An Indoor Farming Framework for decision support towards food security in Society 5.0

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Abstract. One of the key aspects outlined in the Sustainable Development Goals (SDGs), is food security. The discourse around food security recognizes that resources such as water and land are finite, and the agenda to end hunger remains a major challenge. Furthermore, the objective of Society 5.0, to integrate digital technologies and a human-centered society to foster economic advancement and the resolution of social problems, augmented the reasons to address food security. Therefore, the purpose of this paper is to consider indoor farming as an agricultural technology capable of producing more food using fewer resources, as opposed to traditional farming, that is enabled through targeted capital investments. We developed an Integrated Farming Framework (IFF) with the aim to provide decision support to guide potential investors in indoor farming. Ten key aspects were identified and mapped to the Technology-Organization-Environment (TOE) framework, identifying a fourth construct, societal context. These constructs include the basic elements required for investors to consider financing in indoor farming projects. By applying the IFF, investors will be able to consider their investment options holistically.

Keywords: Society 5.0, Sustainable Development Goals, Food security, Human-centered society, Indoor farming, Investment, Decision Support.

1 Introduction

In 2020, the impact of the COVID-19 pandemic resulted in a significant increase in the number of people experiencing chronic hunger, adding up to 132 million to the already 690 million people (≈ 8.9% of global population) experiencing malnutrition and hunger globally [1]. This brings the achievability of eradicating hunger by 2030 as per the SDGs into question, calling for bolder actions on a global scale [2, 3]. The 2020 report on the *State of Food Security and Nutrition in the World* raises the need for modern and innovative approaches to address the growing social challenges in sustainable manners [1].

By seeking to employ technology in a more human-centered manner towards addressing social challenges, Japan's Government introduced Society 5.0 in 2016 as part of their growth strategy [4, 5]. The concept of Society 5.0 builds on the Information Society (Society 4.0) and promotes the development of information networks to create value, by centering the use of technology and the digital transformation around advancing a human-centered society [5]. At the core of Society 5.0 lies the use of innovation and the technological advancements from Industry 4.0, such as artificial intelligence (AI), robotics and big data, to address social challenges including challenges addressed by the SDGs [5]. One of the seventeen (17) SDGs, number two (2), aims to zero hunger by achieving food security and improving nutrition through several global intervention actions, including the promotion of sustainable agriculture [6-8]. As it is the goal of Society 5.0 to enhance society through a close collaboration with technology (i.e. AI and autonomous systems), it is necessary to determine the holistic impact Society 5.0 may have on chronic social problems such as hunger.

This paper aims to contribute to the body of knowledge of Society 5.0 within the context of SDGs by considering the following research question: *"How can an Indoor Farming Framework (IFF) be applied towards decision support for food security in Society 5.0"*. Through the systematic review of available Society 5.0 and indoor farming literature, the paper proposes an IFF aimed at providing potential investors with key consideration for investing in indoor farming with the objective of addressing food insecurity.

In the next section (Sect. 2), an overview of the literature is provided, followed by the research approach in Sect. 3. The data analysis and findings are presented in Sect. 4, with Sect. 5 proving the research contribution of an IFF. Finally, the paper is concluded in Sect. 6.

2 Background

Food insecurity, unlike Society 5.0, is not a novel idea. In 1798, Thomas Malthus predicted food production will be superseded by population growth and reiterated his hypothesis in 1826 stating that "*population has this constant tendency to increase beyond the means of subsistence*" [9, 10:14]. Although the definition of food (in)security has evolved over the last century, hunger remains a persistent social challenge globally [1, 7]. The paper aims to determine to what extent the Society 5.0 approach can be applied in finding solutions for global food insecurity in a sustainable manner. Sect. 2 provides an overview of Society 5.0 and food security, followed by an introduction into indoor faming, and information system frameworks capable of providing decision support to potential investors in the agricultural sphere.

2.1 Overview of Society 5.0

Society 5.0 principles aim to resolve modern social challenges by merging the real world with the virtual world in a manner where humans or society remain at the center [5]. Following the Information Society (Society 4.0), where technology advances have been extensive, Society 5.0 intends to guide the mobilization of innovation and technology to ensure a sustainable future, balancing economic and social advancement [5, 11]. This human-centered approach allows for additional value creation in products and services by addressing gaps and social problems through the connection of technologies and the physical space in a sustainable manner. This goal aligns with the United Nation's SDGs to promote action towards a sustainable future for all [12]. AI, big data, the internet of things (IoT), and robotics are some of the technologies utilized to create social value and address digital divides [13].

