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Smart Greenhouse Technology for Hydroponic Farming: Is it Viable and Profitable Business?

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Abstract—**This study aims to analyze the profitability and sustainability of horticulture agribusiness using hydroponics with a smart greenhouse (SGH) technology. This study also evaluates the acceptability of SGH technology. This study investigates the impact of the COVID-19 pandemic on the supply chain of horticulture vegetables produced using SGH, semi-smart greenhouse (SSGH), and conventional technologies. The methods used in this study are a dynamic model, i.e., the causal loop diagram (CLD), the benefit-cost ratio (B/C), the revenue-cost ratio (R/C), and descriptive analysis. The results show that the feedback structure was complex and dynamic. The determinants of SGH-based agribusinesses were cost, income, and sustainability. The findings showed that business profitability and sustainability proxied by B/C and R/C were higher in SSGH than SGH and were the lowest in conventional. The regulated use of the technology in SSGH is more profitable and applicable in Indonesia. The acceptability of SGH technology was determined by profits, investment and operational costs, market segmentation, price factors, maintenance, and farmers' skills. Meanwhile, the impacts of the COVID-19 pandemic on the supply chain of vegetable commodities vary in SGH, SSGH, and conventional farming. The differences were influenced by business scale, partnerships, production locations, markets, logistics (transportation), and digital marketing. The findings of this study contribute to the literature on smart farming technology, especially the regulated application of SSGH.**

Keywords— Smart farming technology; agribusiness; socio-economic; the COVID-19 pandemic; supply chain.

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I. INTRODUCTION

Agriculture products such as fruits and vegetables are essential parts of the diets of 275 million people in Indonesia. However, approximately 90 percent of Indonesians lack vegetables and fruits. The average consumption is about 100 grams per capita per day [1], [2], which is far below the standard of the World Health Organization (WHO) of around 400 grams per capita per day [3]. This raises concerns because according to WHO and the Food and Agriculture Organization (FAO), a lack of fruit and vegetable intake poses a 14 percent risk of death from gastrointestinal cancer, an 11 percent risk from coronary heart disease, and a 9 percent risk from a stroke [4].

Meanwhile, problems facing food supply in Indonesia include the sustainability of farmers' businesses and the conversion and degradation of agricultural land. The conversion of agricultural land into non-agriculture functions, such as office buildings, industry, and housing or roads, has reduced agriculture production. For example, the average area of rice fields declines by 650 thousand hectares (Ha) per year or is equivalent to 6.5 million tons of rice, assuming production of 10 tons per year [5]. Generally, this agricultural conversion is for long-term development projects, such as housing, factories, toll roads, and other public facilities [6]. The impact includes increasing land degradation; for example, 14 million hectares of land are now in a critical condition [7], which leads to low productivity and income. On the other hand, the price of agricultural land increases along with the demand. The increase in land prices and opportunity cost result in a high cost of land-based crop production.

The COVID-19 pandemic is a momentum to encourage horticultural agribusiness. On the one hand, people have become increasingly aware of the benefits of horticultural foods, including fruits and vegetables, which can increase the immune system. On the other, social distancing and the restrictions of community activities in Indonesia (PPKM) during the COVID-19 pandemic disrupted agribusiness performance, especially in the agricultural commodity supply chain. All agribusiness subsystems were impacted, from upstream, such as procuring and trading production inputs such as seeds, fertilizer, and pesticides, to downstream levels, such as supplying industrial raw materials and finished goods [8]. Agricultural businesses, including horticulture, faced obstacles in transportation and distribution. This leads to a gap between demand and supply and the increased prices of fresh, processed, or derivative vegetable products. On a global scale, these obstacles are exacerbated by world food prices and export-import restrictions.

In Indonesia, the challenges are meeting the demand, making horticultural food more affordable, and increasing the welfare of farmers and agribusiness actors. Small-scale farmers could contribute significantly to the development of the agriculture sector, but the area of land they cultivate is often narrow, ranging from 0.1 to 0.5 ha per farmer family [9]. Other challenges are as follows:

- The vegetable production centers are relatively far from urban areas, scattered without zoning, so the trade chain is long.
- The perishable nature of the agricultural products.
- The limited use of technology.
- The dependence on nature and conventional cultivation makes supply and demand uncontrollable.

The agribusiness system is broad, consisting of five subsystems, as shown in Figure 1. Solving challenges systematically is crucial because the agricultural sector is a source of livelihood for 87.50 percent of the population [10].

