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Perceived Effectiveness of Hydroponic Farming Practices in Bulacan: Basis for a Business Model Canvas

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Abstract

This study examined the perceived effectiveness of hydroponic farming practices among hydroponic farmers in Bulacan, Philippines, and developed a Business Model Canvas (BMC) to support the sustainability and growth of hydroponic enterprises. A mixed-methods convergent parallel research design was employed, combining quantitative and qualitative data collected from twenty (20) purposively selected hydroponic farmers across selected municipalities in Bulacan. A validated semi-structured questionnaire was used to assess perceptions of effectiveness in five business dimensions: management and administration, marketing, operations, financial management, and supply chain coordination. Descriptive statistics were used to analyze the quantitative data, while thematic analysis was applied to interview responses to identify key challenges and opportunities.

The findings revealed that respondents generally perceived hydroponic farming practices to be highly effective across all business dimensions, with operations and marketing receiving the highest ratings. Qualitative results showed that farmers faced significant challenges, including high initial investment costs, limited access to affordable inputs and technical support, market uncertainty, and vulnerability to extreme weather conditions. Despite these constraints, respondents identified strong opportunities for income generation, agricultural innovation, environmental sustainability, and the production of high-quality, pesticide-free vegetables.

Based on the integrated findings, a context-specific Business Model Canvas was developed to strengthen value creation, market access, financial sustainability, and strategic partnerships within the hydroponic farming sector in Bulacan. The study suggests that institutional support, capacity-building programs, improved financing mechanisms, and stronger market linkages are essential to enhance the long-term viability of hydroponic farming enterprises in the province.

Keywords: *hydroponic farming; perceived effectiveness; Business Model Canvas; sustainable agriculture; agripreneurship; Bulacan, Philippines*

Introduction

A country's ability to produce food and other essential resources independently was crucial to its economic growth and stability (Tagle et al., 2018). The agricultural industry played a central role in achieving this, but traditional farming faced significant challenges due to climate change and environmental degradation. Hydroponics, a soil-less farming method that uses nutrient-rich water solutions, presented a sustainable alternative to conventional agricultural practices (Santos & Ocampo, 2021). Hydroponics has a long history, with evidence of its use in ancient civilizations such as Babylon and the Aztec Empire (Reade, 2000; Onofre, 2005). In the modern era, hydroponics offered a solution to traditional farming challenges, such as climate unpredictability, land degradation, and water scarcity. By employing efficient technologies, hydroponics enabled high-yield, resource-efficient agricultural production, making it a viable solution to global food security issues. The need for sustainable agricultural practices has become more urgent as the world faces food system disruptions and declining food security (Goh et al., 2023).

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Hydroponics supported the United Nations Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production), by promoting efficient resource use and increasing food availability (Liu et al., 2024). The hydroponics sector demonstrated substantial market potential, attracting farmers and investors by enabling the production of high-quality, pesticide-free produce (Badrinath et al., 2022). The growth of hydroponic farming aligned with efforts to combat Hunger and improve crop quality (Badrinath et al., 2022; Li & Kee, 2020). Southeast Asia experienced rapid urbanization and population growth, which increased food demand and exacerbated traditional farming challenges (Chong et al., 2021). Vertical hydroponic farming offered a sustainable solution by maximizing space and resources while minimizing environmental impact (Al-Kodmany, 2018). ASEAN governments were encouraged to promote hydroponics to ensure agricultural competitiveness and sustainability (Li & Kee, 2020). As of September 30, 2024, Bulacan had 18 registered hydroponic farmers, with many more operating informally. The COVID-19 pandemic spurred interest in hydroponics as farmers sought additional income, although sustainability challenges remained. In response, TESDA Bulacan, in partnership with the Technical Schools Association, introduced hydroponics training programs, and the Department of Agriculture provided farming demonstrations. A well-defined business strategy was critical to the long-term profitability of hydroponic farming. By utilizing structured business models, farmers could enhance profitability, operational efficiency, financial planning, and supply chain resilience. Moreover, government policies and commercial investments had to support these models to ensure sustainability (Velazquez-González et al., 2022). Hydroponics solved global agricultural challenges, including shrinking arable land and the need for sustainable farming. In Bulacan, with its proximity to Metro Manila and favorable conditions, hydroponics could enhance food security and serve as a model for sustainable farming in the Philippines.

Review of Relevant Theory, Studies, and Literature

Ruttan's (1984) Induced Innovation Theory shows that technology, institutions, and incentives drive agricultural adoption. In Bulacan, urbanization, climate change, and demand for fresh produce are boosting hydroponics as a tech-driven, efficient method.

The Business Ecosystem Theory emphasizes collaboration with stakeholders to create sustainable, adaptable hydroponic business models (Moore, 1993; Basole et al., 2015).

Soil-less culture, inspired by da Vinci's plant nutrition studies, highlights the importance of precise nutrient management for successful hydroponics (Yaalon & Arnold, 2000).

Socio-Economic of Hydroponic Farmers

Hydroponics is popular among young and middle-aged farmers in Bulacan, supported by DOST and DA programs (Stringer et al., 2019; Department of Agriculture, 2020; Tecson, 2023). Education and experience influence management, scale, and efficiency (Stefanakis, 2020; Payne, 2021). Most rely on personal savings or small loans, while high costs and technical demands remain barriers. Hydroponics diversifies income, supplying niche markets and meeting demand for fresh, pesticide-free produce (Chou, 2020; Perez, 2021).

Effectiveness of Hydroponic Farming

Management and Administration. Effective hydroponic farming requires resource optimization, administration, nutrient control, and regulatory support (Smith & Johnson, 2019; Garcia et al., 2020; Jones & Smith, 2018; Tanaka & Yamamoto, 2021). Proper workforce management, including training and performance monitoring, is essential for sustainability and success in Bulacan.

Marketing. Prices were based on yield, supply and demand, price fluctuations, and lettuce weight (Shao et al., 2022). Hydroponic produce can be sold daily to hotels and restaurants or to traditional markets, which accept

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larger quantities at lower prices. Thus, hydroponic products can be marketed to traditional markets with adjusted pricing for lower-quality classes (Prayoga & Putra, 2020).

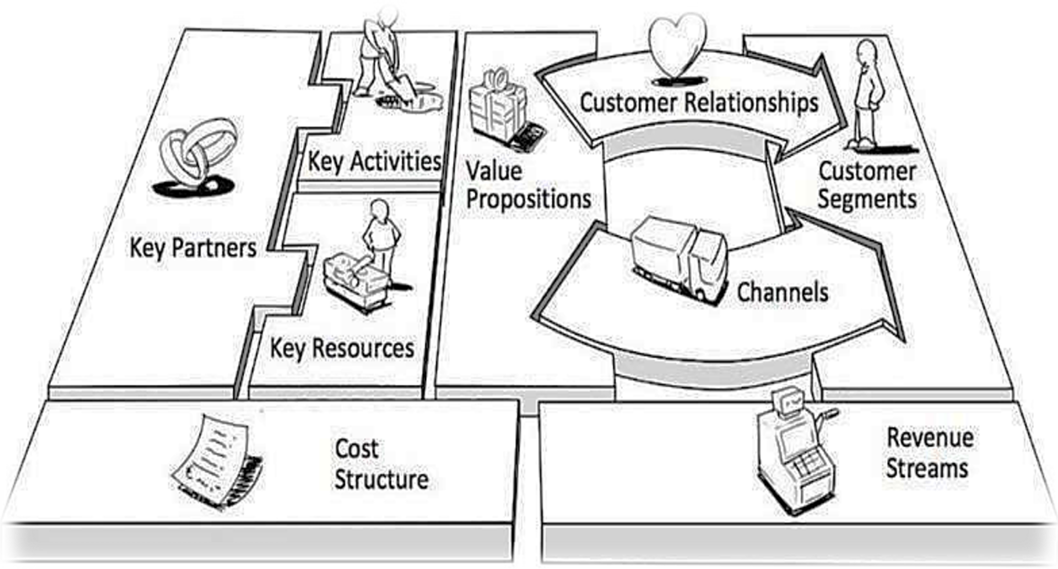
Operations. Hydroponics, from the Greek *hydro* (water) and *ponos* (work), is soil-less farming proven commercially viable by Gericke in the 1930s, with advances including NASA research (Singer, 2021). Systems include DWC, Kratky, NFT, drip, ebb-and-flow, aeroponics, and aquaponics (Nursyahid et al., 2021; Taha et al., 2022).Used on small and commercial farms, hydroponics offers higher yields, greater water efficiency, reduced pesticide use, and lower environmental impact (Love et al., 2015; Ross, 2016), but it faces high startup costs, technical demands, and reliance on water and electricity (Resh, 2022).

Financial. Hydroponic farming in the Philippines includes over 150 farms and 1,000 farmers (Jagdish, 2023). Startup costs range from ₱10,000 to ₱200,000, with feasibility depending on yield, costs, environment, and market (Velasquez-Gonzales et al., 2022). Efficient inputs, technology, and market access can improve income and support sustainable farming (Mishra et al., 2018).

Supply chain management. Effective supply chain management is vital in hydroponics. Optimizing logistics, using technologies like blockchain, ensuring quality control, and adopting sustainable practices enhance performance, transparency, and long-term viability (Smith & Lee, 2019; Nguyen et al., 2020; Gonzalez & Perez, 2018; Chen & Wang, 2021).

The figure below illustrates the Business Model Canvas developed by Osterwalder and Pigneur (2010), a strategic framework for visualizing the key components of a business model.

Figure 1
Business Model Canvas



The Business Model Canvas (BMC) aligns production, marketing, and finances in hydroponic farming (Osterwalder, 2010; Maleki, 2022). Success depends on investment, technical skills, risk management, and funding (Velazquez-Gonzalez et al., 2022; Lavinsky, 2023). Adoption is influenced by age, education, experience, gender, market access, and financial support (Gumisiriza et al., 2022; Mamun et al., 2023; Peñalba, 2019). Hydroponics boosts yield reduces labor and soil degradation, and supports sustainability, but faces high costs and technical demands (Badrinath et al., 2022; Alipio et al., 2022; Velasco et al., 2023). This study develops a context-specific, sustainable business model for hydroponic farms in Bulacan.