On the other hand, the challenges of implementing such lofty goals include ethical concerns, for instance privacy and security in both the physical and digital space, and barriers to technological adoption [5]. In addition, a super-smart society (Society 5.0) requires an extensive level of technological transformation that will allow for tackling of social challenges [3, 13]. Where diversity, social inclusion, cultural balance, innovation, and global perception promote acceptance of technology through positive experiences [14]. To address these challenges, a conscious and purposeful process is required to create a sustainable future through societal evolution.

2.2 Overview of Food Security

Napoli [15] and Kruzslicika [7] provide a thorough background of the evolution of food security and its definition, highlighting the core aspects associated with food security with the progression of time [7, 15]. Although food security is a difficult concept to define and measure, the Food and Agriculture Organization (FAO) defines food insecurity as "*A situation that exist when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life*", opposed to food security defined as "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preference for an active and healthy life*" [15:7-9, 16, 17]. Subsequently, food security considers more than just the **availability** of food, it requires a holistic improvement to the entire food value chain, including **stability**, **accessibility,** and **affordability** as well as the safety and nutritional value of produced food and how it is **utilized** [15, 16].

To mitigate the significant impact of the COVID-19 pandemic on the agriculture and food sector, the FAO is imploring swift global action [2, 6]. The FAO has provided several policies and strategies to establish resilient food systems in areas where food insecurity persists. One of these strategies, the Twin-Track Approach, aims to address the key areas of food insecurity by combining rural development with sustainable agriculture [16, 18]. By fostering sustainable agriculture, social and environmental sustainability can be promoted alongside economic growth. Therefore, sustainable agriculture has the potential to mitigate environmental, social, and economic challenges [19, 20]. In support of this, Kruzslicika [7] also highlights the important role sustainable agriculture and the responsible use of resources play in working towards food security [7]. However, to establish sustainable agriculture and promote rural development, funding and support is required, especially in low-income regions [18, 21]. As the world population continuous to grow and consumption patterns shift, the demand for food increases, adding to the increasing resources requirement that put agricultural systems under great pressure [22]. The increase in resource requirements alone, escalates the food crises further, as food production and distribution are further burdened [22]. Considering the plight of Society 5.0 to address social challenges, one innovative approach to producing food with minimum resource requirements, whilst minimizing natural interferences (i.e. rainfall and sunlight), is found to be Controlled Environment Agriculture (CEA), otherwise known as indoor farming [23-27].

2.3 Indoor Farming

Constraints on natural resources, such as water, requires agricultural practices to find sustainable avenues of producing more food with less resources to play its role in addressing food security [20]. It is the objective of sustainable agriculture to conserve and protect resources while meeting the social needs and not compromise the ability to produce adequately for future agricultural needs [7, 8, 20]. The application of indoor farming technology has evolved significantly in recent years, providing farmers with the ability to produce crops with minimum resources and space, while simultaneously reducing the use of harmful pesticides and fertilizers [23, 24]. In addition, indoor farming complements already established urban and rural farming systems using technologies such as IoT and AI [23, 24, 28].

There are several types of indoor agriculture, ranging from tunnel farming that requires minimum technological input to highly autonomized and controlled systems such as container farming [23, 24, 28-31]. The growing environment (i.e. vertical farms) and growing methods (i.e. hydroponics) require varying levels of technologies [28, 29]. A CEA approach to indoor food productions allows for the utilisation of technology to optimise growing conditions for crops and extend growing season [26, 27, 32]. These enclosed structures provide farmers with the option to control variables such as humidity, temperature and nutrient solutions through the utilisation of a variety of technology and information systems [26, 31, 32]. Although this form of sustainable indoor farming is resilient to various climate conditions, there is still a risks and costs that must be accounted for during the development and design of these projects [23]. As a result of the high start-up cost of indoor farming initiatives, exposure to the market is limited [23]. However, indoor farming may serve to address high operating cost such as fertilisers, transport and water [26]. Regardles of the initial cost associated with indoor farming, Sulser et al. [33] emphasised that investment in agricultural sphere is essential to achieve results in reducing food insecurity [33]. Furthermore, Antornaras & Kostopoulos [8] highlights the crucial role private investors play in the development and implementation of practical and scalable sustainable agricultural solutions addressing social challenges such as food insecurity [8, 23]. To guide investors in the process of investing in the diffusion of farming technology, decision support frameworks can be used as described in the next section.

