THESISES OF THE DOCTORAL (PhD) DISSERTATION

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

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TABLE OF CONTENTS

1. INTRODUCTION OF THE TOPICS AND OBJECTIVE

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).

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.

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.

1.1. Research 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.

1.2. Contribution to knowledge and Research Model

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 1 below

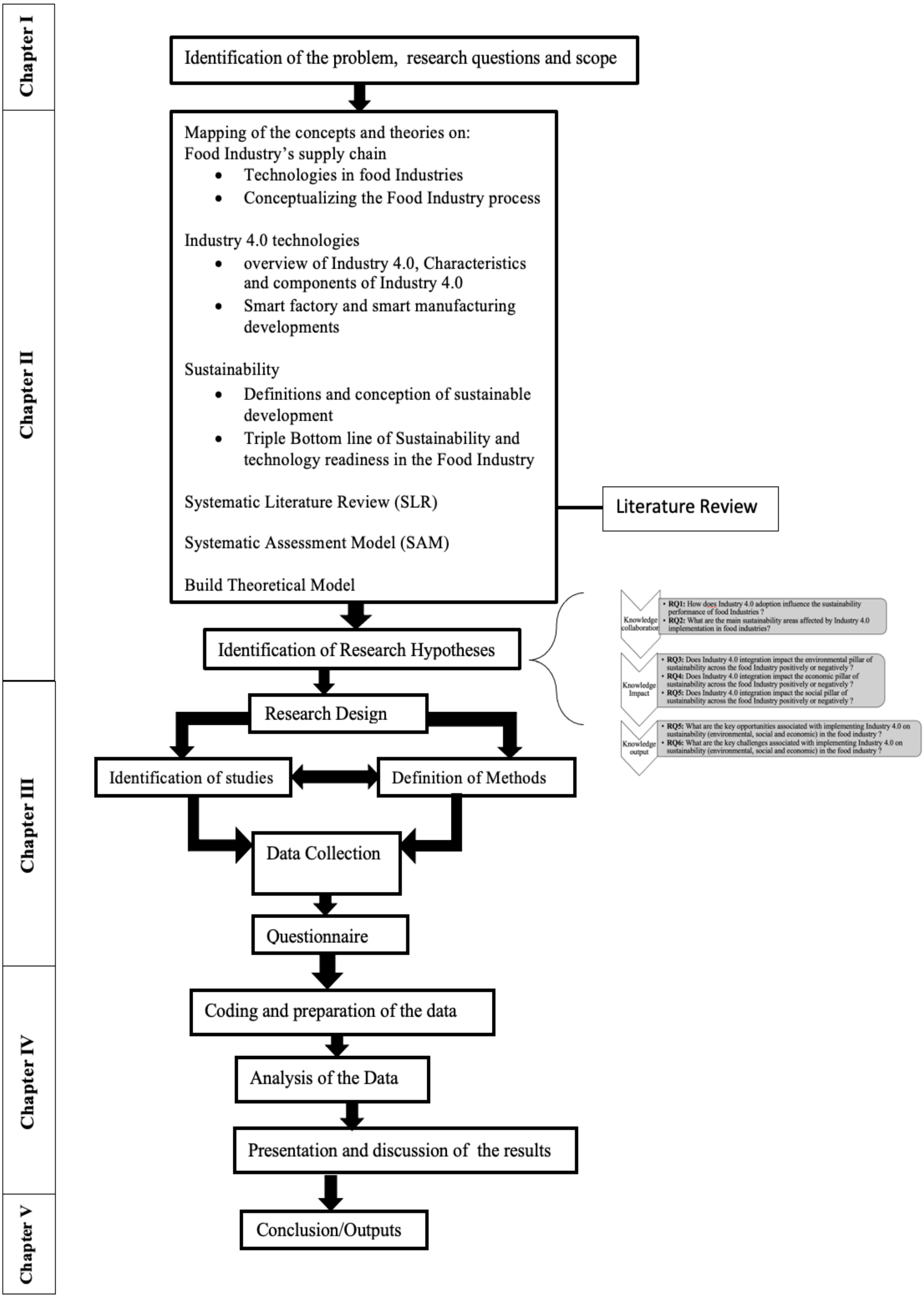

Figure 1: Research model.

