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FEASIBILITY MODEL OF CONTROLLED ATMOSPHERE STORAGE IMPLEMENTATION FOR SHALLOT FARMERS IN WEST JAVA

Herawati1)*; Yanti Nuraeni Muflikh2); Nia Rosiana3); Triana Gita Dewi4)

1),2),3) Department of Agribusiness, Faculty of Economics and Management, IPB University, West Java, Indonesia

4) Social Science Group, Business Science, Business Economics, Wageningen University and Research, Gelderland, Netherlands

* Corresponding Author: hera@apps.ipb.ac.id

ABSTRACT

Smart postharvest technology in the form of Controlled Atmosphere Storage (CAS) is needed to increase the shelf life of shallot. However, the application of CAS requires high investment costs related to the initial setup such as land, warehouse, CAS, and CAS supporting equipment. Thus, it is necessary to analyze the benefits and costs for farmers' welfare reflected by adding the amount of farming margin and income from other sources considering the time adjustment. This study aims to build a dynamic model for the application of CAS technology in shallot farming and evaluate its costs and benefits for farmers' welfare. The method used is the integration of cost and benefit analysis into a dynamic system model. The results showed that shallot farmers' income is very sensitive to price changes and increasing storage costs. Hence, adopting CAS technology could mitigate some of these effects by reducing post-harvest losses and allowing farmers to store their production in favorable situations. Moreover, the CAS model showed that in the management level, CAS could be feasible (in terms of NPV, IRR, and Net B/C), if the storage cost is at least IDR 2.000/kg. According to the minimum profit limit for farmers, the maximum storage cost is IDR 1.500/kg, which makes the CAS unfeasible to run. The successful adoption of CAS is contingent upon substantial financial support from both private-sector investors and government entities. Therefore, the CAS technology is more appropriate for adoption by stakeholders in the food industry who require a consistent year-round supply of shallots.

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INTRODUCTION

Shallots are considered a national staple commodity alongside rice, soybeans, and chillies, as affirmed by Presidential Regulation No. 59 of 2020, which addresses the determination and storage of essential goods. Consequently, in strategic plan No.259/Kpts/RC.020/M/05/2020, the Ministry of Agriculture designates shallots as one of the national strategic commodities. This is due to their high economic value, contributing to food security through price stabilization. Approximately 300,000 farming households rely on shallots for their livelihood (Statistics Indonesia, 2018).

As a national strategic commodity, the harvest area and production of shallots have grown from 2003 to 2019, with annual growth rates of 4.2% and 5%, respectively (Pusdatin, 2020). Furthermore, the consumption of shallot has increased over time with growth reaching 4.5 percent per year (Pusdatin, 2023). However, due to the seasonal nature of shallot production, availability and supply fluctuate monthly. Studies by Kumar et al. (2023) and Cahyaningrum et al. (2023) indicate that seasonal production leads to a mismatch between production timing and market demand, causing supply instability throughout the year. This results in fluctuating shallot prices, categorizing them as volatile products. The volatility of shallot prices, with a coefficient variation of 20%, is a significant contributor to inflation. Wibowo & Novanda (2023) stated that the price volatility of shallot is in the third rank after red chili and cayenne pepper. Therefore, maintaining the stability of shallot supply in the market is crucial to reducing price volatility (see Figure 1).

Research by Puspitasari et al. (2012) proved that fluctuations in shallot supply directly affect market prices. This can cause instability that is detrimental to both farmers and consumers. This price instability can reduce consumer purchasing power and disrupt production planning for farmers, which ultimately has an impact on income uncertainty. Therefore, efficient supply chain management in agricultural products is something that needs attention, including shallots. FAO (2019) asserts that supply stability can be achieved by improving storage and distribution infrastructure, as well as the use of technology to predict and manage production and demand.