2.4 Decision Support Frameworks

Petry, Sebastiao, Martins, & Barros [34] notes that innovation, usally associated with the contribution of new resources and knowledge, in the agricultural sphere typically relates to the increase in production, crop quality and improved production processes [34]. When considering the principles of Society 5.0, technology must be diffused within the social system through a process of information flow to advance the spread and acceptance of technology [13]. Where a decision support framework is an information system solution to support problem solving and complex decision making [27, 35, 36]. Tornatzky and Fleischer's Technology-Organisation-Environment (TOE) framework is one such information system model that facilitates the adoption of innovation [37]. The framework consists of three constructs that consider what may influences the process of technology adoption in organisations [37, 38]. Where the technology contexts consideres the available technology for adoption as well as what is already established within the organisation [38]. Secondly, the organisational context considers the organizational structure, size and communication processes [36]. The final construct, environment, looks at elements such as market structures, infrastructure and external support, including governmental regulations [38].

Although TOE frameworks have been used in other sectors to develop a decision support system that looks at the adoption of sustainability initiatives throughout the value chain and the systems lifecycle, there is little reference to the application of the diffusion framework applied in the agriculture sphere found in literature [38, 39]. The framework considers the technological, organizational, and environmental context wherein the system lies and highlights decision factors for the adoption of specific technologies within the sector. It should be noted that the adoption of innovation and knowledge transfer in the agricultural sphere is influenced by several factors [40]. Diederen, van Meijl, & Wolters [40] also note that market position and access to information is one of the contributing factors to the adoption of innovation [40].

3 Research Approach

The goal of this paper is to provide potential investors with a decision support framework for investing in indoor farming with the objective of addressing food insecurity. To establish this decision support framework that supports investors in the agricultural sphere, a systematic literature review (SLR) is used to identify the key considerations or themes for investing in indoor farming. Where a SLR identifies, evaluates and synthesizes the existing body of knowledge produced by practitioners, researchers, and scholars to answer the stated research question [41]. The SLR follows a clearly defined replicable protocol to conduct a comprehensive search over various databases and grey literature (i.e. technical reports) [41, 42]. Strings of keywords were used to search specific and inclusive peer-reviewed literature published in various approved academic databases as well as to search for grey data published in technical reports found using the Google search engine. Keywords and phrases included "Society 5.0", "food (in)security", "SDG", "sustainable agriculture", "indoor agriculture and farming", "investing in indoor farming", and "innovation and technology diffusion", as well as derivatives thereof. Strings of keywords were also used to refine and focus the literature search, although predominantly sources from 2016 onwards were included, as this was the year when Society 5.0 was introduced. However, older literature is also included to address long standing social challenges and agricultural practices. The total number of articles and technical reports that match the key terms are indicated in Fig 1.

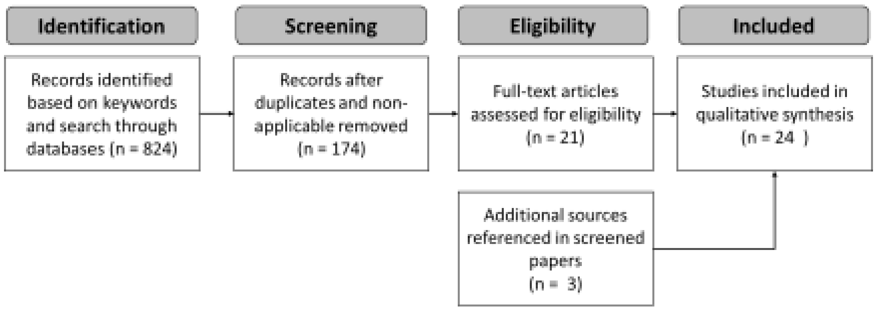

Fig. 1. The number of reports and papers found on databases and grey-literature sources

Although the initial search identified 824 papers and reports, a screening process was applied to refine the search against specific criteria. Papers and reports were excluded if they were found to be duplicates, non-English publications, not relevant to the research question or were unobtainable. After the application of the initial screening process, 174 papers and reports were selected. The detailed screening process of the prospective papers found that 153 documents were excluded based on exclusion criteria such as unrelated context and studies not addressing the research question. During further iterations of framework development, three (3) sources were additionally included in the final SLR.