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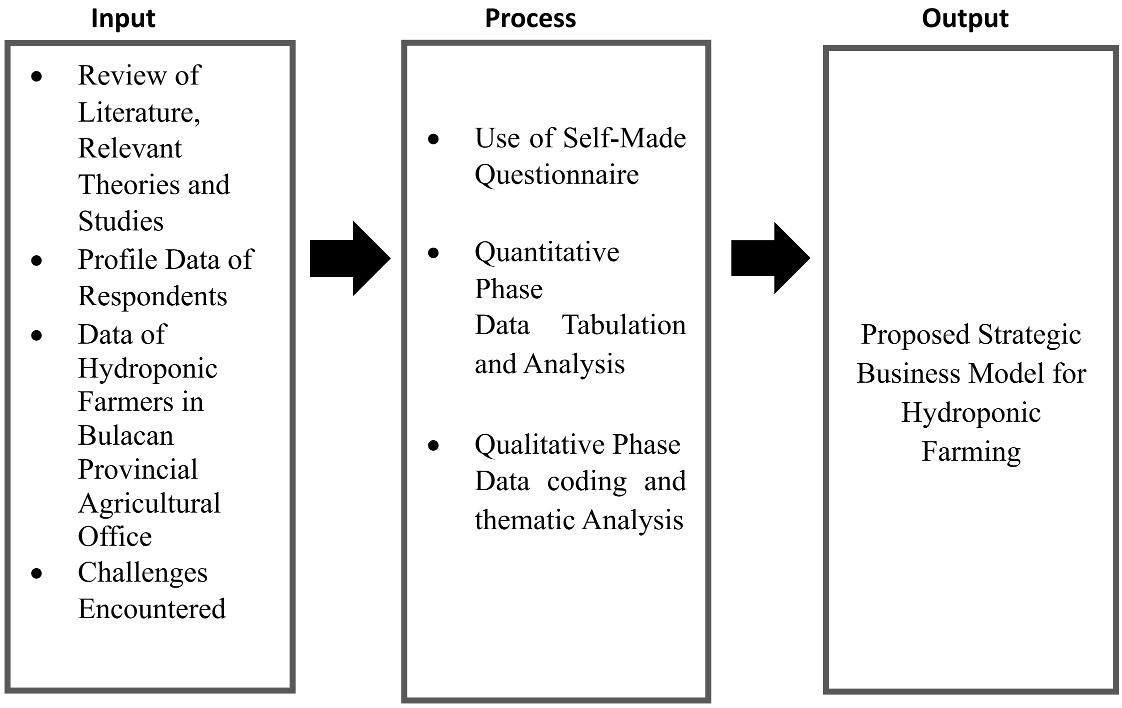
Figure 2

The Paradigm of the Study

Conceptual Framework



This study uses the Input-Process-Output (IPO) model to structure the assessment of hydroponic farming in Bulacan. The Input includes profile data from hydroponic farmers, challenges encountered, and a review of related literature and theories such as the Agricultural Innovation Theory (Ruttan, 1984) and Business Ecosystem Theory (Basole et al., 2015). The Process comprises survey distribution, interview validation, quantitative data analysis, and qualitative thematic coding (Creswell, 2014; Saldaña, J. 2021). The Output is a proposed strategic business model based on the Business Model Canvas (Osterwalder & Pigneur, 2010), intended to support the growth and sustainability of hydroponic farming in the region (Fischer et al., 2019; Maleki, 2022).

Methods of the Study

The study utilized a mixed-methods research approach, combining qualitative and quantitative procedures in a convergent parallel design to analyze the collected data separately and identify and address the study's problems. In a convergent parallel design, a researcher collected quantitative and qualitative data concurrently, analyzed them separately, and compared the results to draw overall conclusions (Creswell, 2014). In Phase I of the study, the researcher collected numerical data and utilized the descriptive survey method. This method was used to describe the socio-economic characteristics and to quantify data on how farmers agreed they effectively handled hydroponic farming operations (Parveen & Showkat, 2015). In Phase II, a qualitative method was used to provide a detailed descriptive account of the challenges and opportunities faced by hydroponic farmers.

This research design was selected to ensure a comprehensive understanding of both the quantitative and qualitative aspects of hydroponic farming.

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Table 1

Participants of the Study

	Participant	*f*	%
1.	Hydroponic Farmers from Bulacan Provincial Office	5	25
2.	Hydroponic Farmer from Bulacan Hydroponic Supply	9	45
3.	Hydroponic farmers from online community	6	30
	Total	20	100%

Through purposeful sampling, this research selected 20 participants from various sources, ensuring a representative sample of the hydroponic farming community in Bulacan. Participants ranged in age from 18 to 60, with varying levels of education, from high school graduates to advanced degree holders. Participants were drawn from 9 farmers affiliated with Bulacan Hydroponic Supply, five identified by the Bulacan Provincial Agriculture Office, and others from the online community for local hydroponic farmers. Purposeful sampling, as described by Creswell (2014), allowed for the inclusion of individuals who could provide valuable insights into specific areas of interest, such as hydroponic farming. By leveraging multiple channels, the study gathered diverse perspectives from individuals with varying levels of experience and operating scales, enriching the data and providing a comprehensive understanding of the current state and challenges of hydroponic farming in Bulacan.

To ensure the study accurately reflected the hydroponic farming community in Bulacan, specific inclusion criteria were established. Participants were required to be active hydroponic farmers residing in Bulacan, at least 18 years old, and willing to sign the provided informed consent prior to participating in the survey and interview. Those who did not meet these criteria or were unable to commit to the study were excluded. Additionally, withdrawal criteria permitted participants to exit the study at any time, whether by personal choice or for reasons related to their safety or the study's integrity. Clear communication channels were set up to facilitate a smooth and respectful withdrawal process.

To assess the quantitative and qualitative aspects of the research, a semi-structured survey questionnaire was administered to gather data from the respondents. This survey was carefully designed to capture relevant information pertaining to the objectives of this study. To enhance the credibility of the survey instrument, it underwent rigorous validation. Practitioners proficient in business administration and hydroponic farming evaluated the questionnaire for its veracity and reliability.

The researcher initially visited the Provincial Agriculture Office and the TESDA offices in Bulacan to obtain a list of hydroponic farmers. The Provincial Agriculture Office identified eighteen (18) hydroponic farmers, but only five (5) participated in the study, while TESDA had no available participants. The researcher also visited Bulacan Hydroponic Supply in Baliuag, Bulacan, to seek assistance in identifying additional respondents. This effort was successful, resulting in nine (9) participants. To complete the participant set, the researcher identified potential respondents from relevant online community groups. Out of twenty-two (22) individuals approached, six (6) agreed to participate.

Survey questionnaires were distributed to participants electronically via Google Forms or in hard copy, depending on their preference, to facilitate data collection. The researcher sought permission to use various communication channels, such as formal email, mobile phone, or Facebook Messenger, and scheduled interactions based on participants' availability to avoid disrupting their work or operations.

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The quantitative and qualitative data gathered were organized, analyzed, and processed in Microsoft Excel. The questionnaire was self-made, validated by the experts, and systematically formulated by the researcher based on the study's problems.

Data processing involved translating the questionnaire responses to produce statistical results. This includes encoding, data entry, editing, checking, and monitoring of the overall data processing procedures and protocols. To support the survey data, the researcher applied the Likert scale to interpret and analyze the study. The Likert scale is a four-point scale that allows individuals to describe the effectiveness of a particular topic or statement. For the quantitative analysis, mean, descriptive equivalent, and standard deviation were used to describe the effectiveness of hydroponic farming in Bulacan.

The table below shows that the Likert scale was used to describe the effectiveness of hydroponic farming in Bulacan.

Scale	Range	Verbal Interpretation
4	3.60-4.00	Highly Effective
3	2.60-3.59	Effective
2	1.60-2.59	Less Effective
1	1.0 -.1.59	Ineffective

The study used data coding analysis techniques to discern recurrent themes, patterns, and insights as defined by Saldaña, J. (2021), pertaining to the challenges and opportunities associated with hydroponic farming. These findings will also serve as the foundation for developing a business model for hydroponic farming in Bulacan.

Results and Discussion

I. Socio-Economic Characteristics of Hydroponic Farming in Bulacan

Table 2 presents the socio-economic characteristics of hydroponic farmers categorized by age groups.

Table 2

Frequencies of Age

Age	n	%
18 to 25	1	5%
26 to 35	4	20%
36 to 50	9	45%
51 to 60	6	30%

The table displayed the frequencies and percentages of farmers falling within each age bracket. The age groups ranged from 18 to 60 years, with corresponding counts and percentages indicating the distribution of farmers across these age categories. For instance, the age group of 18 to 25 counted one and 5%, which was the lowest percentage among the group, while the age group from 26 to 35 years old comprised four farmers, accounting for 20% of the total sample, while the age group of 36 to 50 years old included nine farmers, representing the highest percentage at 45%. Moreover, the age bracket 51-60 accounted for 30% of the total age group. Overall, the table offered a snapshot of the age demographics among hydroponic farmers, highlighting the prevalence of middle-aged individuals within this sector. Gumisiriza et al. (2022) found that most hydroponic farmers in Tanzania and Uganda were between the ages of 26 and 35, indicating that hydroponics was more popular among young people there. Similarly, in Sweden, most likely due to greater access to technology and computer literacy (Maleki, 2022).

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On the other hand, Mamun et al. (2023) found that the average age in urban China was between 31 and 40 years. Hence, Bulacan farmers were slightly older; age might affect risk-taking and innovation, suggesting the need for youth-targeted programs.

Table 3 presents the socio-economic characteristics of hydroponic farmers categorized by sex.

Table 3

Frequencies of Sex

Sex	N	%
Male	16	80%
Female	4	20%

The table displayed the frequencies and percentages of farmers identified as either female or male in the total sample. 20% were female farmers, accounting for four individuals, while 80% were male farmers. This table provides a concise overview of the gender demographics in the hydroponic farming sector, revealing a predominance of male farmers over female farmers. This reflected a traditional male dominance in farming, consistent with Alipio et al. (2022), who observed similar trends in Tagaytay. Nevertheless, it contrasted with the findings in China (Mamun et al., 2023), where programs specifically encouraged gender-inclusive participation, resulting in more balanced representation. Tecson (2023) cited the increasing involvement of female farmers in Bulacan through DOST and DA programs as hinting at a gradual shift toward inclusivity.

Table 4 presents the socio-economic characteristics of hydroponic farmers, categorized by educational attainment.

Table 4

Frequencies of Educational Attainment

Educational Attainment	N	%
Postgraduate (Master’s, PhD)	2	10%
Master’s Degree/on-going	7	35%
College/University (bachelor’s degree)	8	40%
Vocational	2	10%
Highschool Graduate	1	5%

The table provided frequencies and percentages of farmers across various educational categories. It illustrated the educational attainment of hydroponic farmers in Bulacan. The data revealed a predominantly well-educated group of respondents, with 85% of farmers having completed at least a college degree. Specifically, 40% (8 individuals) were bachelor’s degree holders, while 35% (7) were pursuing or had completed a master’s degree. Additionally, 10% (2 individuals) had attained postgraduate qualifications such as a master’s or PhD. A further 10% had completed vocational or technical education, while only 5% (1 individual) reported high school as their highest educational level. These findings aligned with global studies cited in Gumisiriza (2022), with 64.7% having university education, highlighting education as a key enabler in adopting advanced farming technologies. The high

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educational profile of respondents supported the hypothesis that hydroponic farming in Bulacan was attracting technically competent and academically prepared individuals.