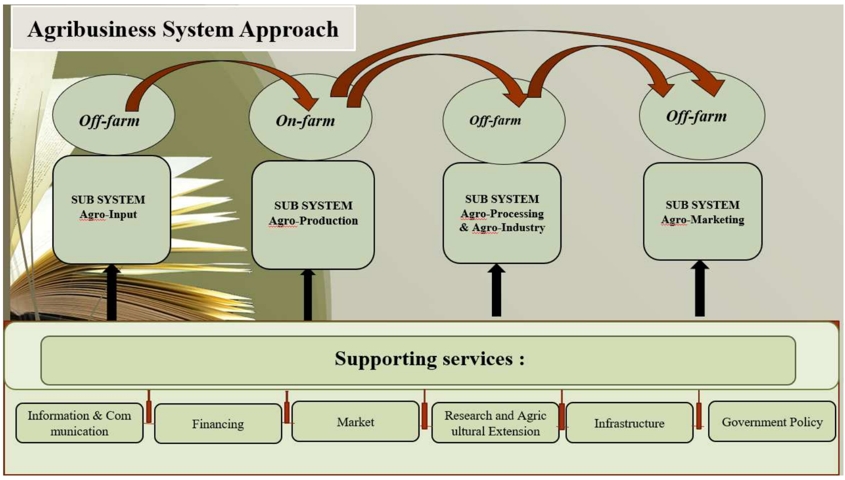

Fig. 1 The agribusiness system approach

Innovations in agribusiness are needed to improve production, including precision farming technology and business partnership development from upstream to downstream. Several weaknesses of the current food logistics system include the inability to calculate demand and supply accurately and in real-time and record transactions precisely, authentically, and transparently. The risk of leakage, damage, and expiration along the supply chain is high [11]. To overcome this problem, precision agriculture technologies (PATs) can be applied in the management to optimize inputs, reduce costs, and optimize production in terms of quality and quantity [12]. These technologies include smart farming, characterized by sustainable market segmentation and the diversification of technology and production systems that can make agriculture more profitable for farmers [13]. Another example is efficiency in selecting input that can increase product durability [14], productivity, and profits, as shown in Figure 2.

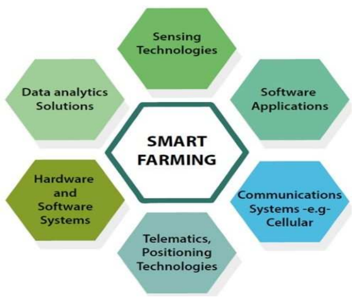

Fig. 2 Smart Farming Technology. Source: Centre for Agrotechnology and Smart Farming Studies, Gunadarma University, Jakarta

Smart farming is an agricultural management concept that utilizes information and communication technology (ICT) to track, monitor, automate, and analyze the overall operations of agricultural cultivation systems. An example of a smart farming application is the smart greenhouse (SGH). The use of SGH for hydroponic agriculture overcomes limited land issues because it can be applied anywhere as long as the microclimate is adjusted for the plants. It is also measurable so that it can reduce the excess demand or supply. Moreover, the input factors will be more efficient, resulting in greater profits and improving welfare business sustainability.

Hydroponics comes from the Greek *'hydro',* which means water, and *'ponos',* which means labour. Literally, it means water work. In the early 1930s, Professor William Gericke coined the word hydroponics to describe the growth of plants with roots suspended in nutritious water [15]. Agribusiness using the NFT hydroponic system without using a greenhouse is fairly efficient (R/C>1) and profitable. The efficiency of oriental vegetable farming, such as bok choy, mustard greens, and kale plants, can be seen in the analysis of the revenue and cost ratio (R/C). The oriental vegetable commodities such as spinach, *caisim,* and *pak choy* produced R/C values of 1.17, 1.07, and 1.22, respectively.

Among hydroponic commodities, *pak choy* is the most efficient and profitable to cultivate [16]. However, vegetable production using a greenhouse is not yet widespread. Past research [17] has shown that 98.3 percent of farmers and business actors find difficulty in building a greenhouse and perceive the construction cost as high. The chi-square calculation results also show a significant relationship between these limitations and the socio-economic importance of using a greenhouse. Most respondents were aware of the socio-economic importance of greenhouse technology, namely, to increase production yields (94.3 percent), ensure product availability throughout the year (85.7 percent), and generate higher incomes (75.7 percent). Regarding the impact of the COVID-19 pandemic, past research [18] has systematically mapped the impact of the pandemic on operations and supply chain management (OSCM), as shown in Figure 3.