Source: Author's own contribution

2. CONCEPTUAL FRAMEWORK

At the beginning, the concepts of food industry and Industry 4.0 were defined, where their characteristics and components are previewed in details. Later the Systematic Literature Review (SLR) of sustainability in the context of Industry 4.0, as well its linkages with the three pillars of sustainability were investigated, 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 form the theoretical model and the research hypotheses.

2.1. Sustainability Assessment Model (SAM)

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 2 shows 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.

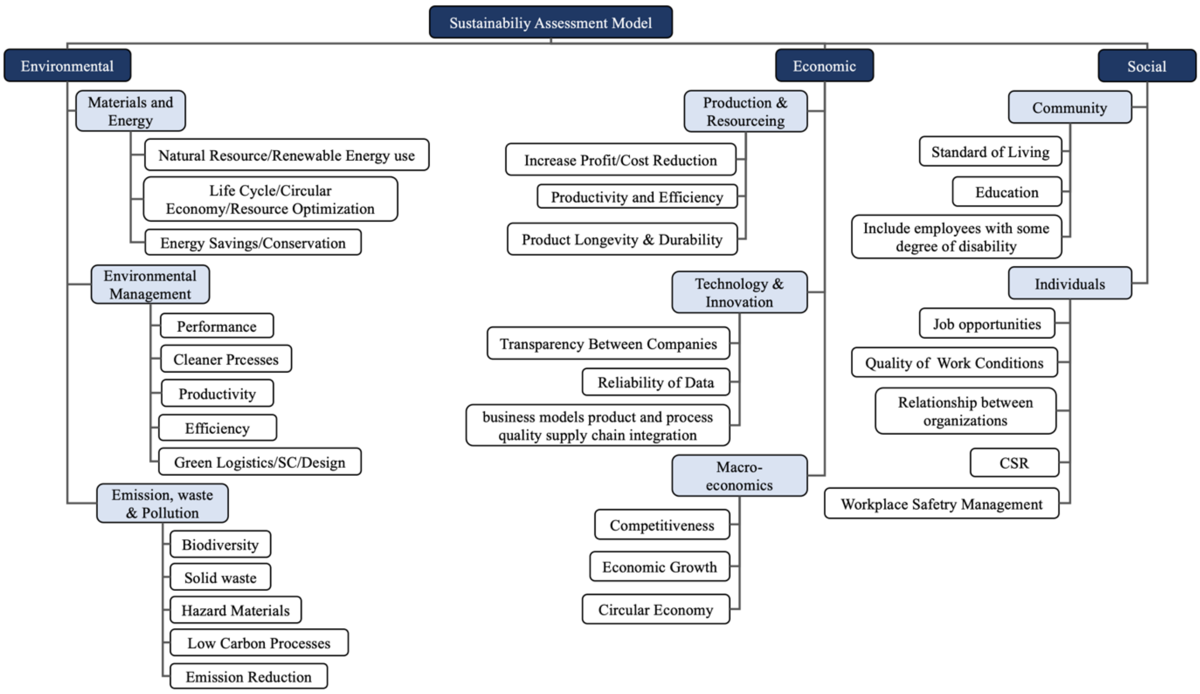

Figure 2: Framework of sustainability assessment tools.

Source: Author's own elaboration.

2.2. Theoretical Model and Hypotheses

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.

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. The second segment portrays various sustainability factors representing the three pillars of sustainability, encompassing materials & energy, environmental management, emissions waste and pollution, production and resourcing, technology and Innovation, macroeconomy, community and individuals. 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. This thesis presents three primary propositions to elucidate the function of the variables and the interactions among them within the theoretical model:

- **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 3.