Table 5 presents the socio-economic characteristics of hydroponic farmers in terms of their years of experience practicing hydroponics.

Table 5

Frequencies of Experience

Years of Experience	n	%
3 to 4yrs	16	80%
5 to 6yrs	2	10%
7 to 8yrs	1	5%
9 to 10yrs	1	5%

The table revealed that the majority had relatively moderate experience in this agricultural method. Among the respondents, 80% (16 individuals) had been practicing hydroponics for 3 to 4 years, making this the largest and most significant group. A smaller proportion, 10% (2 individuals), had 5-6 years of experience. Additionally, 5% (1 individual) had been engaged in hydroponics for 7 to 8 years, while another 5% (1 individual) had 9 to 10 years of experience. This data indicated that most hydroponic farmers were relatively new to the practice, with a smaller segment of more experienced practitioners. This showed that 80% of farmers had only 3–4 years of experience, which mirrored trends in emerging markets. Like Bulacan, the Tagaytay case (Alipio et al., 2022) showed that hydroponic ventures under five years old could be profitable. However, a contrast was found in West Africa, as cited by Peñalba (2019), where hydroponics had been refined over decades, enabling greater institutional expertise and automation. The findings highlighted a growing interest in hydroponics, with most farmers still adopting this innovative technique in their early years.

Table 6 illustrates the socio-economic characteristics of hydroponic farmers categorized by their sources of capital for initiating hydroponic farming ventures.

Table 6

Frequencies of Source of Capital

Source of Capital	n	%
Savings	18	90%
Loan	1	5%
Private investors	1	5%

The table presented the frequencies and percentages of farmers by the source of their funding, including savings, loans, personal loans, and private investors. For instance, 18 farmers, representing 90% of the total sample, relied on their savings to finance their hydroponic farming endeavors. Furthermore, one respondent (5%) received investment from private investors, and another (5%) secured a loan for capital. This table provides insights into the

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financial resources used by hydroponic farmers to finance their agricultural operations, ranging from personal savings to loans and investments. This aligned with Kibiti and Gitonga (2017), who noted that limited access to credit hindered the scaling of hydroponic farming in Latin American and African contexts.

In contrast, Alipio et al. (2022) demonstrated that support from programs such as OWWA's Balik Pinas Balik Hanapbuhay could help bridge funding gaps for returning OFWs starting hydroponic farms. Furthermore, Maleki (2022) highlighted that access to government and investor financing significantly improved the viability of farming operations. This contrast demonstrated how, when available in Bulacan, government-backed financial programs could favor financing trends.

Table 7 outlines the socio-economic characteristics of hydroponic farmers, categorized by their other sources of income in addition to hydroponic farming.

Table 7

Frequencies of Source of Income

Source of Income	N	%
Both	9	45%
Farm Income	8	40%
Employment	3	15%

The table provided frequencies and percentages of farmers based on whether they derived income from hydroponic farming and other sources, solely from farm income, or employment. For example, nine farmers, representing 45% of the total sample, generated income from both hydroponic farming and other sources, while eight farmers (40%) solely relied on farm income. Additionally, three farmers (15%) derived income from employment outside of hydroponic farming. This table offered insights into the diverse income streams and livelihood strategies adopted by hydroponic farmers to support their financial stability and agricultural enterprises. This corresponded with Perez (2021) and Gumisiriza et al. (2019), who observed that several farmers globally employed hydroponics to diversify and stabilize their income. In Bulacan, this indicated optimism among farmers, who were inclined to experiment while maintaining alternative resources. On the other hand, the study by Alipio et al. (2022) revealed that hydroponic farming might have provided stable, full-time employment in Tagaytay, which was entirely reliant on hydroponic farming, indicating greater confidence and potentially more reliable market access in their environment.

The socio-economic characteristics of Bulacan's hydroponic farmers, as illustrated in Tables 2 to 7, underscore their substantial relevance to advancing the Business Model. Consistent with global trends, the farmers were educated, relatively inexperienced in hydroponics, and motivated by the necessity to innovate due to constrained arable land. Their attributes affirmed the significance of institutional support, access to training, and financial availability in promoting sustainable hydroponic agriculture. The structural barriers that had to be addressed to expand inclusion and sustainability were evident in the heavy reliance on personal capital and the male-dominated practice.

These results substantiate the need to develop a strategic business model informed by global best practices and local context to ensure the long-term success of hydroponics in Bulacan.

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Table 8

Summary of Socio-Economic Characteristics of Hydroponic Farmers in Bulacan: A Comparative Analysis with Existing Literature

Socio-Economic characteristics	Bulacan	Similar Findings	Dissimilar Findings	Analysis / Implication
Age	Majority aged 36–50 years old (45%)	China: Majority aged 31–40 (Mamun et al., 2023) (almost)	Uganda & Tanzania: Majority aged 26–35 (Gumisiriza et al., 2022)	Bulacan farmers are slightly older; age may affect risk-taking and innovation; suggest youth-targeted programs.
Sex	80% Male, 20% Female	Tagaytay (Alipio et al., 2022): Predominantly male	China: 54.9% Female adopters (Mamun et al., 2023)	Gender imbalance in Bulacan may limit diversity; gender empowerment initiatives needed.
Educational Attainment	85% college graduates	Tanzania: 64.7% with university education (Gumisiriza et al., 2022)	Rural Africa: Lower educational levels (Peñalba, 2019)	High educational level supports effective adoption; training programs could boost less-educated sectors.
Years of Experience	80% have 3–4 years of experience	Tagaytay: Mostly new adopters (Alipio et al., 2022)	West Africa: Longer traditional farming experience (Peñalba, 2019)	Bulacan is in the early adoption phase; peer-to-peer learning and extension services are essential.
Source of Capital	90% personal savings/family funding	Kenya: 52% use self-funded (Kibiti & Gitonga, 2017)	Sweden: Access to investor and government capital (Maleki, 2022) OFW Balik Pinoy (Alipio et al., 2022)	Limited financing access in Bulacan slows scalability; government or NGO-led financing programs are needed.
Other Sources of Income	45% use hydroponics as a side income	Urban PH and Tanzania: Used as supplemental livelihood (Perez, 2021; Gumisiriza et al., 2022)	full-time income from the start (Alipio et al., 2022)	Reflects flexibility of hydroponics; potential for scale-up to full-time with proper support systems.

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Bulacan shares key traits with early adopting regions like Tagaytay, Tanzania, and China, particularly in education and farming experience. However, gaps in youth and gender participation and access to capital reveal areas for improvement. While its strong educational base supports growth, addressing financial and inclusive challenges is essential to fully scale hydroponic farming in the province.

The results and discussion section of a study presents and interprets the findings in relation to the research questions and hypotheses. It begins by clearly reporting the key results, often using tables, graphs, and charts to illustrate data trends and patterns. Statistical analyses are summarized to highlight significant findings, and any unexpected results are also noted. In the discussion part, these findings are contextualized within the existing literature, examining how they align with or challenge previous research. The implications of the results are explored, considering their significance in the field and potential practical applications. Furthermore, the discussion addresses the study's limitations and suggests areas for future research. By linking results to broader themes and ongoing debates in the discipline, this section enriches the understanding of the study's contributions and relevance, providing a comprehensive analysis that connects empirical evidence with theoretical frameworks.

II. Effectiveness of Hydroponic Farming in Bulacan

The assessment of the effectiveness of hydroponic farming in Bulacan highlighted the respondents' recognition of its potential as a sustainable, resource-efficient, high-yield agricultural method. In line with Agricultural Innovation Theory (Ruttan, 1984), adopting hydroponic systems was viewed as a strategic approach to address the significant challenges posed by land scarcity, urban growth, and the rising demand for pesticide-free produce. Respondents noted that hydroponic farming offered considerable benefits, including improved resource use, increased crop yields, and reduced environmental impacts, as Garcia et al. (2020) and Singer (2021) pointed out. However, a significant initial investment was required for system setup, and operational challenges were also noted, including the need for specialized technical expertise and the critical reliance on a stable supply of water and electricity (Perez, 2008). Additionally, marketing emerged as an essential factor affecting effectiveness, highlighting the need for focused strategies that cater to health-conscious and premium consumers, aligning with the findings of Prayoga and Putra (2020). Based on the Business Ecosystem Theory (Basole et al., 2015), these observations emphasized the importance of developing integrated business strategies that foster cooperation among suppliers, distributors, and consumers to fully harness the economic and environmental benefits of hydroponic farming in Bulacan.

Table 9 presents a comprehensive evaluation of how respondents perceived the effectiveness of management/administration in hydroponic farming across Bulacan, along with the interpretation of these perceptions.

Table 9

Descriptive Measure of the Hydroponic Farming in Bulacan in Terms of Management/Administration

Management/Administration	Mean	SD	Descriptive Interpretation
1. They oversee the allocation of resources and funding for hydroponic farming research initiatives, ensuring adequate support for data collection, experimentation, and analysis	3.75	0.4443	Highly Effective
2. Administration facilitates collaboration among interdisciplinary teams of researchers, agronomists, and agricultural	3.80	0.4104	Highly Effective

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engineers to address various aspects of hydroponic farming, from crop cultivation techniques to system optimization.			
3. Management coordinates outreach efforts to engage stakeholders such as farmers and industry partners in discussion about the potential benefits and challenges of adopting hydroponic farming practices.	3.65	0.4894	Highly Effective
4. Administration establishes protocols and guidelines for data management, ensuring the accuracy integrity, and confidentiality of research findings related to hydroponic farming.	3.80	0.4104	Highly Effective
5. Management evaluates the impact of hydroponic farming research on organizational goals and objectives, seeking opportunities to translate research findings into practical applications and innovations that benefit the agricultural community.	4.00	0.0000	Highly Effective
Average	**3.80**	**0.1451**	**Highly Effective**

SD - Standard Deviation

The table included five statements related to management functions: overseeing resource allocation, facilitating collaboration, coordinating outreach efforts, establishing data management protocols, and evaluating research impact. Each statement was rated on a scale from 1 to 4, with 1 indicating highly effective and four indicating ineffective. The mean score and standard deviation for each statement were provided, along with the interpretation of the mean score. In this case, the average mean score across all statements was 3.80, with a standard deviation of 0.1451. The interpretation reflected that effective management/administration was perceived as playing an important role in the sustainability of hydroponic farming in Bulacan.

The results were consistent with the study by Armas et al. (2023), which highlighted that farm management and effective practices were crucial to the success of hydroponic farming in Bulacan.

Table 10 outlined the perceptions of marketing strategies and practices in hydroponic farming in Bulacan, along with their interpretations.