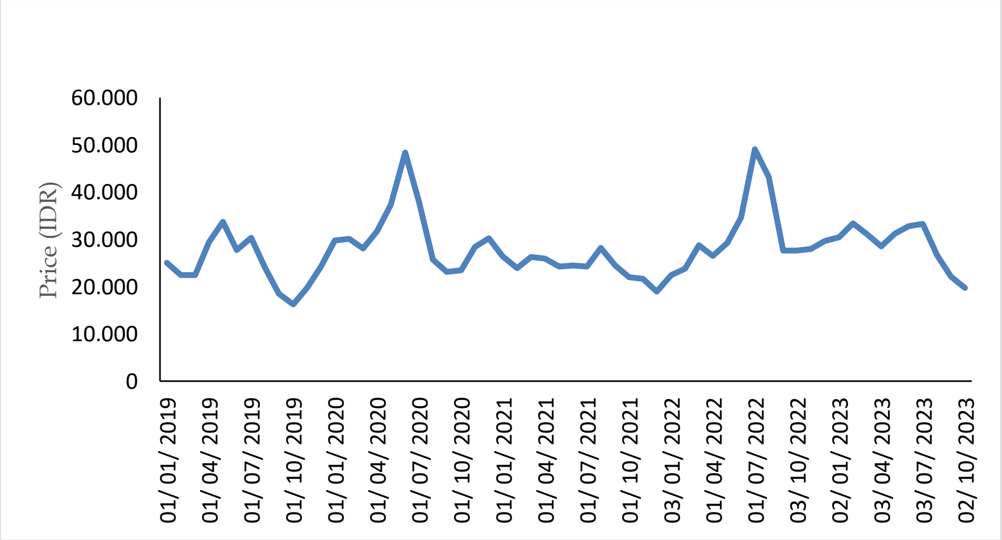

Figure 1.
National Average Of Shallot Prices At The Consumer Level
Source: Data processed (PHIPS, 2023)

In addition to seasonal production, the unstable supply of shallots is affected by the risk of crop failure due to extreme weather and pest attacks (Hidayah et al, 2023; Chhogyel et al., 2020). High post-harvest losses along the shallot distribution chain also contribute to reduced shallot supply. This is reinforced Prasad et al., (2023); Priyadarshi et al. (2023) and Yahia et al. (2019) that postharvest losses in agricultural supply chains are a significant problem as with horticultural crops. The postharvest loss rate of shallots reaches 45% after two months of storage (BBP4, 2016). These losses are often caused by improper handling, storage, and transport, as well as the negligence of intermediaries (Gunarathna, 2020). Thus, there needs to be an effort to overcome supply constraints outside the harvest season and reduce price volatility with the use of post-harvest technology. The use of appropriate postharvest technologies is suggested as a potential solution to reduce losses (Van et al., 2013; Tomlins, 2016). Tuffa (2016) and Schudel (2023) corroborate that it is important to improve value chain efficiency, increase co-operation among stakeholders, and invest in infrastructure and technology.

Farmers have been using conventional post-harvest technology by tying shallots in para-para houses without regulation of aeration, temperature, humidity, and sanitation. One of the smart storage technologies being considered is Controlled Atmospheric Storage (CAS). CAS technology is storage with cooling, maintaining the humidity of O_2, CO_2, N_2 and ethylene, thus slowing down the shrinkage of shallots. For shallots, usually there will be a shrinkage of 1%-10% per day if stored in a conventional warehouse, but with

CAS technology, the shrinkage of shallots can be suppressed to a maximum of 10% for three months (Waseso, 2019).

Several studies have demonstrated the efficacy of CAS in extending the shelf life of various agricultural products. Research conducted by Ikegaya et al. (2023); Arshad (2023); and Thompson et al. (2019) showed that CAS can significantly reduce the spoilage rate of shallots by maintaining optimal storage conditions. The study found that shallots stored under CAS conditions had a significantly longer shelf life and were able to retain the essential nutrients of shallots compared to those stored under normal conditions, with less weight loss.