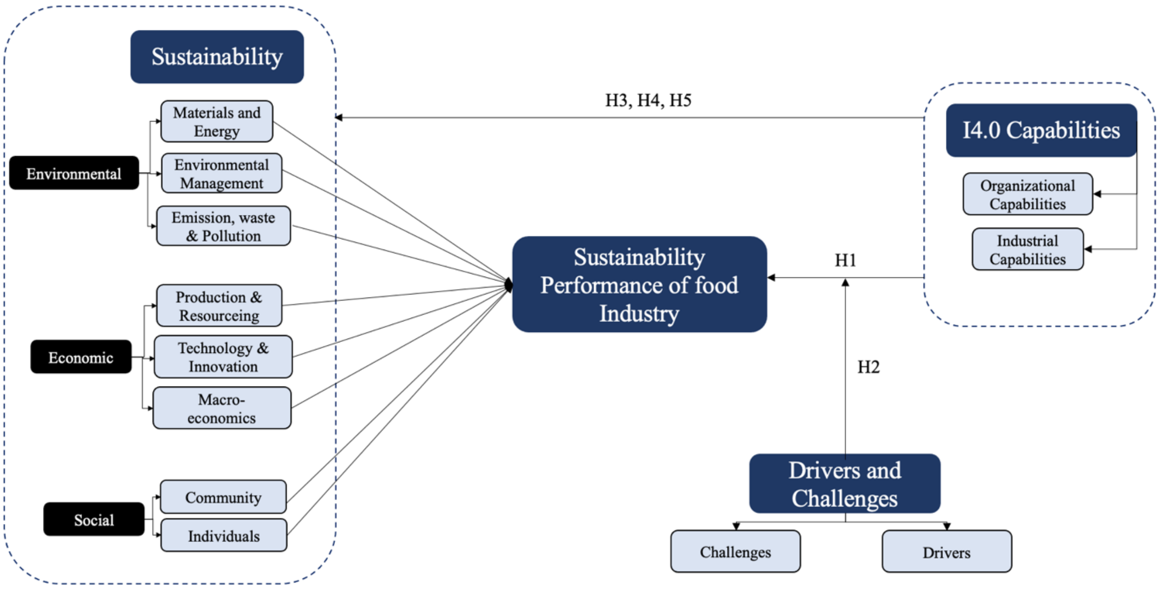

Figure 3: Theoretical Model showing hypotheses 1,2,3,4 and 5.

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. Hypotheses 3, 4, 5 theorizes state that there is a positive impact of Industry 4.0 capabilities on each pillar of sustainability, Table 1 presents a compilation of statements corresponding to the hypotheses.

Table 1: 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. MATERIAL AND METHODS

3.1. Methodology

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 first step in designing the research is finding the research philosophy. Research involves forming a philosophical stance towards the world, selecting appropriate methods, and determining the researcher's perspective on the study (CRESWELL, 2014). Ontology and epistemology are two fundamental branches of philosophy that are particularly relevant in research and academic inquiry. 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 principles and methodologies as those employed in the natural sciences for collecting and analyzing data (BRYMAN, 2012). The research philosophies selected in this study are objectivism and positivism.

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. 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. Figure 4 summarizes the philosophical positions of the research.

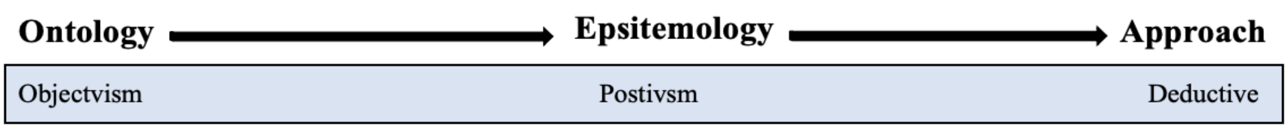

Figure 4: Philosophical positions of the research.

Source: Author’s own collaboration.

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. 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.

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.

3.2. Research Instrument (Quantitative : Questionnaire Survey)

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.

The process of developing a survey for sustainability performance research is intricate and depends on a theoretical 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 5. 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.