Table 10

Descriptive Measure of the Hydroponic Farming in Bulacan in Terms of Marketing

Marketing	Mean	SD	Descriptive Interpretation
1. Marketing strategy for promoting and selling hydroponic farming products emphasizes the unique advantages of soil ness cultivation, including increased crop yields, water efficiency, and year-round production capabilities.	4.00	0.0000	Highly Effective
2. Through targeted advertising campaigns across digital platforms and industry publications, we showcase the superior quality and reliability of our hydroponic farming products, capturing the attention	3.85	0.3663	Highly Effective

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of farmers, horticulturists, and commercial growers.			
3. We leverage strategic partnerships with agricultural cooperatives, distributors, and retailers to expand our market presence and ensure the widespread availability of our hydroponic farming solutions to customers worldwide.	4.00	0.0000	Highly Effective
4. Our sales team employs consultative selling approaches, offering personalized recommendations and comprehensive support services to assist customers in selecting the most suitable hydroponic systems, equipment, and nutrient solutions for their specific needs and requirements.	3.90	0.3078	Highly Effective
5. By investing in product innovation research and development, we continuously enhance the performance, efficiency, and sustainability of our hydroponic farming products, maintaining a competitive edge in the market and driving long-term growth and profitability.	3.95	0.2236	Highly Effective
Average	**3.94**	**0.1142**	**Highly Effective**

SD - Standard Deviation

The table included five statements related to marketing activities, such as promoting the advantages of soilless cultivation, leveraging digital advertising campaigns, establishing strategic partnerships, employing consultative selling approaches, and investing in product innovation. Each statement was rated on a scale from 1 to 4, with 1 indicating ineffective and four indicating highly effective. The mean score for each statement was provided, along with the interpretation of the mean score. In this case, the mean score across all statements was 3.94, with a standard deviation of 0.1142, indicating unanimous agreement among stakeholders on the effectiveness of marketing strategies and practices in promoting hydroponic farming products in Bulacan.

A significant study by Reyes et al. (2020) examined marketing strategies and consumer behavior in hydroponic farming operations in Bulacan. The research concentrated on important areas such as product promotion, digital marketing, partnership building, sales strategies, and product development. By using surveys and interviews with farm managers, marketers, and consumers, Reyes et al. evaluated the effectiveness of these strategies in shaping consumer preferences and purchasing choices. Their results validated the findings presented in Table 9, highlighting the importance of strategic marketing in improving market reach, engaging customers, and fostering sustainable growth within the hydroponic farming industry.

Table 11 presents the perceptions of operational aspects of hydroponic farming in Bulacan, along with their interpretations.

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Table 11

Descriptive Measure of the Hydroponic Farming in Bulacan in Terms of Operations

Operations	Mean	SD	Descriptive Interpretation
1. Operations in hydroponic farming involve the daily management and maintenance of hydroponic systems, including nutrient solution management, PH monitoring, and water quality control to ensure optimal growing conditions for plants.	4.00	0.0000	Highly Effective
2. Efficient scheduling and execution of planting, harvesting, and crop maintenance tasks are essential components of operations in hydroponic farming, requiring careful coordination and attention to detail to maximize crop yields and minimize wastage.	4.00	0.0000	Highly Effective
3. Implementing integrated pest management (IPM) strategies and disease prevention measures are critical aspects of operations in hydroponic farming helping to safeguard plant health and mitigate the risk of pest infestations or disease outbreaks.	3.95	0.2236	Highly Effective
4. Monitoring environmental factors such as temperature, humidity, and light intensity is integral to operations in hydroponic farming, as these variables directly impact plant growth and development.	3.95	0.2236	Highly Effective
5. Continuous training, education, and skills development for farm workers and staff are essential for effective operations in hydroponic farming, ensuring proficiency in hydroponic techniques, equipment maintenance, and safety protocols to uphold productivity and quality standard.	4.00	0.0000	Highly Effective
Average	**3.96**	**0.1392**	**Highly Effective**

SD - Standard Deviation

The table included five statements related to operations, such as daily management and maintenance of hydroponic systems, efficient task scheduling, implementation of pest management strategies, monitoring environmental factors, and continuous training for farm workers. Each statement was rated on a scale from 1 to 4, with 1 indicating ineffective and four highly effective. The mean score for each statement was provided, along with the interpretation of the mean score. In this case, the mean score across all statements was 3.96, with a standard deviation of 0.1392, indicating that the stakeholders strongly believed in the importance of effective operational practices in hydroponic farming in Bulacan.

A relevant study by Velasco et al. (2023) examined operational practices and performance evaluation in hydroponic farming enterprises in Bulacan. The research focused on task scheduling, system and pest management, and environmental monitoring; the researchers gathered data through field observations, interviews, and surveys with

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farm managers and employees. Their results reinforced the findings in Table 11, highlighting the critical role of operational excellence in improving productivity and sustainability in hydroponic farming.

Table 12 provides insights into perceptions of the financial aspects of hydroponic farming in Bulacan, along with their interpretations.

Table 12

Descriptive Measure Hydroponic Farming in Bulacan in Terms of Financial

Financial	Mean	SD	Descriptive Interpretation
1. Financial management in hydroponic farming involves careful budgeting and cost analysis to ensure efficient allocation of resources, including equipment, nutrients, utilities, and labor, while maximizing profitability.	4	0.0000	Highly Effective
2. Monitoring and analyzing financial performance indicators such as revenue, expenses, profit margins and return on investment (ROI) are essential for evaluating the economic viability and sustainability of hydroponic farming operations.	4.00	0.0000	Highly Effective
3. Strategic financial planning, including investment decisions, pricing strategies, and risk management, plays an important role in optimizing financial outcomes and long-term success in hydroponic farming.	3.90	0.3078	Highly Effective
Average	**3.95**	**0.1302**	**Highly Effective**

SD - Standard Deviation

The table included three statements related to financial management practices, such as budgeting, cost analysis, financial performance monitoring, strategic financial planning, and risk management. Each statement was rated on a scale from 1 to 4, with 1 indicating ineffective and four indicating highly effective. The mean score for each statement was provided, along with the interpretation of the mean score. In this case, the mean score across all statements was 3.95, with a standard deviation of 0.1302, indicating unanimous perceptions that financial management best practices were important for the effectiveness of hydroponic farming in Bulacan.

A relevant study by Santos and Reyes (2020) examined financial management practices in hydroponic farming ventures in Bulacan, focusing on budgeting, cost analysis, performance monitoring, strategic planning, and risk management. The study assessed how these practices influenced profitability, efficiency, and sustainability by using surveys and interviews with farm managers and financial professionals. The findings supported the themes in Table 11, underscoring the vital role of sound financial management in ensuring the economic viability and long-term success of hydroponic farming.

Table 13 provided insights into the perceptions of the supply chain aspects of hydroponic farming in Bulacan, along with their means and standard deviations and interpretations.

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Table 13

Descriptive Measure Hydroponic Farming in Bulacan in Terms of Supply Chain

Supply Chain	Mean	SD	Descriptive Interpretation
1. Hydroponic farming encompasses the sourcing and procurement of inputs such as seeds, growing mediums, nutrients, and equipment required for hydroponic cultivation.	3.90	0.3078	Highly Effective
2. Efficient logistics and distribution channels are essential components of the supply chain in hydroponic farming, ensuring timely delivery of inputs and harvested produce to from hydroponic facilities, markets, and end consumers.	3.85	0.3663	Highly Effective
3. Supply chain management in hydroponic farming involves optimizing inventory levels, minimizing waste, and maximizing shelf life to ensure the availability of fresh, high-quality produce while minimizing costs and environmental impact throughout the supply chain.	3.90	0.3078	Highly Effective
Average	**3.84**	**0.2333**	**Highly Effective**

SD - Standard Deviation

The table included three statements related to the supply chain: sourcing and procurement of inputs, logistics and distribution channels, and supply chain management practices. Each statement was rated on a scale from 1 to 4, with 1 indicating ineffective and four indicating highly effective. In this case, the mean score across all statements was 3.84, with a standard deviation of 0.2333, indicating that stakeholders believed supply chain best practices were essential to the effectiveness of hydroponic farming in Bulacan.

A pertinent study by Nguyen et al. (2020) scrutinized supply chain management practices in hydroponic farming ventures in Bulacan, focusing on procurement, logistics, inventory management, waste reduction, and quality control. The study evaluated how these practices affected productivity and sustainability using interviews and surveys with farm managers and supply chain professionals. The findings aligned with the themes in Table 13, emphasizing the importance of an efficient supply chain in ensuring input availability, reducing costs, and enhancing the environmental sustainability of hydroponic farming operations.

The results summarized in Tables 9-13 collectively highlighted the multidimensional effectiveness of hydroponic farming in Bulacan. Respondents rated the system positively across all key business areas, particularly operations and supply chain management. While the financial and marketing aspects showed moderate effectiveness, they also revealed areas for improvement, including access to capital and market expansion strategies. Overall, upon evaluation, the data supported the viability of hydroponic farming as a sustainable and effective agricultural model, reinforcing the need for strategic business planning and continued institutional support to optimize performance across all domains.

Table 14 and Figure 3 present a summary of the key results, trends, and perspectives for the development of a sustainable business model.

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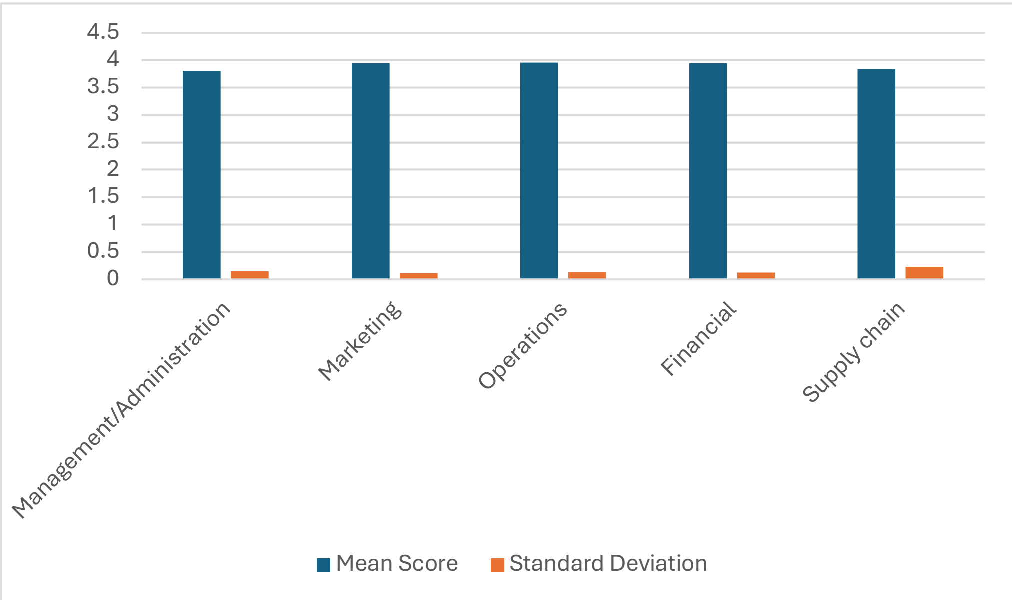
Table 14

Summary of Effectiveness Ratings of Hydroponic Farming in Bulacan

Key Areas	Mean Score	Standard Deviation	Interpretation
Management/Administration	3.86	.1451	Highly Effective
Operations (Production)	3.94	.1392	Highly Effective
Marketing Strategies	3.96	.1392	Highly Effective
Financial Management	3.95	.1302	Highly Effective
Supply Chain Coordination	3.84	.2333	Highly Effective

Figure 3

Summary of Effectiveness Ratings of Hydroponic Farming in Bulacan



The data presented in Table 14 and Figure 3 provided a comprehensive summary of the effectiveness ratings across key operational areas of hydroponic farming in Bulacan. The consistently high mean scores in management and administration, operations, marketing strategies, financial management, and supply chain coordination reflected a strong consensus among respondents regarding the importance of effectiveness in their hydroponic farming practices. These results underscore the critical role of operational efficiency in sustaining and scaling hydroponic farming ventures. Furthermore, the findings were a foundation for developing a strategic business model.