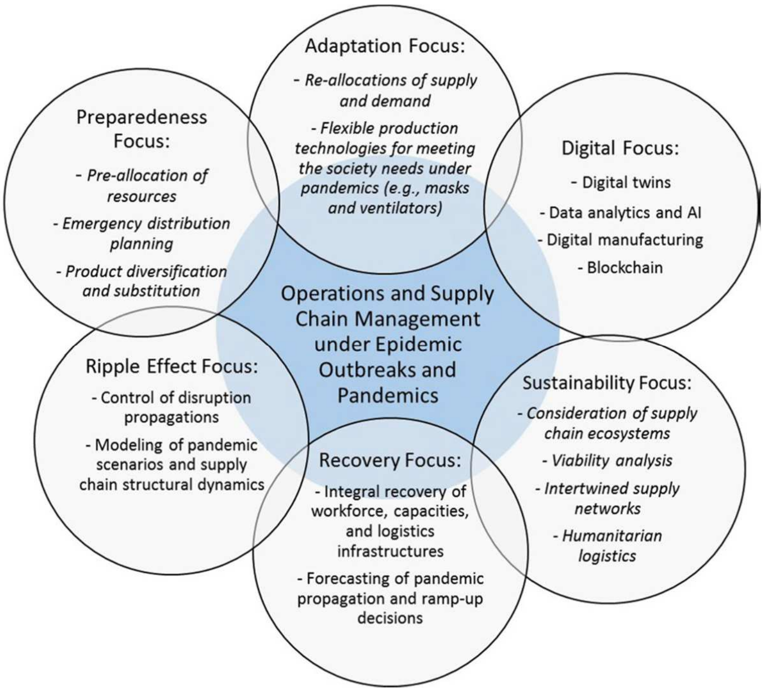

Fig. 3 Emerging OSCM research agendas under a health crisis scenario

Precision farming requires, among others, the adoption of smart greenhouses (SGHs). However, the pace of adoption is slow and not straightforward, constrained by the high investment and operational costs, the low income among farmers, and the limited human resources. These characteristics of Indonesian agribusiness and farmers are the determinants of the SGH technology application. Considering the constraints, adaptations and adjustments are needed, for example, by turning the SGH into a semi-smart greenhouse (SSGH) model for hydroponic production systems. Therefore, this research aims to discover the performance of SGH-based agribusiness, the acceptability among farmers and business actors, and the causal relationship of the business factors in SGH-based agribusiness. This research fills the gap in the literature on the implementation of SSGH by comparing them with SGH and conventional agriculture.

The three agribusiness models elaborated in this study are SGH, SSGH, and conventional agriculture. The questions are: 1) What are the causal relationships between the cost, income, profit, and sustainability of SGH-based agribusiness? 2) What is the acceptability rate of SGH-based technologies among farmers? 3) How has the COVID-19 pandemic affected SGH, SSGH, and conventional agribusiness?

II. Materials and Method

This research uses the system dynamic method considering its accuracy in formulating a comprehensive model to solve complex issues [19] and its ability to manage complex feedback systems, model non-linear behaviors, and create the best scenarios [20]. The B/C financial analysis, cost, and income behavior were used to determine profitability and business sustainability. Meanwhile, the descriptive analysis aims to determine the acceptability rate among farmers or business actors regarding the application of SGH technology and how the COVID-19 pandemic affects their agribusinesses, especially in the supply chain context. In brief, the research began with determining the topic, reviewing related literature, and determining research methods. The data for the descriptive analysis were collected through interviews with respondents selected through purposive sampling (farmers and hydroponic business actors using the SGH, SSGH, and conventional technologies). In addition to data from the interviews, field observations were carried out (in compliance with the COVID-19 pandemic protocol) to provide information not captured in the interviews.

The operational definitions in this study are as follows. SGH is vegetable horticulture cultivation using sensors and Android, using a hydroponic system in an automatically controlled greenhouse. SSGH is a vegetable horticulture cultivation with a hydroponic system in a greenhouse, whose operations are manually controlled using sensors and Android. The difference between SGH and SSGH in this research is that SSGH does not apply a fully automated technology to adjust the plant microclimates. Meanwhile, the conventional system is a horticultural cultivation system on land. The three systems cultivate the same type of leaf vegetables. The research objects were agricultural businesses that have implemented SGH, SSGH, and conventional methods in hydroponics. The research framework is shown in Figure 4.