The economic benefits of CAS are substantial, benefiting both farmers and storage facility operators, including traders, farmer groups (Gapoktan), Regional-Owned Enterprises (BUMD), and government entities. CAS not only enhances farmers' income but also reduces economic losses by minimizing spoilage, thereby stabilizing market prices and ensuring a consistent supply of high-quality products throughout the year. Studies by Espindola et al. (2022) and Mohan et al. (2023) have shown that CAS can significantly reduce postharvest losses, with potential savings of up to 30% due to extended storage periods and improved product quality. These advantages collectively contribute to the economic resilience of agricultural stakeholders and the broader agricultural sector. The implementation of CAS requires high investment costs, and the need for technical expertise to manage these storage facilities is a significant constraint, especially in developing countries. Thus, a financial feasibility study is essential to be understood. Nevertheless, the studies on it are limited.

The absence of studies on the costs and benefits of CAS for farmers' welfare encourages this research to focus on dynamic system modelling of CAS implementation in shallots. In addition, there is no CAS warehouse in all shallot production centres other than Brebes, including Garut, West Java. A dynamic systems approach in simulating the costs and benefits of CAS implementation can help farmers and stakeholders in shallot production centres make a thorough assessment of the implementation of this technology. Therefore, it is necessary to comprehensively study the costs and benefits of CAS, especially for the welfare of shallot farmers in Indonesia. Therefore, the objectives of this study are (1) to build a dynamic model of the application of CAS technology in shallot commodities; (2) to evaluate the costs and benefits of CAS technology for the welfare of farmers.

RESEARCH METHOD

Data Collection Methods

This study used primary and secondary data related to shallot agribusiness. Primary data include processes, costs, and benefits of shallot farming, post-harvest, and marketing activities at the farm level, including farmers' perceptions of CAS implementation. Additional data covers issues and policies related to shallots at the stakeholder level. Primary data were obtained by conducting in-depth interviews with seven shallot farmers in Garut Regency and purposively selected stakeholders, three representatives of The Agricultural Training Center of Bayongbong Subdistrict (BPP), and three representatives of Garut Regency Agriculture Office. The shallot farmers are representatives of shallot champion farmers in Garut Regency who are assisted by the Indonesian Ministry of Agriculture. Garut Regency was chosen because CAS for shallots has not yet been implemented; thus, a pre-implementation evaluation is needed to improve the effectiveness of CAS use if implemented. Secondary data include time series data on production, area, input prices, and output prices, as well as qualitative data related to the implementation of CAS, Resi Gudang System, and other related policies.

Model parameters and scenarios were gathered through focus group discussions (FGDs) with stakeholders, particularly the government. The FGDs and in-depth interviews are qualitative research methods that prioritize the identification of key issues over strict sampling size requirements. Both FGD and in-depth interviews aim for information richness rather than a specific sample size, where trust and ethical considerations are paramount (Seetharaman, 2016; Guerrini et al., 2022). For the FGD and in-depth interviews aims to identify key issues and general parameters of shallot farming practices from the farmers. Unlike statistical modeling, systematic modeling is simulation-based, and data can be obtained from multiple sources, including secondary and primary data, as long as the parameters reflect the real conditions of the shallot farming system.

Secondary data were sourced from various local government agencies, villages, non-governmental organizations, and the private sector through direct visits and desktop research. The secondary data selected for analysis include the cost structure of shallots in Indonesia from Statistics Indonesia (BPS, 2023) and the consumer and producer price data of shallots from Kramat Jati market. The selection of these sources was based on a number of criteria. (1) BPS is a reputable and authoritative source for agricultural data in Indonesia, renowned for its comprehensive coverage and accuracy; (2) Kramat Jati market is a principal market hub in Jakarta, offering representative price data that reflects broader market trends. The rationale for selecting these sources is to ensure the reliability of the secondary data and its capacity to validate the primary data collected through in-depth interviews with the Ministry of Agriculture and focus group discussions (FGDs) with farmers in Garut.

Data Analysis Method

In a systems thinking approach, the modeling process should be conducted systematically to ensure a comprehensive understanding of the issues addressed by the developed model. Several steps are involved in building a dynamic system model and evaluating the use of CAS (Figure 2). Referring to research conducted by Muflikh et al. (2021) these steps are:

(1) Stakeholder analysis. Stakeholder analysis is crucial in building a dynamic system model and evaluating the use of CAS because it ensures that the model considers the perspectives and needs of all relevant parties. Key stakeholders include farmers, agricultural extension agents, policymakers, researchers, technology providers, and market actors. Engaging these stakeholders helps identify key issues, ground the model in real-world experiences, and make it more accurate and relevant. Their input ensures the model addresses practical concerns like economic feasibility and adoption barriers. This collaborative approach also fosters ownership and increases the chances of successful implementation of CAS technology, leading to a more effective model for decision-making.

