to the provisions and stipulations related to the dissertation;
- I indicated the original source of other authors' unpublished thoughts and data in the references section in a complete and correct way in consideration of the prevailing copyright protection rules;
- No dissertation which is fully or partly identical to the present dissertation was submitted to any other university or doctoral school for the purpose of obtaining a PhD degree.

Debrecen, 2024 March 11th



Luma AlQudah

signature

ACKNOWLEDGEMENT

This Thesis is dedicated to the memory of my father, Ali Alqudah and my loving mother Alia Hamawi who I am indebted to for giving me their love of learning and life.

I would like to express my sincere gratitude to my supervisor, Professor Judit Olah, for her invaluable guidance, support, and unwavering commitment throughout this journey. Her expertise, encouragement, and constructive feedback have been instrumental in shaping this dissertation.

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I express my gratitude to the Hungarian Government for awarding me the Stipendium Hungaricum Scholarship, which has provided me with the means to embark on this journey in the first place.

This thesis and my pursuit of a PhD are deeply meaningful to me in many ways. They symbolize a transformative journey of self-discovery and personal growth, marking a significant chapter in my quest toward self-fulfilment. They represent the realization of aspirations seeded long ago, now blooming into fruition through rigorous research and scholarly inquiry, where each discovery and challenge has contributed to my intellectual and personal development, and every insight gained has shaped my understanding and perspective. In summary, this journey encompasses not only academic achievement but also a profound evolution of my scholarly identity.

Thank you to my mum, Alia, for her support in my decision to pursue my research and, above all, for her love and continued support through this journey. Her belief in me has been a constant source of motivation, strength and determination.

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