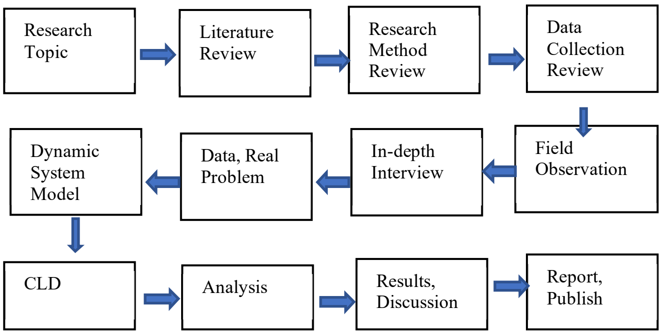

Fig. 4 Research Framework

The calculations in this study cover the same land area, namely 2000 m^2 or 4000 planting holes. This land area was determined based on the average land area owned by the vegetable farmers, so the comparison is realistic. First, the primary data were collected from in-depth and structured interviews, then mapping the problems in the causal loop diagram (CLD) and constructing the model structure using the Stella software. The result was a causal diagram of the system. The dynamic system model was built in five stages: problem identification and definition, system conceptualization, model formulation, simulation and validation, and policy analysis and improvement. Financial analysis was conducted on the three agribusiness models (SGH, SSGH, and conventional), comprising cost behavior, income behavior, and benefit-cost ratio (B/C). The behavior of costs, benefits, and B/C simulate a ten-year scenario. The B/C analysis shows how many benefits were obtained from the total costs incurred in one cycle of business projects. If the B/C value > 1, the business is profitable. The B/C analysis is also used to measure the project's feasibility. The respondents consist of representatives from SGH companies (15 percent), SSGH companies (35 percent), conventional farmers (35 percent), and academics and researchers (15 percent). The number of respondents participating in this study was relatively small because of the limitation imposed by the movement restrictions during the pandemic. This research areas include Lembang, Pangalengan, Bogor, Cianjur, and Depok, in West Java Province. The data were collected from April to December 2021 during the COVID-19 pandemic. The methods and analyses mentioned above are summarised in Table 1.

TABLE I
RESEARCH METHODS

Question Research	Analysis	Assumption	Respondent/ Source
What is the causal relationship between the cost, income, profitability, and sustainability of SGH-based agribusiness?	System Dynamic Model, causal loop diagram (CLD) Vensim PLE software 7.3.5 behavioral analysis: costs, revenues, benefit-cost ratio (B/C), revenue-cost ratio (R/C); comparison between SGH, SSGH, and conventional methods	Analysis: for ten years, On an area of 2000 m^2 or 4000 planting holes	In-depth interviews with company leaders/owners, farmers, business actors, and SGH, SSGH, and conventional vegetable horticulture farming stakeholders
What is the acceptability of SGH-based technologies among farmers?	Descriptive analysis of the in-depth interviews and field observations	Socio-economic agribusiness with a systemic approach	Company leaders/owners, farmers, business actors, and other stakeholders in SGH, SSGH, and conventional vegetable horticulture farming
How does the COVID-19 pandemic affect SGH, SSGH, and conventional agribusinesses?	Descriptive analysis of the data from the in-depth interviews and field observations	Agribusiness with a systemic approach, supply chain	Company leaders/owners, farmers, business actors, and other stakeholders in SGH, SSGH, and conventional vegetable horticulture farming

III. Result and Discussion

A. *Agribusiness Profitability and Sustainability*

The feedback loop structure determined the behavioral dynamics of the SGH-based hydroponic agribusiness. This structure explains the causal relationship between elements. The structure and behaviors are part of a dynamic phenomenon that can be simplified in a model. The feedback loop is the main shaper of the building block. The dynamic model solves and anticipates problems by considering the dynamic complexity. The causal diagram of the system components is called a causal loop diagram (CLD). It describes events as a causal relationship from the variables formed [21] with three sub-models: production cost, income, and sustainability.