(2) Problem articulation. Problem articulation is the most important step in system dynamics modeling. It helps define CAS, identify key issues, analyze important variables, establish a time frame for examining problem behavior, and establish historical patterns of these variables.

(3) Dynamic hypothesis formulation. After defining the problem behavior over a suitable time period, the system boundary is set by conceptualizing the system and forming a dynamic hypothesis. This boundary is defined by causal relationships and explains the problem behavior. The dynamic hypothesis, which is a theory about the causes of the problem, is tested through simulation. It guides model development by focusing on feedback loops—reinforcing and balancing. The dynamic hypothesis outlines the causal structure and feedback loops within feasibility study of CAS to ensure the model is structurally and behaviorally accurate.

(4) Simulation model formulation. The dynamic hypothesis from the previous step is converted into a comprehensive simulation model. This formalization process clarifies any ambiguous concepts from the dynamic hypothesis by constructing a stock and flow model that illustrates the system's material and information flows. It also includes defining the mathematical equations and initial conditions for the model. In most studies, the dynamic hypothesis and the simulation

model are distinctly developed, allowing for a clear distinction between qualitative and quantitative models and providing stakeholders with a transparent understanding of the model development process.

(5) Model testing and validation, including various intervention scenarios. In this step, simulations are conducted using the formalized models to assess their performance and reliability. The most frequently used tests are the behavioral reproduction test, which determines if the simulated behavior aligns with real-world behavior, and sensitivity tests, which examine how variations in assumptions influence the outcomes. Additionally, some studies adhered to Sterman's model testing approach, involving a review of the model structure, ensuring all key elements are included, verifying consistency, and evaluating how the model responds under extreme conditions.

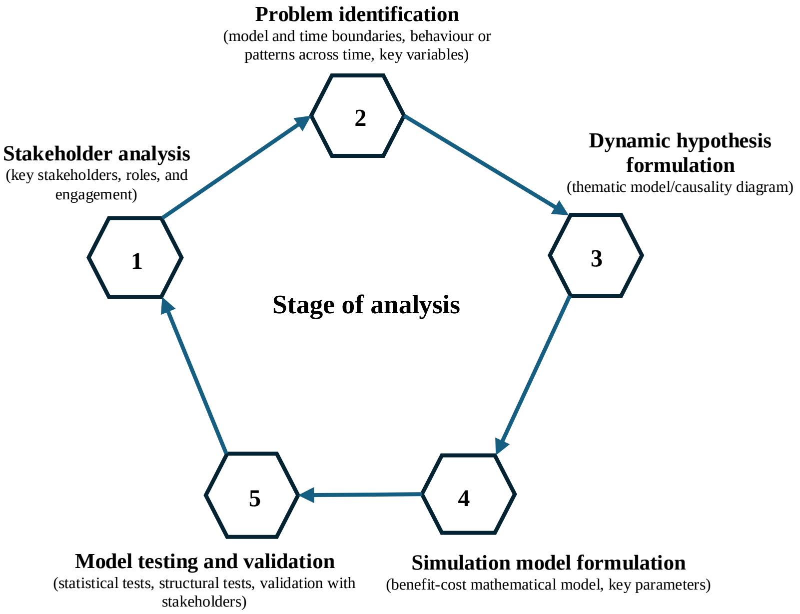

Figure 2.
Stages of Analysis of the Application of CAS in Shallots
Source: Developed by Authors (2023)

The expected pattern or behavior of the system in the implementation of CAS includes a decrease in costs, an increase in farmers' income, and a stable supply of shallots. Hypothetical model formulations use causal loop diagrams to generate these targeted patterns of system behavior. Figure 3. presents the dynamic model framework at the level of farmers as users and stakeholders as

CAS managers. The results of the cost and benefit analysis serve as the basis for evaluation and policy recommendations.