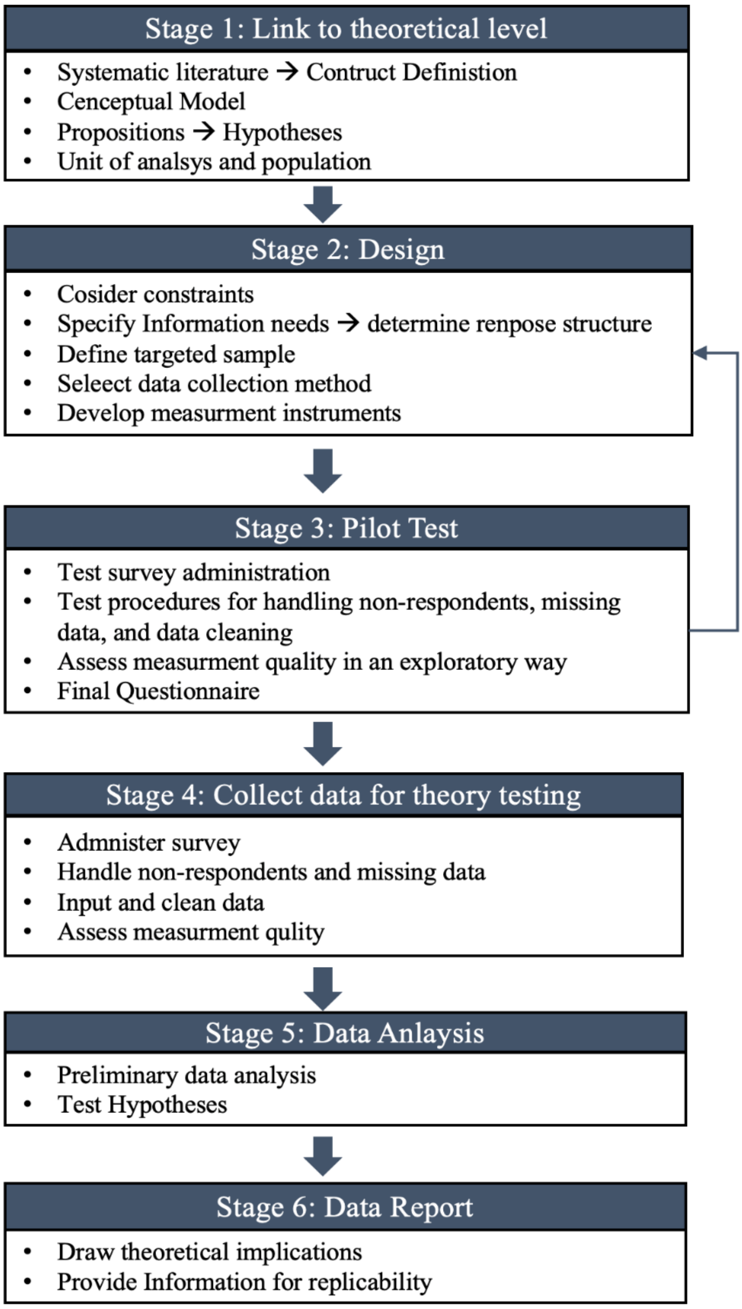

Figure 5: Survey research Process.

Source: Author's own collaboration.

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

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 2 presents the Construct, item codes, variable and number of questions corresponding to each variable, which are included to facilitate the data collection input process.

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 analysed through their respective websites. This systematic approach of identification and classification yielded a directory of 9 organizations. 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.

Table 2: 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.

3.3. Data Analysis

This section delineates the analytical procedures undertaken in the study. Initially, data from the online Google survey were imported into Excel for processing. Subsequent to this crucial step, a meticulous phase of data coding and editing ensued, whereby numerical values were systematically assigned to participant responses, and a thorough validation process was conducted to ensure logical consistency across all data points. Likert scale responses were coded using a 5-point system.

Upon completion of the data cleansing and preparation phase, the analysis transitioned into the realm of descriptive statistics, leveraging the robust capabilities of SPSS software to conduct a rigorous examination of the collected questionnaire data. This phase entailed the adoption of Exploratory Factor Analysis (EFA), strategically chosen for its inherent flexibility in elucidating complex variable relationships within the dataset. Subsequently, Principal Component Analysis (PCA) was employed to further validate the instrument's reliability and efficacy, thereby bolstering the credibility of subsequent analytical outcomes.

Descriptive statistical analysis followed, offering a broad overview of quantitative data. This phase involved the meticulous calculation of key statistical metrics, including mean, median, standard deviation, and percentages, thereby providing a rich and nuanced depiction of the dataset's characteristics and trends. Notably, this descriptive study of practices within the food industry enabled the elucidation of sustainable organizational activities, thereby facilitating both a visual and mathematical comparison of data points.

Subsequently, the analytical focus shifted towards an exhaustive evaluation of normality, correlation, and multicollinearity, crucial elements in ensuring the robustness and reliability of subsequent regression analyses. Normality, correlation, and multicollinearity were assessed to ensure the validity and reliability of regression analysis, which explored the impact of Industry 4.0 capabilities on performance across various dimensions. Regression analysis involved fitting linear equations to predict outcomes based on predictor variables, with R^2, F statistics, and Beta values used to assess model fit and variable relationships.