III. Challenges Encountered by Hydroponic Farmers in Bulacan

The results of in-depth interviews were coded using various methods, including Descriptive, Process, Emotion, and In-vivo, to derive thematic perceptions. This section explored the themes generated from each coding method. Refer to Table 15 for a comprehensive overview of the categories and themes below.

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Table 15

Challenges of Hydroponic Farming in Bulacan

Respondents	Categories	Theme
3,4,6,7,11,13, 14,16,17,19,	Weather and Environmental Factors	**Theme**: Environmental and Economic Challenges
2,5,8,20	Pest, Disease, and Seedling Management	**Sub-Theme 1**: Extreme Weather, Pests, and Plant Diseases
1,10,12,18	Market and Demand Issues	
9, 15	Training, Capital, and Resources	**Sub-Theme 2**: High Costs and Market Uncertainty

The theme generated from various codes in challenges was "Environmental and Economic", which highlighted several challenges the hydroponic farmers faced in Bulacan. The availability of sufficient sunlight, essential for photosynthesis and plant growth in hydroponic systems, was a frequently cited obstacle. According to farmers, plants need at least 6 to 8 hours of sunlight daily to thrive and reach their full potential. However, many farms suffered from insufficient light exposure due to environmental obstacles such as nearby trees or buildings. Some farmers chose to build greenhouses in key spots or even cut down trees to increase the amount of sunlight reaching their crops.

The described challenges are closely aligned with those cited in the papers by Velazquez-Gonzalez et al. and Alipio et al. (2022), who emphasized the importance of resource efficiency and strategic hydroponic system setup. This supported the findings that farmers noted insufficient sunlight due to environmental obstructions and took costly corrective actions, such as cutting trees or building greenhouses in new locations, that would affect them economically.

On the other hand, hydroponic farming was celebrated for reducing land use and soil degradation (Resh, 2013); the alteration of natural landscapes, such as the removal of nearby trees to optimize greenhouse performance, could have had negative environmental consequences, including biodiversity loss and microclimate disruption (Pineda et al., 2020). This indicated that, while hydroponics was often regarded as a green alternative, its application in specific regions such as Bulacan necessitated context-sensitive design to minimize trade-offs between economic impact and environmental conservation.

Moreover, reflecting the result "Extreme Weather, Pests, and Plant Diseases," it became evident that the challenges identified in the descriptive code were further compounded by climate-related risks such as typhoons, heavy rainfall, and extreme weather, pests, and insects further compounded the challenges. Typhoons posed a direct threat to greenhouse structures, often causing damage that disrupted farming operations.

During the dry season, extreme weather stressed crops and increased reliance on misting or cooling systems. This led to increased electricity consumption and operational costs, directly affecting the farming enterprise's profitability. These weather-related factors demonstrated the vulnerability of hydroponic farming to climate variability, even though it was considered a more controlled method of agriculture. The in-vivo code "WEATHER, BOLTING, LEGGY, PEST CONTROL" highlighted a critical aspect of this challenge, emphasizing that extreme weather and pest infestations exacerbated the difficulties faced in Bulacan, causing significant concern among farmers. This difficulty led to growing fear and doubt about the future of hydroponic farming in Bulacan, thereby demonstrating the emotion code.

Additionally, farmers noted issues with seedling management, including poor germination and susceptibility to fungal infections. These problems often stemmed from inconsistent temperature and humidity control within

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greenhouses, limited access to high-quality seeds, or technical guidance on nutrient management. Stefanakis (2020) emphasized the importance of education and experience in managing hydroponic systems. Findings aligned with this, as seedling issues and nutrient mismanagement often stemmed from limited technical knowledge, reinforcing the need for formal training and guidance.

Pointedly stated in the paper of Sisodia et al. (2020) that to minimize losses, farmers reported investing in stronger greenhouse frames, using more durable materials, and reinforcing the foundations of their setups. Hydroponics, as a controlled and effective system, revealed that climate variability, such as typhoons and extreme weather, still significantly disrupted operations.

Despite being in a controlled environment, the issue of pest infestation and insects was addressed as a challenge. Farmers operating near forested or water-rich areas, such as those near the Tibig Dam, reported frequent infestations due to the proximity of wildlife, which could introduce pests into the system. Closely aligned with Barbosa et al. (2015), hydroponic systems were susceptible to biological risks in the initial stages, particularly when farms were near open natural habitats. Many farmers relied on organic pest control methods, aligning with their goal of producing healthy and eco-friendly crops. This finding aligned with Santos and Ocampo (2021), who noted that hydroponic vegetables require fewer chemical treatments, resulting in safer, higher-quality produce.

However, according to Basilio et al. (2023), farmers often adopted more aggressive pest management techniques to maintain high yields; when these methods failed to control severe pest infestations and plant diseases, they turned to chemical insecticides, raising concerns about cost, health risks, and environmental impacts. Also, some respondents raised concerns about relying on synthetic nutrient solutions, a viewpoint echoed by Jagdish (2023), who warned that improper nutrient management could undermine sustainability.

Another theme generated by the codes was "High Costs and Market Uncertainty." One of the most pressing economic issues faced by hydroponic farmers was market uncertainty. Interviewees shared experiences of harvesting crops only to find no immediate buyers, threatening income stability. Unlike traditional farmers, who may have had long-standing supply chains, hydroponic practitioners, many of whom were relatively new to the industry, struggled to establish consistent market linkages. Farmers turned to personal networks and partnerships to counteract this, such as collaborating with vendors at public markets or selling directly to friends and acquaintances. While this strategy helped ensure that their products were sold, it limited their market expansion and may not have been sustainable in the long term. The need for broader market access and value chain integration remained a critical area for development. Another key challenge identified was the lack of training support. Farmers needed regular training programs to stay up to date with the latest hydroponic technologies, techniques, and best practices. Lack of knowledge may have led to high costs because of the trial-and-error practice.

Similarly, Alipio et al. (2022) pointed out that hydroponics' economic and market challenges revealed real-world challenges such as inconsistent buyer access and unstable income, especially for newcomers without an established market. Farmers' reliance on personal networks showed resilience but highlighted the absence of structured supply chains, a gap noted by Dona et al. (2021).

Stefanakis (2020) agreed that the importance of experience and education in managing hydroponic systems aligns with this, as seedling concerns and nutrient mismanagement are often limited by limited technical knowledge, reinforcing the need for formal training and guidance, which can lead to high costs. Payne (2021) directly reflected this, as farmers voiced frustrations over the high capital costs of regular government training, clear barriers to entry, and scale.

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The data gathered from the hydroponic farmers in Bulacan reflected a comprehensive view of the multi-layered challenges they faced. Therefore, more substantial policy support, infrastructure investment, training programs, and market development. These interventions could help unlock the full potential of hydroponic farming as a viable solution for sustainable agriculture in Bulacan.

Table 16 below summarizes the challenges, with descriptions to facilitate easy comprehension of the narration.

Table 16

Summary of Challenges Encountered by the Farmers in Bulacan

Challenges	Description
High Initial Investment Costs	Farmers face significant financial barriers in purchasing hydroponic equipment, systems, and quality inputs.
Limited Access to Affordable Inputs	Essential materials like nutrients, growing media, and infrastructure are costly and not readily available locally.
Insufficient Technical Knowledge and Support	Farmers lack consistent access to training, updated technologies, and expert consultation.
Difficulty in Market Penetration	Farmers struggle to reach broader markets and mainly rely on personal networks for selling produce.
Inconsistent Supply Chain Coordination	Delays in supply deliveries and lack of coordinated logistics affect production and marketing efficiency.
Vulnerability to Environmental Risks	Although hydroponics is more controlled, external factors such as extreme weather events still affect operations.

In summary, hydroponic farming in Bulacan faces challenges related to financing, technical skills, access to supplies, and environmental management. Addressing these issues is essential to support the sector's growth and long-term sustainability.

IV. Opportunities of Hydroponic Farming in Bulacan for Sustainable Agriculture

The results from Table 17 highlight important opportunities for hydroponic farming in Bulacan, as perceived by the respondents.

Table 17

Opportunities of Hydroponic Farming in Bulacan

Respondents	Categories	Theme
1, 5, 6, 7, 8, 12, 13, 15, 16	Additional Income and Economic Benefits	**Theme**: Hydroponic Farming as a Sustainable and Profitable Agricultural Solution in Bulacan
2, 3, 19, 20	Sustainability and Environmental Benefits	
10,11,18	Health and Lifestyle Benefits	**Sub-Theme 1**: Economic Growth and Livelihood Opportunities

Sub-Theme 2: Environmental and Health Benefits

Through interviews with hydroponic farmers in Bulacan about opportunities, highlighted codes generated a theme: "Hydroponic Farming as a Sustainable and Profitable Agricultural Solution in Bulacan." It became apparent that the decision to explore hydroponic farming was influenced by the COVID-19 pandemic and the changing agricultural landscape in the region. The pandemic, with its restrictions on movement and access to traditional markets, prompted farmers to seek alternative livelihood options. One respondent mentioned that the idea of hydroponic farming arose from the need to sustain livelihoods despite the pandemic's limitations. Additionally, the intrusion of major developments, such as the airport, in the region led to the displacement of traditional farmers, further motivating individuals to explore modern farming methods like hydroponics. The potential to assist fellow farmers, particularly those who had lost land due to development, was a driving factor in the decision to venture into hydroponic farming, with the aim of providing a sustainable source of income and support to the agricultural community in Bulacan.

Another theme generated was "Economic Growth and Livelihood Opportunities." Respondents expressed optimism about the potential of hydroponic farming to not only provide additional income but also to introduce modern farming practices to others in their community. The prospect of earning 10,000 to 20,000 pesos per month through hydroponic farming was seen as a significant contribution to the livelihoods of farmers in Bulacan, particularly in San Nicolas, where traditional agriculture was prevalent. While some respondents acknowledged that hydroponic farming sometimes resulted in break-even net profits, they remained hopeful that with further investment and opportunities for collaboration with larger companies, profitability could be increased. To preserve their standard of living and support their communities, farmers are increasingly embracing new technologies and adapting to changing agricultural conditions.