The cost sub-model consists of fixed, variable, and investment. The SGH and SSGH fixed costs include land rental, fixed labor, operational technology, electricity, and building depreciation. The variable costs include daily wages, fertilizers, seeds, and cultivation equipment, such as rock wool. Meanwhile, costs for conventional cultivation consist of fertilizers, seeds, pesticides, other chemicals, and maintenance. The causal loop model shows that investment, fixed, and variable production costs influence production costs. Investment costs are influenced by the use of technology and the nature of land ownership. Variable costs are influenced by the type of commodity, the use of fertilizers, and maintenance intensity. Income is influenced by the production quantity, the total cost, and the market price (which is influenced by consumer interest and demand). Sustainable income can be reinvested as capital so the business can continue operating. Figure 5 shows the causal loop diagram.

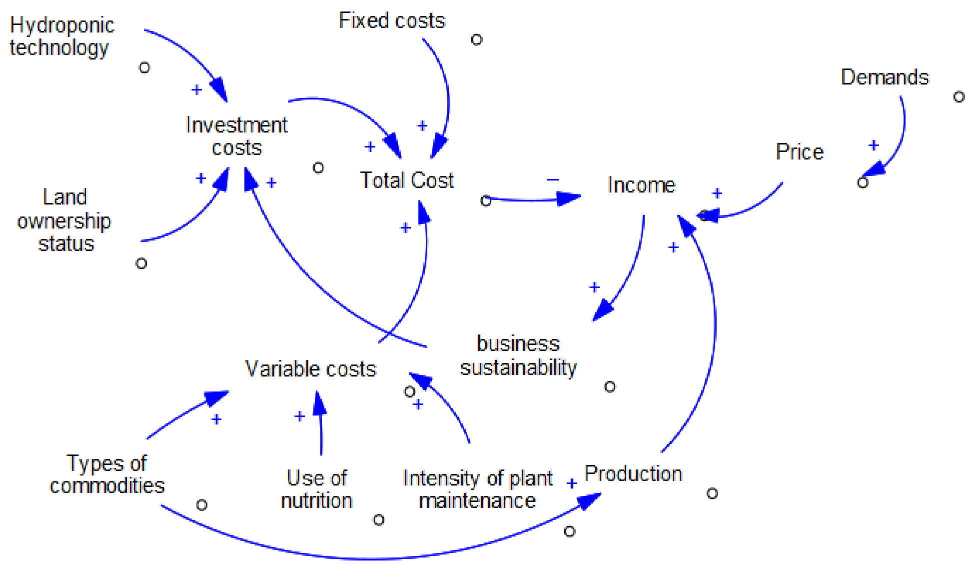

Fig. 5 Causal Loop Diagram

The investment, fixed, or variable costs in SGH for hydroponics is reasonably high. The smart greenhouse consists of two parts: hardware and software. In addition to the cost of building hardware and installing software, the land ownership will also incur some costs, especially if the land's opportunity cost in the SGH location is high.

In precision farming, a greenhouse is recommended to increase crop yields as it accurately adjusts internal climate and growth conditions, such as temperature, humidity, light intensity, and CO_2 concentration. Smart greenhouse technologies can be grouped into sensor, food, automation, and engineering categories. Sensor technology allows for immediate traceability and identification of crops and multiple independent farming practices. Food technology involves genetic adjustment and growing food directly in a laboratory, and automation technology can inspect and maintain crops. Since these technologies often cost much money to produce, the challenge is designing devices that suit farmers' budgeting for their greenhouses.

Previous research has shown that innovation ecosystems are not subjects of decisions and actions. Instead, they are special organizational spaces tailored to co-create values through collaboration [22]. Previous research has also shown that innovation-oriented enterprises allocate all their resources to productive economic activities and base their development on innovation [23]. However, creating innovative ecosystems and instilling innovation orientation among hydroponic farmers is difficult. This issue needs to be addressed immediately so that technologies such as those mentioned previously, in addition to monitoring technology and mobile applications, can assist farmers in determining when, where, how, or what to plant in precision farming [24]. Developing low-cost hydroponic technologies is essential to reduce dependence on human labor, lower overall start-up and operational costs, and promote the profitability of hydroponic farming [25]

As shown in Figure 6, conventional leaf vegetable farming costs less than SGH- or SSGH-based hydroponic systems. The ten-year simulation shows that the cost increase in the conventional system is not as sharp as using the SGH or SSGH system. The cost of SGH technology remains the highest, and the profit increases only when the commodities are vegetables with high economic values. The simulation also shows that the benefit-cost ratio (BCR) of the SGH technology increases but decreases in the long term. In other words, this scenario is not sustainable and requires improvements and subsequent strategic steps. Figure 6 displays the cost patterns.