In summary, the analytical journey embarked upon within this section exemplifies a holistic and methodologically rigorous approach, underpinned by a meticulous attention to detail and a steadfast commitment to extracting meaningful insights from the collected dataset.

Through a carefully orchestrated sequence of analytical techniques spanning from data cleansing and preparation to factor analysis, descriptive statistics, and regression analysis, this section lays the foundation for robust and insightful findings that promise to contribute significantly to the scholarly discourse within the field of sustainable business practices and Industry 4.0 integration.

4. MAIN FINDINGS

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.

4.1. Influences of Industry 4.0 on Food Industries' Performance

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

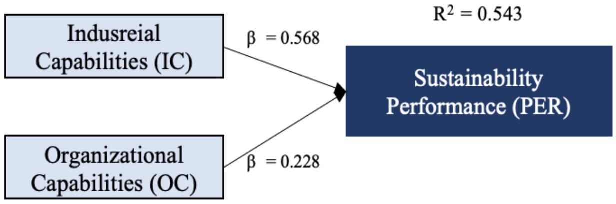

Figure 6: Effects of I4.0 capabilities on sustainability performance.

Source: Author's own contribution

The regression model depicted in Figure 6 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 6 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.

4.2. Sustainability Dimensions

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.

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 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

4.3. Effects of Industry 4.0 on sustainability dimensions

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.

Table 3 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 3, 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 3: 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 3 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 7 illustrates these interaction effects between each factor of sustainability before and after I4.0 adoption. Figure 7 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.

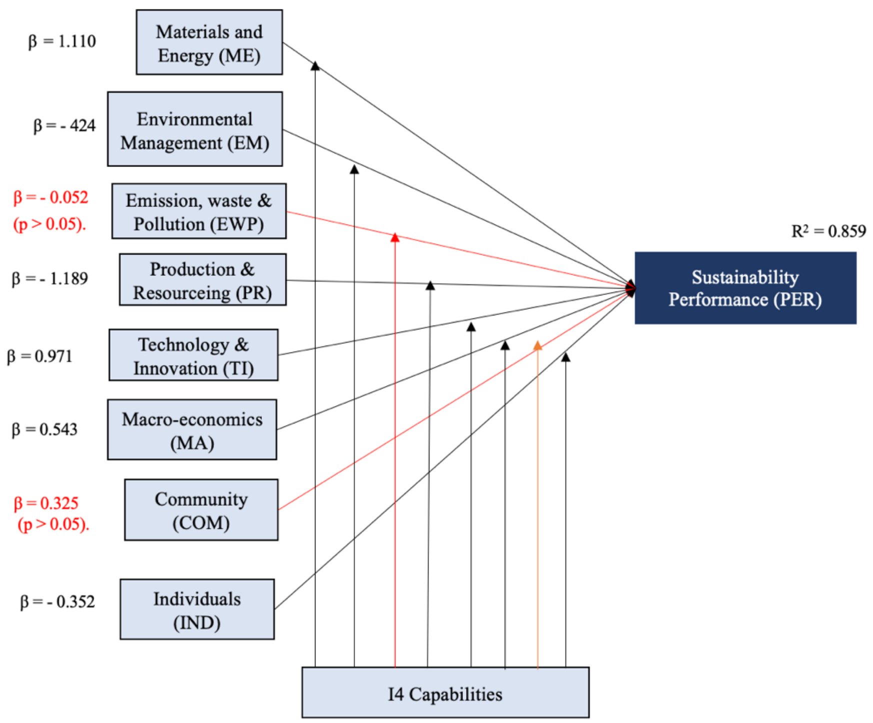

Figure 7: Interaction effects of I4.0 capabilities and on sustainability factors.

Source: Author's own contribution

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

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.

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 4 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 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).

5. MAIN CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

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.

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).

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

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 Recommendations

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 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.

6. NOVEL FINDINGS OF THE DISSERTATION

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.

7. PRACTICAL APPLICABILITY OF THE RESULTS

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.

Also, academic collaboration with 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). This study can help stakeholders to create creative solutions that tackle the difficulties of integrating Industry 4.0 in the sustainability of the food business by sharing 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, academic collaboration is crucial for successfully implementing Industry 4.0 in the food industry sustainability and realizing its full potential for sustainable development.

The applicability of this study 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.

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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.
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   Cross-Cultural Management Journal. 23 (1), 57-69, 2021. ISSN: 2286-0452.

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