This study confirmed the conclusions of Chong et al. (2021) that some hydroponic systems may be installed in industrial and urban environments where traditional farming is impractical. According to the article by Maniego et al. (2018), hydroponic farming was a feasible industry for small business owners, as indicated by interviews with farmers. The potential of hydroponics to advance food security and sustainability aligns with the UN Sustainable Development Goals (SDGs), particularly Zero Hunger (Goal 2) and Responsible Consumption (Goal 12) (Goh et al., 2023).

Although other respondents also saw this as a restriction, Yasay (2021) noted that high upfront costs and technical knowledge requirements may have deterred small-scale farmers from implementing the strategy. According to Despommier (2024), legislative and technological support were needed for hydroponic farming to be widely used.

Moreover, respondents emphasized promoting healthy living by eating vegetables in the theme "ENVIRONMENTAL and HEALTH BENEFITS." Aside from the health benefits, it would encourage agricultural innovation through environmental conservation, as hydroponics' ability to save water was essential in regions experiencing periodic droughts. This finding aligned with Goh et al. (2023), who reported that hydroponic systems use 90% less water than soil-based farming, making them a sustainable option in water-scarce areas. A contrasting view from Hancock (2023) highlighted that while water use was minimized, energy consumption for climate control and lighting could be a drawback, which some respondents also acknowledged.

The opportunities outlined in Table 17 align with global and regional research findings and reflect local realities based on respondents' experiences. While hydroponics offered clear advantages in land use efficiency, yield, and resource conservation, challenges such as cost, technical expertise, and energy consumption remained key considerations for long-term sustainability.

Table 18 below summarizes the opportunities, with descriptions to facilitate easy comprehension.

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Table 18

Summary of Opportunities of Hydroponic Farming in Bulacan

Opportunities	Description
Growing Demand for Healthy, Pesticide-Free Produce	Increased consumer awareness of health and wellness creates strong demand for fresh, chemical-free vegetables.
Urban Market Expansion	Urbanization and infrastructure development (e.g., Bulacan Airport) offer new markets and distribution channels for hydroponic products.
Year-Round Production	Hydroponic farming allows continuous cultivation regardless of seasonal changes, increasing overall productivity and profitability.
Technological Advancements	Access to improved hydroponic systems, automation tools, and digital marketing platforms enhances operational efficiency and market reach.
Supportive Government Policies	Emerging policies promoting sustainable agriculture and urban farming create opportunities for grants, subsidies, and training programs.
Potential for Export and Institutional Markets	Growing interest from hotels, restaurants, supermarkets, and export markets boosts potential for bulk sales and business expansion.
Resource Efficiency and Climate Resilience	Hydroponic systems require less water and land, offering a competitive advantage in areas affected by climate change and resource scarcity.

In summary, hydroponic farming in Bulacan presents significant opportunities to advance sustainable agriculture, meet the rising demand for healthy produce, and create new economic pathways. Strengthening support systems and expanding market access will be key to maximizing these opportunities.

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Figure 4

Transition Flow to Strategic Business Model

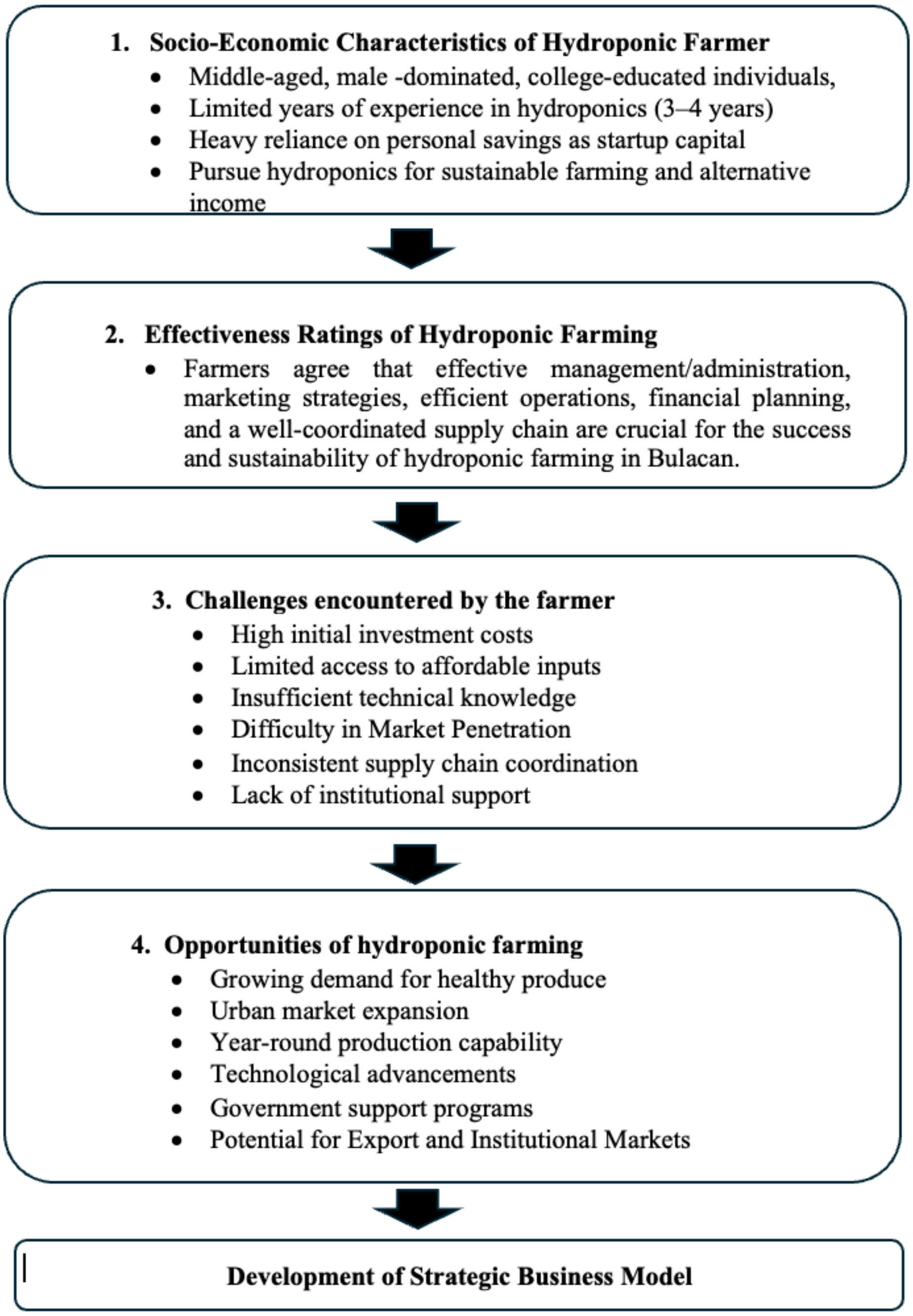

Figure 4 illustrates the logical flow from the farmers' socio-economic profile, effectiveness perspective, challenges encountered, and opportunities identified to the formulation of a strategic business model tailored for sustainable and scalable operations.

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Table 19

Synthesis of Quantitative and Qualitative Findings

Quantitative Findings	Qualitative Findings
Majority are middle-aged (31–50 years old). More males than females Most have college degrees 3–4 years hydroponic experience Capital from personal savings Farming secondary source of income	Farmers are educated and motivated, but financial limitations and lack of accessible financing restrict growth. Hydroponic farming serves as both a main and alternative source of income.
Hydroponic farming in Bulacan was rated as "Highly Effective" in management, marketing, operations, finance, and supply chain.	Farmers emphasized the importance of personal management skills, creative marketing strategies, and technology adaptation. Challenges mainly involve infrastructure costs, access to consistent utilities, and technical skills development. Recognized potential in pesticide-free produce, health-conscious buyers, and urban farming growth. Farmers recommend improvements in branding, financial assistance, government and private sector collaboration, digital presence.

The findings on the socio-economic characteristics, operational effectiveness, challenges, and opportunities of hydroponic farming in Bulacan provided a comprehensive foundation for strategic planning. Guided by these insights, the following section presents the development of a proposed business model to enhance the sustainability and growth of hydroponic farming in the province.

V. Strategic Business Model for the Sustainable Success of Hydroponic Farming in Bulacan

Table 20 presents participants' responses from qualitative interviews, thematically analyzed as the basis for developing a business model in hydroponic farming in Bulacan.

Table 20

Strategic business model of hydroponic farming

Respondents	Categories	Theme
1, 13, 18	Social media and Marketing Strategies	**Theme**: Sustainable Market-Driven Strategies for Hydroponic Farming Success in Bulacan **Sub-Theme 1**: Innovative Marketing and Market Expansion **Sub-Theme 2**: Quality Production and Strategic
2, 3, 19, 20	Sustainability and Environmental Benefits	
2, 11, 14	Quality Control and Farm Management	
3, 10, 11, 15, 16, 19	Marketability and Selling Strategies	
5, 6, 10, 17, 20	Business Strategy and Planning	

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The theme generated from respondents' answers was "Sustainable Market-Driven Strategies for Hydroponic Farming Success in Bulacan." Ensuring the success of hydroponic farming in Bulacan required a strategic business model that addressed key aspects, including sustainable, market-driven strategies, innovative marketing and market expansion, quality control, and farm management.

Market analysis was crucial for identifying target markets, understanding consumer preferences, and assessing the competition. By conducting thorough market research, hydroponic farmers could tailor their products to meet local consumer demands and differentiate themselves from competitors through a value proposition. Diversifying revenue sources through products could reduce risks and improve the long-term viability of Bulacan hydroponic farming operations. Farmers should investigate value-added ventures, such as processing, packaging, and distributing hydroponic goods like herbs, spices, and prepared salads, in addition to selling fresh fruit. Crafting an engaging brand narrative that highlights the unique value proposition, environmental initiatives, and community benefits of hydroponic farming could attract clients and help the business stand out from competitors.

The respondents emphasized that consumer demand for fresh, pesticide-free vegetables was increasing, making hydroponics a profitable venture. This aligned with Badrinath et al. (2022), who highlighted that hydroponically grown produce commanded premium prices in urban markets due to its higher nutritional value and safety. However, Jagdish (2023) argued that despite rising demand, public awareness and affordability remained challenges in developing markets. Some respondents echoed this concern, noting that hydroponic produce was perceived as expensive, potentially limiting its market reach.