4 Data Analysis and Findings

The paper aims to develop a conceptual framework that will provide potential investors with key considerations for investing in indoor farming to sustainably address food insecurity. Key considerations have been grouped using a process of thematic analysis as shown in Table 1 [43]. The first column indicates the primary themes as context elements, while the second column indicates the secondary theme as mapped from the TOE framework. The third column provides key considerations, and the final column indicates the applicable references.

Themes were identified by considering the Tornatzky and Fleischer's TOE framework structure as a baseline. However, several themes derived from the SLR could not be mapped according to the TOE framework. These themes address the social challenges associated with food insecurity and were included through the addition of a new primary theme, social context (shaded grey).

The first primary themes emerging from the SLR relates to the *organizational context* of indoor farming. Within the organizational context, consideration is given to secondary themes that link the indoor farming value chain, both formally and informally, as well as the organizational size, communication processes and logistical elements. Where elements to consider before investing in any agricultural sector include a range of interlinking components that stretch from preproduction to the point of sale of the food produced indoor. Secondly, the *environmental context* serves as the second primary theme where the industry's characteristics, legal regulations and practices, as well as technological infrastructure are considered. These considerations, both physical and human related, play a significant role in the feasibility of indoor farming investment. The third primary theme is identified as the *technological context*, that emphasizes the influence of innovation diffusion and the availability of technological features on the successful adoption of indoor farming. Considerations include the availability of technology and the organizational characteristics such as the organizational ideals, resources, and investment budget. In addition to the traditional structure of a TOE framework, the shortfall of social construct consideration is included to produce an extended IFF framework to address the final primary theme. Furthermore, the extension of the framework allows for the alignment with SDGs and Society 5.0 principles. Hence, the *social context* serves to address the aspects of social development and achievement of food security through the adoption of indoor farming.

Table 1. Extracted IFF themes and sub-themes

Primary Theme	Secondary Theme	Key Considerations	References
Organizational Context	Formal and informal linking structure	Pre-Production	[7, 8, 22, 26, 27]
Organizational Context	Formal and informal linking structure	Production	[22, 27, 40, 44]
Organizational Context	Formal and informal linking structure	Harvest	[22, 27]
Organizational Context	Formal and informal linking structure	Processing	[22, 27, 40, 44]
Organizational Context	Formal and informal linking structure	Distribution, Packaging & Handling	[22, 23, 27, 40]
Organizational Context	Formal and informal linking structure	Point of Sale	[22, 26, 27]
Organizational Context	Formal and informal linking structure	Disposal/End of Life	[27]
Organizational Context	Communication Processes	Regulations & Government	[8, 23, 40, 45]
Organizational Context	Communication Processes	Associations	[8, 31]
Organizational Context	Communication Processes	Community	[8, 26, 40]
Organizational Context	Communication Processes	Business Development	[8, 27, 33, 40]
Organizational Context	Communication Processes	Suppliers & Service Providers	[8, 27, 33]
Organizational Context	Communication Processes	Target Market	[26, 33, 40]
Organizational Context	Size	Farm Size	[26, 40]
Organizational Context	Size	Location/Climate	[8, 23, 26, 27, 31, 32]
Organizational Context	Size	Labor Requirement	[23, 26]
Organizational Context	Size	Harvest Size	[26]
Organizational Context	Size	Investment Cost	[8, 23, 26, 27, 31, 33]
Environmental Context	Industrial Characteristics and Market Structure	Consumer	[23, 26]
Environmental Context	Industrial Characteristics and Market Structure	Market Structure	[26, 27]
Environmental Context	Industrial Characteristics and Market Structure	Competitors	[26]
Environmental Context	Industrial Characteristics and Market Structure	Suppliers & Service Providers	[8]
Environmental Context	Industrial Characteristics and Market Structure	Investors & Stakeholders	[8, 26, 27, 40]
Environmental Context	Technology Support Infrastructure	Crop Technology	[3, 8, 26, 27]
Environmental Context	Technology Support Infrastructure	Level of Farming Technology	[23, 26, 27, 31, 32, 40]
Environmental Context	Technology Support Infrastructure	ICT & IS	[3, 14, 26, 32, 44]
Environmental Context	Technology Support Infrastructure	Skill Development & Training	[8, 23, 26]
Environmental Context	Technology Support Infrastructure	Data Management	[3, 14, 27, 32, 44]
Environmental Context	Technology Support Infrastructure	Maintenance & Upgrades	[26, 31]