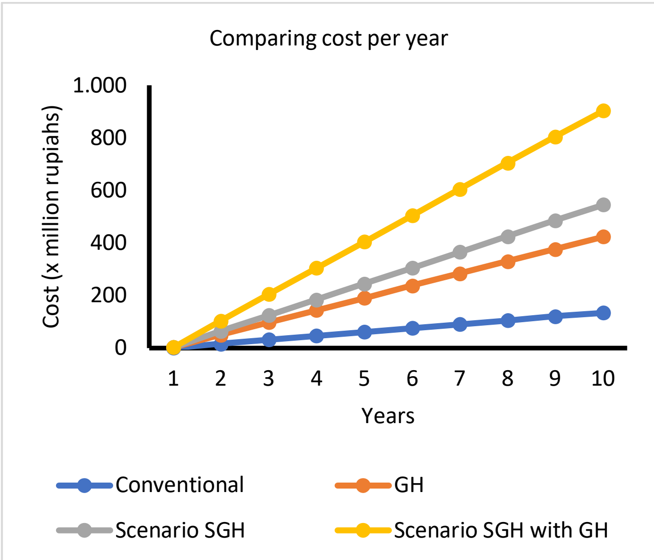

Fig. 6 Cost Patterns

The income in greenhouse-based hydroponic farming (SGH and SSGH) increases more sharply than the expenditure. Meanwhile, the income increase in conventional farming is substantially lower than the greenhouse-based systems and tends to be marginal in the long term (ten years). Figure 7 describes the income trends of leaf vegetable horticulture using SGH, SSGH, conventional methods, and the combination of SGH and SSGH.

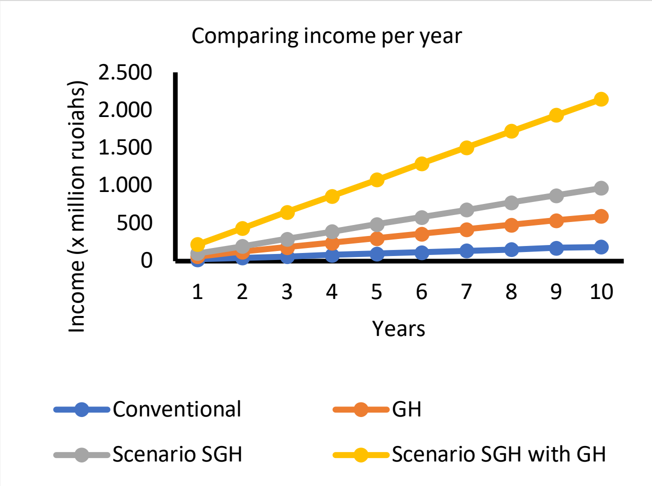

Fig. 7 Income Patterns

The B/C of hydroponic vegetables in the SSGH system is higher than in the SGH system due to the higher operational costs of a fully automated system. Meanwhile, conventional farming has the lowest B/C compared to other systems. The B/C values of conventional, SSGH, and SGH systems are 0.51, 4.23, and 1.56, respectively. In the long term, the sustainability of conventional farming businesses could be threatened by changes in cost or income variables. Meanwhile, the revenue-cost ratio (R/C) calculation shows that the R/C values are 1.53, 4.23, and 1.56 for conventional, SSGH, and SGH, respectively. A previous study on chili pepper cultivation in a greenhouse without automation showed an R/C of 3.3 [26], which means that each additional unit of the cost would generate additional revenue of 3.30 units. The R/C Ratio was more significant than 1, so the chili pepper agribusiness was profitable. The summary of the benefit-cost ratio (B/C) patterns is shown in Figure 8.