The sub-theme developed was "Innovative Marketing and Market Expansion." Leveraging digital marketing channels such as social media, websites, and online marketplaces could reach a wider audience and drive sales. Moreover, offering agritourism experiences such as farm tours, workshops, and farm-to-table dining could generate additional income and promote brand awareness. Furthermore, exploring niche markets such as organic, specialty, or ethnic produce could tap into new customer segments and create competitive advantages. Building a strong brand identity and marketing strategy was essential for creating awareness, attracting customers, and establishing credibility in the hydroponic farming industry in Bulacan. Consequently, building strong partnerships with local markets, restaurants, and grocery stores could help secure reliable distribution channels and establish a loyal customer base.

The study recommended direct-to-consumer sales, collaborations with supermarkets, and integration with farm-to-table efforts to assure market penetration. Santos and Ocampo (2021) supported this approach, noting that urban hydroponic farms benefited from shorter supply chains, thereby reducing spoilage and transport costs. In contrast, Despommier (2024) claimed that logistical concerns, such as cold storage and effective delivery, remained a barrier for hydroponic farmers in developing countries. Some respondents mentioned the necessity for government aid in infrastructure and transportation to create supply chains.

The sub-theme of "Quality Production and Strategic Business Planning" was found using a code created from respondents' responses. Efficient use of water, nutrients, energy, and space was critical to maintaining operations while minimizing resource consumption. Implementing modern hydroponic methods with water recirculation and nutrient recovery capabilities minimizes environmental impact while incorporating renewable energy sources, such as solar power, to enhance sustainability and reduce operational costs. Smart monitoring and control technologies also enabled real-time surveillance of environmental parameters and plant health, resulting in proactive management and resource optimization.

Technology adoption was an important driver of efficiency and innovation in hydroponic farming. Investing in cutting-edge solutions such as vertical farming, automated nutrient dosing, and data analytics software helps streamline operations, improve crop quality, and increase yields. Furthermore, adopting advanced technologies such as blockchain for supply chain transparency and the Internet of Things (IoT) for remote monitoring improved

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traceability and accountability across the production process. Hydroponic farmers may preserve their competitiveness and establish themselves as industry leaders by staying up to date with technological breakthroughs and continually innovating.

The most important factors for consumer trust and legal compliance were food safety and quality control. Strict adherence to sanitation guidelines, hygiene standards, and pest control techniques protected the quality of the produce. Implementing circular economy concepts, such as turning organic waste into compost or bioenergy, improves resource efficiency and reduces waste. The long-term viability of hydroponic farming in Bulacan was largely dependent on environmentally conscious agricultural methods and sustainable farming practices. Using environmentally friendly practices, such as organic farming, conserving water, and enhancing biodiversity, decreases environmental impact and increases ecological resilience. By combining technological innovation, quality assurance, and sustainable practices, as outlined in Goh et al. (2023), hydroponic farming may be a viable way to ensure food security and agricultural sustainability in Bulacan. It also promotes resource-efficient farming, which aligns with the global sustainability goals (SDG 2 & SDG 12).

Conversely, Hancock (2023) noted that reliance on technology increased energy costs, which some respondents identified as a financial hurdle to running large-scale hydroponic farms. Consequently, Sisodia et al. (2020) cautioned that not all hydroponic farms used eco-friendly practices, and excessive reliance on synthetic nutrients could pose environmental risks. Some respondents recognized this issue and suggested more research into organic alternatives to enhance sustainability. The long-term viability and profitability of hydroponic farming operations in Bulacan depended heavily on risk management and financial planning. To secure capital and attract investors, a thorough business plan with reasonable financial projections—such as launch costs, operating expenses, revenue projections, and cash flow analysis — was crucial. Risk management applications such as insurance, crop diversification, and backup plans for bad weather or market swings can also protect against unforeseen difficulties and ensure business continuity.

The business model implied careful investment in cost-effective processes to guarantee profitability. Li and Kee (2020) supported this strategy, arguing that economies of scale could lower operationally costs while increasing return on investment (ROI) for commercial hydroponic farms. However, Yasay (2021) warned that costly initial capital expenditures remained a substantial obstacle, particularly for small-scale farmers. Some study respondents stated that financial help from the government and private investors was critical for business viability.

Education and community involvement were essential elements of a successful business plan to increase awareness and acceptance of hydroponic farming in Bulacan. Locals may learn about the advantages of hydroponics and gain support and trust if workshops and farm tours are offered. Furthermore, working with government organizations and educational institutions to incorporate hydroponics into extension programs and school curricula may inspire a new generation of hydroponic enthusiasts and business owners.

The strategic business model in Table 20 addressed market demand, financial sustainability, technology use, and policy support to guide the growth of hydroponic farming in Bulacan.

Table 21 and Figure 5 below illustrate this model, developed from data and interviews, as a practical tool for sustainable and competitive operations.

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Table 21

Business Model Canvass of Hydroponic Farming in Bulacan

Business Model Canvass Component	Management / Administration	Operations	Marketing	Financial	Supply Chain
Key Activities	training	crop production, nutrient, and pest control	promotion	cost control	
Key Resources	skilled staff	greenhouses, water, nutrient and seeds hydroponic systems,	social media	capital	
Key Partners		Agricultural expert	Reseller		supplier
Customer Segments			restaurants, local market, reseller		
Value Proposition			sustainable, fresh high-quality crops		
Revenue Streams			direct sales of crops, bulk orders		
Cost Structure		equipment, seeds, nutrient solutions, pest control			
Customer Relationships		quality assurance of crops	bulk order deals		collaborative arrangement
Channels			social media, direct selling, farm to table partnerships		

Figure 5

Strategic Business Model of Hydroponic Farming in Bulacan

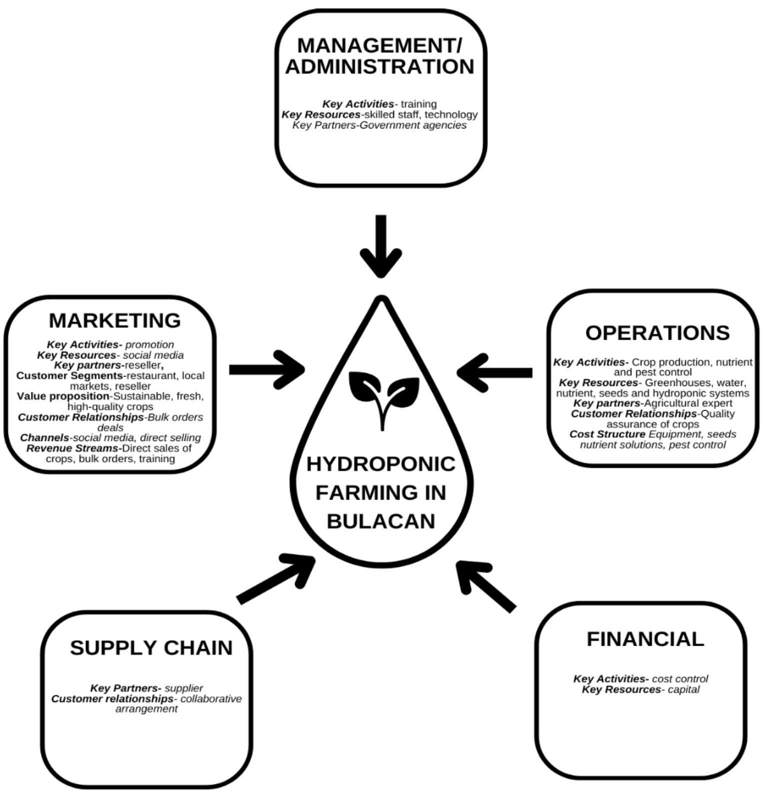

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Figure 5 shows the Strategic Business Model of Hydroponic Farming in Bulacan, illustrating the key drivers needed to sustain long-term success. The model emphasized the integration of innovation, strategic partnerships, efficient resource utilization, and a market-driven approach. It also underscored the importance of collaboration among public-sector institutions, academia, and the private sector, as well as the need for continuous farmer education, efficient logistics, and targeted promotional efforts. With a comprehensive framework for the area to promote hydroponic farming as a viable and profitable industry in Bulacan.

To evaluate the viability of the proposed hydroponic farming business model in Bulacan, a SWOT analysis was conducted using the framework of Gürel (2017). The analysis, supported by the findings and a review of related literature, identified key strengths, weaknesses, opportunities, and threats, as summarized in the table below.

Table 22

SWOT Analysis of the Hydroponic Farming Business Model in Bulacan

Strengths	Weaknesses
Efficient use of water and space; uses up to 90% less water than soil-based farming.	High initial investment required for setup and infrastructure.
Enables high yield and year-round production under controlled conditions.	Requires technical knowledge in system operation and nutrient management.
Produces pesticide-free, high-quality vegetables, appealing to health-conscious consumers.	Dependence on consistent water and electricity supply, which can be unreliable.
Well-suited for urban and peri-urban settings with limited land.	Limited marketing channels and distribution systems for small producers.
Opportunities	**Threats**
Growing demand for organic and sustainable produce in local and niche markets.	Vulnerable to waterborne diseases, pests, and system failures.
Support from government programs such as TESDA and the Department of Agriculture.	Fluctuating market prices and stiff competition with traditional farming.
Integration into schools and communities for food security and education.	Limited access to financing, especially for smallholder farmers.
Potential for export and scalability through public-private partnerships.	Technological access challenges in remote and low-income areas.

The hydroponic farming model was adaptable for both smallholders and commercial scales. Smallholders could use low-cost methods like the Kratky or NFT method, which require minimal capital and space and are ideal for urban or backyard farming (Wanniachchi & Jayakody, 2022). These setups benefited from local direct-to-consumer sales and community-based support (Prayoga & Putra, 2020).

In contrast, commercial operations could scale vertically with greenhouse automation and advanced systems, supporting high-volume production and formal market integration (Souza et al., 2019). The model was also regionally flexible and suitable for urban, rural, coastal, or mountainous areas by adapting inputs to local conditions (Cifuentes et al., 2020).

According to the SWOT analysis, hydroponic farming in Bulacan displayed much potential as a scalable and sustainable business model. Despite obstacles such as high startup costs and technical requirements, there were ample opportunities stemming from the benefits of efficient production, rising market demand, and supportive

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government policies. Strategic planning, focused training, and supporting policies would mitigate threats and ensure the long-term sustainability of hydroponic farming in Bulacan.

Conclusion, Limitations, and Recommendations

This section summarizes findings from the five specific issues addressed in the study. Both quantitative and qualitative data were examined to provide a thorough understanding of hydroponic farming in Bulacan.