Primary Theme	Secondary Theme	Key Considerations	References
	Government and International Standards and Regulations	Quality Assurance	[27, 31]
		Food Safety	[26]
		Health & Safety	[8]
		Community Relations	[8, 26, 40]
		Technology	[40]
		Inputs (i.e. Seeds, fertilizer, etc.)	[7]
		Water, Energy & Waste Management	[7, 23, 27, 32]
		Site & Facility Management	[26, 45]
		Financial & Business Management	[26]
		Certification	[8, 23, 45]
Technological Context	Availability	Inputs (i.e. Seeds, fertilizer, etc.)	[3, 8, 26, 27, 46]
		Indoor Farming Structures & Material	[23, 26, 40]
		Farming Technology	[3, 23, 26, 27, 46]
		Information Systems	[3, 14, 26, 27]
	Characteristics of the Organization	Resources	[26, 40]
		Budget (Time/Cost)	[27, 32, 40, 46]
		Ideals	[26, 27, 40]
		Production Goals	[8, 46]
		Skilled Labor	[8, 23, 40]
Societal Context	Social Development	Heritage/Culture	[26]
		Tenure	[26]
		Women Development	[7, 47]
		Education	[7, 8, 26, 40]
		Extension Services	[7, 32]
		Self-Reliance	[7, 8, 26, 46, 47]
	Food Security	Access	[1, 7, 16-18, 23, 26, 31, 32, 48]
		Availability	[1, 7, 16-18, 26, 33, 48]
		Utilization	[1, 7, 8, 16-18, 44, 48]
		Stability	[1, 2, 7, 16-18, 44, 48]
		Sustainability	[5-8, 23, 26, 27, 46]

Ten secondary themes were mapped to create the four primary themes namely organizational context, environmental context, technological context and the societal context. In the next section we discuss the primary and secondary themes and how it contributes to proposing an IFF in more detail.

5 A Conceptual IFF Model

From the analysis in Table 1, combining the themes from literature and by mapping the key considerations to TOE, the existing TOE framework has been enriched to create an IFF. This IFF model aims to provide potential impact investors with key considerations for investing in sustainable indoor farming.

The conceptual IFF in Fig 2 derived from the raw data in Sect. 4 is created across the four constructs, namely technology, organization, environment, and social context. Despite the arrangement of the TOE framework structure around the adoption of technology, the organizational context provide the base around which the remaining constructs are centered. The *organizational context* observes the characteristics of the farm, considering the structure, scope, and size as well as the communication processes. These considerations provide potential farmers with a set of key considerations that guide the decision-making process for investing in indoor farming technology. Themes identified in Sect. 4 were aligned with the skeleton structure of the TOE framework, highlighting variables potential investors need to take into account prior to investing in an indoor farm. When considering the informal and formal links in an organization (the farm), attention should be given to the complete life cycle of the indoor farm, from preproduction elements that include the preparation of facilities, information systems, pesticides and seeds, up to the logistics and management associated with marketing and the sale of produced food. Furthermore, the market players that serve to support the core farming activities include the government, employees, nonprofit organizations (NPO), associations and business membership which need to be established. Also, investors need to consider the available support network as well as the size of the farm. As the size of the organization refers to more than the farm size, consideration must be given to the location, harvest size, investment cost, and required workforce.

The *environment context* does not only consider the market structure and industrial characteristics but also the technology support infrastructure and associated regulations and standards underlining the production of food. Investors are to consider the distance to consumers, competitors' operations and products, market structure, and suppliers as well as stakeholders in the indoor farm. The infrastructure for supporting technology is another essential consideration that emphasizes the necessity of understanding how effectively various forms of technology can be used to support food production. Crop technology (i.e. increased nutrient content), information systems, training, data management and maintenance are some of the considerations associated with the environmental technology support infrastructure. Finally, the organizational environment needs to look at the underlying regulations, standards and governmental objectives addressing food safety, community relations (i.e. labor laws), health and safety, facility and site management, production input (i.e. seeds and fertilizers), water and electricity use, financial management and farming certification.