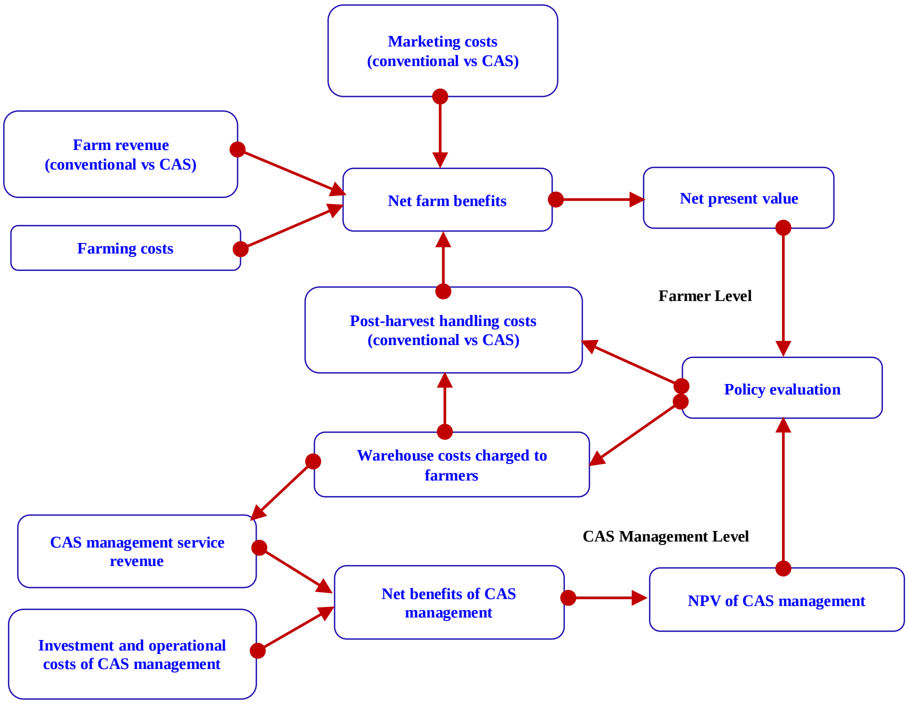

Figure 3.
Dynamic Modelling Framework for the Application of CAS in Shallots
Source: developed by authors (2023)

The dynamic systems approach allows for testing various planning or policy scenarios as well as the impact of unexpected environmental changes such as the Covid-19 pandemic on the implementation of CAS. Assessment of various alternative planning scenarios is useful to anticipate various possible trade-offs and negative effects (Maani & Cavana, 2007).

The systems approach is a problem-solving method based on systems thinking where there is a reciprocal relationship between elements in the system (Maani & Cavana, 2007; Sterman, 2000). These systems thinking approach is very useful for building a model of a system and evaluating interventions (both in the form of policies and internal and external changes) (Rich et al., 2011). Dynamic system simulation examines the relationship between the structure of a system and the behaviour or trend pattern of a system whether exponential, fluctuating or stagnant (Sterman, 2000; Muflikh et al., 2021).

We employed multiple data collection methods to ensure triangulation. This included consultations with experts, such as an IPB professor who has conducted extensive research on post-harvest technology, to discuss the feasibility study of CAS technology; consultations with Pasar Jaya DKI Jakarta, which has implemented CAS technology, to gather insights on CAS practices and associated costs; and discussions with the Directorate General of Horticulture regarding programs, policies, farming practices, and harvesting costs.

Integration Of Cost And Benefit Analysis Into Dynamic System Modelling

To effectively incorporate cost-benefit analysis into dynamic system modeling for implementing controlled atmosphere storage for agricultural products, it is essential to consider various factors and technologies related to postharvest storage and atmosphere control. By developing a comprehensive approach, this integration can optimize storage conditions, enhance product quality, and maximize economic returns in agricultural practices. Regarding the economic aspects of implementing controlled atmosphere storage, references such as Ukoha (2020) provide valuable insights into cost-benefit analysis in agricultural practices.