1. **How may the socio-economic characteristics of hydroponic farmers in Bulacan be described in terms of:**
   1.1. *Age*. Regarding age, most farmers were between 36, and 50 years old, followed by those aged 51–60, indicating that middle-aged individuals predominantly practice hydroponic farming. Younger farmers, aged 18–25, indicate a limited presence of youth in this sector.
   1.2. *Sex.* Gender analysis showed that most hydroponic farmers were male, while females accounted for a notable proportion, reflecting a male-dominated field with notable female participation.
   1.3. *Educational attainment*. Educational attainment revealed a highly educated demographic, indicating that the sector attracts individuals with advanced education.
   1.4. *Years of experience practicing hydroponics*. Regarding experience, farmers had 3–4 years of practice, suggesting the relative newness of hydroponic farming. A smaller proportion had more than 5 years of experience, indicating that the technique was still emerging and gaining popularity.
   1.5. *Source of capital*. Farmers primarily fund their ventures through personal resources, relying on savings. External financing options were limited, and securing loans and receiving support from private investors was difficult.
   1.6. *Sources of income*. Income sources were diverse, including farmers earning from hydroponics and other activities, on-farm income, and supplemental income from external employment.

2. **How may the perceived effectiveness of hydroponic farming in Bulacan be evaluated in terms of:**
   2.1. *Management/Administration*. Participants agreed on the significance of supervising resource distribution, fostering interdisciplinary collaboration, coordinating outreach efforts, managing data, and assessing impact.
   2.2. *Marketing*. Respondents firmly asserted that crucial marketing practices included digital campaigns, strategic collaborations, product innovation, and consultative selling.
   2.3. *Operations.* Respondents agreed and emphasized the importance of effective system maintenance, pest management, environmental monitoring, and continuous staff training.
   2.4. *Financial*. Respondents unanimously agreed that financial management effectiveness included budgeting, profitability monitoring, and strategic planning.
   2.5. *Supply chain*. Respondents unanimously affirmed that effectiveness covered input sourcing, distribution efficiency, and inventory management.

3. **What challenges have farmers in Bulacan encountered with hydroponic farming?**
   The interviews with hydroponic farmers in Bulacan revealed several challenges encountered in hydroponic farming, reflecting the complexities of implementing innovative agricultural practices in the region. They faced high initial investment costs, with most relying solely on personal savings due to a lack of access to loans or government grants. They also had limited technical training, especially in nutrient mixing, system maintenance, and troubleshooting. Marketing difficulties included limited customer reach, informal pricing strategies, and a lack of branding. A weak supply chain was characterized by inconsistent availability of materials and inputs, often at high costs. Minimal government or institutional support, both in policy and extension services, was another challenge. These challenges indicated a strong need for support systems such as training, access to finance, and cooperative-based supply networks.

4. **What opportunities does hydroponic farming offer for sustainable agriculture in Bulacan?**
   Hydroponic farming presented significant opportunities for sustainable agriculture in Bulacan, as evidenced by interviews with local farmers. Notwithstanding the challenges, significant opportunities were identified that positioned hydroponic farming as a viable and scalable enterprise. Rising demand for fresh, pesticide-free, and

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health-oriented produce among households, restaurants, and wellness businesses was observed. Independent of weather conditions, year-round production made it resilient against climate-related risks. Urban adaptability made hydroponics suitable for small spaces and urban households' interest in innovation among younger and tech-savvy farmers seeking sustainable, high-return ventures. There was potential for value-added products like salad kits, potted herbs, and agritourism experiences. These opportunities supported the case for hydroponics as a future-ready agricultural solution, especially when coupled with proper education and marketing.

5. **What strategic business model may be recommended to ensure the success of hydroponic farming in Bulacan**.

To provide a comprehensive understanding of the study, both quantitative and qualitative data were synthesized. Quantitative findings showed that while hydroponic farmers demonstrated strong operational and managerial capabilities, significant gaps remained in marketing strategies, financial management, and supply chain coordination. These numerical results were supported by qualitative observations, which revealed that farmers often relied on personal networks for sales, faced difficulties in accessing affordable inputs, and struggled with limited technical assistance. The convergence of these findings underscored the importance of the Agricultural Innovation Theory by emphasizing that, despite adoption, institutional and resource constraints continued to impede the full expression of innovation. The relevance of external collaborations was also emphasized in the qualitative narratives, highlighting the applicability of Business Ecosystem Theory to understanding the relationships among hydroponic farmers, suppliers, customers, and support organizations. This comprehensive analysis reinforced the foundation for developing a strategic business plan tailored to the unique circumstances of hydroponic farming in Bulacan.

Overall, the study highlighted that hydroponic farming in Bulacan was a promising but currently under-supported venture. It presented significant findings that aligned with a strategic business model, offering practical guidance for farmers to overcome challenges and maximize their potential. With the right support, hydroponics could thrive as a sustainable and profitable agricultural practice in the region.

Conclusions

Considering the findings of the study, the following conclusions were drawn:

1. The study concluded that most hydroponic farmers in Bulacan were middle-aged, college-educated individuals with limited experience in the industry. They were dedicated to sustainable and innovative farming practices despite their limited experience. It reflected the Agricultural Innovation Theory, which suggested that farmers responded to changing market demands, urbanization, and land scarcity by adopting novel techniques such as hydroponics. Their participation in hydroponics represented a growing trend toward creative, climate-resilient, and space-efficient farming methods. Establishing suitable development programs and ensuring efforts match Bulacan hydroponic practitioners' skills, requirements, and incentives required an understanding of the farmers.
2. The findings indicated that hydroponic farming in Bulacan was generally effective in management/administration and operations. However, there were significant deficiencies in marketing strategies, financial management, and supply chain coordination. This supported the Business Ecosystem Theory, which highlighted that business success depended not only on internal efficiency but also on collaboration with external stakeholders such as suppliers, distributors, and customers. Identifying effectiveness across key areas ensured that strengths could be reinforced and weaknesses strategically addressed through capacity-building initiatives.
3. Hydroponic farmers faced critical challenges, including high initial investment costs, difficulty in accessing affordable inputs, limited market reach, and insufficient technical support. These challenges were consistent with Agricultural Innovation Theory, which acknowledged that the adoption of innovation was often constrained by economic and institutional barriers. Identifying specific challenges provided clear direction for policy reforms, funding programs, and institutional support efforts to reduce barriers to successful hydroponic farming.

4. Despite the challenges, hydroponic farming presented numerous opportunities, particularly the growing demand for pesticide-free, high-quality produce among health-conscious consumers, urbanization trends, and infrastructure projects such as the Bulacan Airport. These opportunities were consistent with the Induced Innovation aspect of Agricultural Innovation Theory, which emphasized that economic incentives drove technological adoption. Recognizing and leveraging these opportunities enabled farmers to scale their operations, improve profitability, and strengthen their contribution to local and regional food security.
5. A strategic business model was developed to maximize the potential of hydroponic farming through five core components: management, operations, marketing, supply chain, and financial management. Aligned with Agricultural Innovation and Business Ecosystem Theories, the model addresses current gaps while building on existing strengths. It offers a practical, scalable framework tailored to hydroponic growers in Bulacan, promoting sustainability, profitability, and long-term success. As hydroponics gains traction, it presents a powerful tool for revitalizing local agriculture, improving food security, and driving economic growth in an evolving world.

Recommendations

Based on the findings and conclusions of the study, the following recommendations were hereby submitted:

1. Providing capacity-building programs that concentrate on the design, operation, maintenance, pest management, and sustainable agricultural practices of hydroponic systems is essential for farmers and farming communities. Their entrepreneurial and operational capabilities will be further developed through training in financial planning, digital literacy, farm administration, and marketing. To enhance environmental sustainability and efficiency, farmers should be encouraged to implement water recycling systems and adopt renewable energy solutions, such as solar panels. Establish farmer cooperatives to enhance collective bargaining power, facilitate market access, and promote resource sharing. Furthermore, to ensure consistent demand and visibility for hydroponic produce, it is imperative to strengthen supply chains by establishing strong partnerships with Bulacan Hydroponic Supply, local hotels, supermarkets, and restaurants. Adopt best practices, participate in training, form coops to reduce costs, and access better markets.
2. To create a conducive environment for hydroponic farming, governments and policymakers must develop regulatory frameworks, infrastructure, and enabling policies. Subsidies, financial incentives, cooperative funding schemes, and microloan access should be available to scale small-scale enterprises and reduce entry barriers. Demonstration farms and publicly funded training centers will be learning sites and promote broader adoption. To ensure quality and build consumer confidence, the government should also encourage the use of certification and branding for hydroponically grown products. Local government units (LGUs) should implement subsidy programs for hydroponic inputs (e.g., PVC pipes, grow lights, nutrient solutions) and offer tax incentives to agripreneurs investing in urban farming technologies. TESDA and the Department of Agriculture should develop tiered training modules (Basic, Intermediate, Advanced) focusing on system setup, pest management, nutrient calibration, and business planning. Modules should include hands-on demos and online certification.
3. Women and underrepresented groups should develop inclusive training programs tailored to their unique responsibilities and requirements in the agricultural sector. Empowerment and participation will be fostered by facilitating access to capital and support for female-led hydroponic ventures. To cultivate innovation and equity within the agricultural sector, it is imperative to encourage gender-inclusive entrepreneurship actively.

   Entrepreneurs and startups are encouraged to drive agricultural innovation by joining incubation programs, tech clusters, and agri-business centers that support the development of localized hydroponic solutions.
4. Entrepreneurs and startups are encouraged to engage in agricultural innovation through incubation programs, tech clusters, and agri-business centers. These platforms will help create value-added products such as pre-packed greens and ready-to-eat salad kits tailored to urban consumers. By promoting Bulacan as a model for sustainable and resource-efficient agriculture, entrepreneurs can align their initiatives with national development goals and contribute directly to Sustainable Development Goal 2: Zero Hunger.

5. Private-sector actors and technology providers are essential to enhancing hydroponic agriculture in Bulacan by fostering innovation, increasing efficiency, and broadening market access. They should partner with local cooperatives and government entities to provide cost-effective, scalable hydroponic systems, leveraging new technologies such as automation, IoT sensors, AI-powered monitoring tools, and vertical farming configurations to improve productivity. Creating intuitive digital tools and mobile applications for smallholder farm management can enhance operational efficiency and decision-making. Expanding market access and increasing consumer awareness can be achieved through strategic partnerships with culinary service providers, retailers, and e-commerce platforms.
6. Educational institutions are encouraged to incorporate hydroponics into their formal curricula and extracurricular programs. Integrate hydroponic modules in K-12 and higher education; build on-campus demo farms to encourage learning and food production. The industry's academic foundation will be fortified, and youth interest in agripreneurship will be stimulated through partnerships with universities for research, training, and technology transfer.
7. Establish a partnership model of public-private partnerships (PPP) where local agri-tech companies provide system installation and maintenance, while LGUs handle farmer enrollment and agreements. Community cooperatives can manage group purchasing and market linkage.
8. Lastly, the researcher recommends that research institutions and prospective researchers conduct longitudinal studies on the financial sustainability and profitability of hydroponic farming across different farm scales and locations. Conduct consumer acceptance studies on hydroponically grown produce to better understand market potential and branding strategies. Analyze cost-benefit comparisons between hydroponics and traditional farming over multiple cropping cycles in the same region. The generalizability and applicability of the findings will be improved by broadening the scope of future studies to encompass various regions of the Philippines.

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