Conversely, the *technological context* considers the availability of the technology to be adopted as well as the organizational characteristics. For indoor farming to be diffused in the traditional agricultural space, the availability of suitable inputs (i.e. seeds, nutrients and growth mediums), indoor farming structures and materials, farming technologies and information systems need to be considered. The investor is encouraged to align these considerations with the characteristics of the organization itself, looking at the resources, budget, ideals, production goals and the availability of skilled labor, including the farmer.

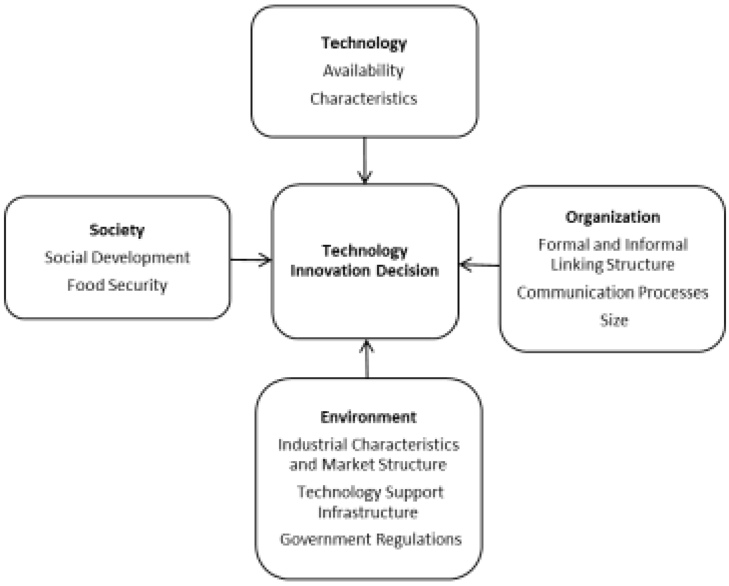

Fig. 2. Conceptual Indoor Farming Framework for Decision Support towards food security.

The IFF model strives to provide potential investors with a complete range of considerations for the adoption of indoor farming as a potential solution to sustainably addressing food insecurity through impact investment. Hence, consideration is given to social aspects not addressed in traditional TOE frameworks. The *social context* is concerned with two main themes, social development and food security. Where social development addresses factor such as tenure, education, extension services, women upliftment, as well as heritage and culture protection to promote self-reliance. On the other hand, the food security theme emphasizes the four pillars of food security (access, availability, utilization, and stability) and the sustainability thereof. *Access* does not solely refer to access to food but, also access to markets, assets, labor, guarantees and institutions, while *availability* considers the land, production, and market investments available to the investors and the community. When considering the *utilization* of food, the knowledge of nutrition, food preparation, food safety and storage processes are essential to effectively address food security challenges by ensuring that available food is nutritionally sufficient. The final pillar, *stability*, requires the investor to look at diversifying crops and labor, risk management, security and safety as well as promoting peaceful relations among governance and communities. All these factors need to be considered with sustainability in mind, to ensure social and economic challenges are addressed for the future by supporting the environment.

6 Conclusion

Although the international community have committed to the agenda set out by the SDGs to end hunger, food insecurity remains a major challenge. With the human-centered nature of Society 5.0 and the objective to achieve sustainable food security, effective targeted investments in agriculture are required. Indoor farming is an agricultural technology capable of producing more food using fewer resources in comparison to traditional farming methods. The purpose of this paper is to present a conceptual framework that will provide decision support towards improving food security. This proposed IFF contains four main constructs derived from a two-step process of SLR and thematic analysis. These constructs include the basic elements from the TOE framework with an extended primary construct that considers the social context of investing in indoor farming for addressing food insecurity. The primary constructs include technology, environment, organization, and social context with underlying key considerations. By applying the IFF, investors will be able to consider a broad range of holistic elements associated with indoor farming investment to mitigate the risk of incurring unplanned expenditure, legal restraints, operational and technological restrictions, as well as social and cultural problems. Furthermore, investors using the IFF as a decision support tool will be required to consider far reaching impacts prior to investing capital to ensure a successful operational indoor farm capable of supporting food security goals.

This extended framework serves as a conceptual model that can be validated through further research to align the framework model with real-world scenarios.

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