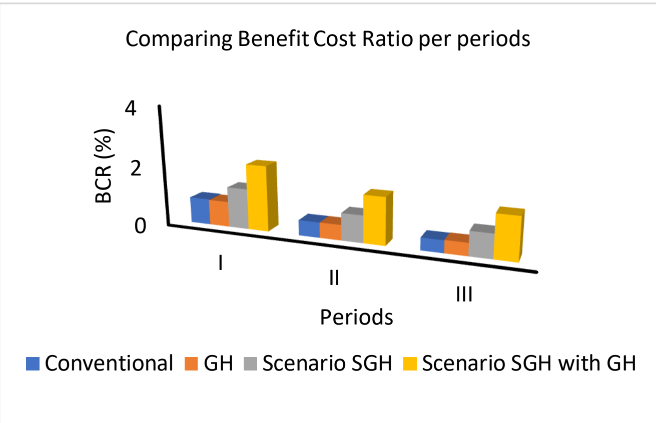

Fig. 8 The Benefit-Cost Ratio

One of the problems in an agriculture business such as this is poor management due to the low capacity of human resources. Previous research has shown that managing a complex network with cross-functional and cross-firm interactions is challenging, but success will lead to value co-creation and business-to-business (B2B) relationships. Therefore, managers need actionable frameworks to implement service-dominant business logic with cross-functional involvement [27].

B. The Acceptability of SGH-based Agribusiness

Research has shown that the acceptance and adoption of smart farming technology are influenced by investment and operational costs (which tend to be high), the limited market segment, and uncertain prices. The findings in this study show that most business actors (80 percent) knew the advantages of SGH. However, they considered the investment in the implementation high and unaffordable for farmers. This study shows that 90% of farmers did not fully automate their operations. In addition to costly software installations, 80 percent of farmers were also worried about technical limitations in case of damage or needing spare parts. Aside from the high operational costs, such as electricity, farmers and business actors argued that it is not easy to prepare the human resources to sustain the operations. Therefore, 90 percent of business actors and farmers were more inclined to adopt the SSGH system. Around 85 percent of businesses or farmers owned and operated the SGH software minimally.

Regarding the products' selling prices, business actors who implemented full automation stated that there was no difference between the SGH and SSGH products. SSGH incurs lower investment and operational costs but generates the same selling price. As such, 90 percent of farmers and agribusiness actors prefer SSGH. These findings confirm the dynamics and causal loop model developed in this research. Given the characteristics of Indonesian agribusiness and farmers, the application of SGH needs modifications or adjustments, not only in terms of technicality but also in the socio-economy; for example, it is unlikely for small-scale businesses to support significant investments.

This finding is in line with the findings of previous studies on the application of greenhouses, highlighting the high production costs. In brief, farmers choose not to adopt the system because they cannot afford it. Also, market prices fluctuate, so farmers do not want to take the risk of borrowing capital to adopt a greenhouse system and scale up. They cannot take the risk of maintaining their prices either, considering the short shelf life of the products. This result is in line with the findings in previous research [28]. For conventional farming, implementing precision or smart farming requires meeting the economies of scale above 40 Ha. In addition, the low digital literacy among farmers [25] also needs to be improved. Indonesian farmers and companies can implement precision or smart farming to achieve an economy of scale. However, this is possible only if supported by a stable market, adequate managerial capabilities, and controlled price fluctuations.

Smart farming is operation management that integrates information and communication technology. Farmers and business actors in this system manage their agribusiness using technology and adequate managerial skills. However, in the context of Indonesia, both drivers are low. Improvement and training are needed in implementing smart farming, including SGH, to be more affordable for farmers and agribusiness actors. The SGH technology should be modified by considering the socio-economic conditions of Indonesian agribusiness and farmers and business actors, who are often low-educated and from the boomer generation.

Yoon et al. [29] did an empirical study based on Rogers' innovation diffusion theory, examining organizations' existing information technology adoption model. The results show that the adoption is supported by the relative advantages, complexity, compatibility of technologies, innovation, and the CEO's IT knowledge; and hindered by financial costs, human resource inadequacy, lack of skills, competitive pressures, lack of government support, and changes in the digital environment. Likewise, the adoption of smart agriculture is also influenced by technological compatibility, financial costs, and changes in digital environments. For this reason, training related to sustainable agriculture and precision agricultural technology is needed to prepare young graduates [30].

A study in Ghana identified six barriers to technology adoption: design and infrastructure issues; seeds, pests, and diseases; technical capacity and quality of extension services; postharvest handling, warehouse, and marketing; and access to financing/credit [31]. Another study suggests that the drivers for the successful implementation of innovation ecosystems are resources, governance, strategy and leadership, organizational culture, human resources management, people, partners, technology, and clustering [32]. This study found that the conditions in Indonesia's hydroponic agriculture sector did not interact with the associations. Also, the government's role as a business catalyst has not been optimal. A study conducted by Schwartz and Bar-El. [33] showed a positive influence of a local industry association in catalyzing the innovation process, acting through five main channels: increasing the awareness of all actors, providing information and knowledge, assisting firms in developing their innovation capabilities, developing the milieu's innovation capabilities, and establishing long-term sustainability of the process.

C. The Impact of the COVID-19 Pandemic on the Vegetable Supply Chain

Since this research was carried out during the COVID-10 pandemic, the field observations with the supply chain actors and related stakeholders were limited. The empirical data showed the different impact levels between SGH, SSGH, and conventional agribusinesses. Overall, the conclusion is that the supply chain of vegetable horticulture was disrupted. Conventional agribusiness was more severely affected. Farmers stopped their production at some points, which is predictable because, in conventional agribusiness, the scale is smaller, and the location is usually remote, which is suitable for the micro-climate of the commodity. Farmers also sell their products to traditional markets only, which were mostly closed during the pandemic. In addition, transportation and people's movement were limited due to the implementation of the large-scale social restriction.

Meanwhile, the SGH and SSGH agribusinesses were not impacted as severely. Their market demand was certain and predictable based on the partnerships with supermarkets. However, the supply and production were significantly reduced because the demand for hotel catering stopped during the pandemic. Similar to conventional agribusinesses, the supply chains were disrupted. The export market stopped due to global restrictions. Prices fluctuated, and there were price disparities, especially in urban areas with high supply and demand gaps. In March 2020, six agricultural commodities' trade values declined due to global movement restrictions [34]. Several commodities' prices increase above 50 percent, such as chicken meat, red chilli, beef, and shallots. Staple foods were impacted most profoundly because the transportation and warehousing sectors were disrupted [35]. Implementing information systems in logistics is essential to support the distribution of the commodity in the right quality and quantity at the right location and time [36].

The price decline at the producer level was due to the accumulation of products. Meanwhile, at the consumer level, the decline was due to the decline in people's purchasing power. The supply was available but could not be delivered to consumers. Since food commodities are perishable, much of the supply must be disposed of. Another reason for the decline is the workforce shortage and supply chain disruption [37]. The supply was stopped in export activities due to market demand factors, transportation barriers, and increased logistics costs. Conventional agribusiness was hit the hardest in this case. Farmers or actors in the SGH- and SSGH-based agribusiness could survive because they use e-commerce platforms to meet the market demand.

This research's findings align with a previous study [38], explaining significant differences in consumer preferences before and during the COVID-19 pandemic. Income and motivation influenced the preferences positively. Meanwhile, spending and education influenced preferences negatively. From the results of the F test, income, expenditure, education, and shared motivation affected consumer preferences for online vegetable businesses during the COVID-19 pandemic at 74.9 percent. Previous research also indicates changes in consumers' preferences. Green product consumers were driven by self-realization related to environmental issues. This positively affects their attitude and purchase intention. By contrast, non-green consumers show none of these relationships. In addition, social norms related to Green food consumption influence non-green consumers' attitudes toward Green food more than green consumers [39].

IV. Conclusion

This study has shown that the complex and dynamic feedback structure influences the business sustainability of greenhouse-based horticulture agribusiness in the causal loop diagram. The determinants were costs, revenues, and sustainability. The profitability and business sustainability calculations were reflected by the benefit-cost ratio (B/C) and revenue-cost ratio (R/C), with the ratio of SSGH-based agribusiness being higher than SGH-based and conventional agribusiness.

The farmers' acceptability was influenced by the relative advantages of using the SSGH and SGH methods compared to the conventional method. The dynamic behavior includes high investment and operational costs, limited market segments, and fluctuating prices. Most farmers chose SSGH over SGH because it is more profitable and requires lower investment costs, maintenance, and skills.

The impact of the COVID-19 pandemic on the supply chain differed between agribusiness in SGH, SSGH, and conventional businesses. The business resilience of the three models depends on the scale of business, partnerships, production locations, markets, logistics, especially transportation, and digitalization.

The current SGH model still requires relatively high production costs due to technological and transaction costs.

Thus far, it can be concluded that the full SGH model is not feasible and profitable. Strategic efforts are needed to increase profits through human resource capacity development. Meanwhile, partnerships and selecting a business site closer to consumers can improve the market structure.

There should be other efforts to overcome cost problems by adopting smart greenhouse technology. For example, solar cells can be used as an electricity resource to reduce the high variable costs. Further research can also examine the feedback structure, the behavior, and the causal relationship of the elements in the dynamic phenomenon.

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