The dynamic modeling framework for the application of CAS technology in shallots, which is compiled based on the results of interviews with related parties, is presented in the following Figure 3. In the following model, two conditions of shallot storage are simulated, namely with CAS and conventional.

Integration Of Cost And Benefit Analysis Into A Dynamic System Model

In developing the implementation of CAS, quantitative data will be collected, including inputs, outputs, post-harvest costs, and prices, which will then be further analysed using the main investment criteria. The cost and benefit analyses that will be integrated into the dynamic system simulation model (Figure 3.) are as follows (Gittinger, 1986; Nurmalina et al., 2009):

a) ***Net Present Value*** **(NPV)**

$$\text{NPV} = \sum_{t=0/1}^{n} \frac{Bt}{(1+i)^t} - \sum_{t=0/1}^{n} \frac{Ct}{(1+i)^t} = \sum_{t=0/1}^{n} \frac{Bt - Ct}{(1+i)^t}$$

where: Bt = benefits in year t; Ct = costs in year t; t=0/1 the time the initial investment or cash outflow occurs; t = year of business activity (t = 1, 2, 3, ... n); i = discount rate (%). The NPV indicator is that if NPV > 0, then the application of CAS benefits farmers and managers and is feasible to apply to shallot commodities. However, if NPV < 0, then the application of CAS must be re-evaluated.

b) ***Net Benefit Cost Ratio*** **(Net B/C)**

$$\text{Net}\frac{\text{B}}{\text{C}} = \frac{\sum_{t=0/1}^{n} \frac{Bt - Ct}{(1+i)^{t}}}{\sum_{t=0/1}^{n} \frac{Bt - Ct}{(1+i)^{t}}} \quad \frac{(Bt - Ct) > 0}{(Bt - Ct) < 0}$$

where: Bt = benefits in year t; Ct = costs in year t; t=0/1 the time the initial investment or cash outflow occurs; t = year of business activity (t = 1, 2, 3, ... n); i = discount rate (%). The Net B/C indicator is that if Net B/C > 1, then the application of CAS benefits farmers and managers and is feasible to apply to shallot commodities. However, if Net B/C < 1, then the application of CAS must be re-evaluated.

c) ***Internal Rate of Return*** **(IRR)**

$$\text{IRR} = i_1 + \frac{NPV_1}{NPV_1 - NPV_2} \times (i_2 - i_1)$$

where: i = two discount rates (i_1 and i_2) that are reasonably close to the expected IRR; NPV_1 = the NPV at discount rate i_1; NPV_2 = the NPV at discount rate i_2. The IRR indicator is that if IRR > Discount Rate, the application of CAS benefits farmers and managers and is feasible to apply to shallot commodities. However, if IRR < Discount Rate, then the application for CAS must be re-evaluated.

Dynamic System Model Testing

In testing dynamic models, several criteria are commonly employed to ensure the accuracy and reliability of the models. These criteria include the unit consistency test, the non-negativity element test, and the model structure conformity test with the desired behavior pattern, such as costs decreasing and benefits increasing. While historical data patterns or trends like historical price data are not typically tested, validation of the model with stakeholders is crucial to ensure that the model aligns with reality.

The unit consistency test is essential to verify that the units of measurement in the model are coherent and consistent throughout the calculations (Koenker & Zhang, 2006). The non-negativity element test ensures that dynamic quantities within the model remain non-negative, which is crucial for the model's validity (Mickens, 2010). Additionally, the model structure conformity test assesses whether the model behaves as expected, with costs decreasing and benefits increasing over time (Bleichrodt et al., 2021).

In the stock and flow model, unit consistency for each parameter is carefully checked. For example, units related to processes, costs, productivity, and production are verified to ensure no inconsistencies. Non-negativity is enforced for stock variables where negative values are not permissible, such as land area. However, for income, which may be negative due to potential business losses, negative values are allowed. Additionally, the model structure is assessed to ensure it accurately reflects the frameworks of both the farming income analysis model and the feasibility study model. All tests will be documented and analyzed to ensure accuracy and relevance.

Although historical data patterns are not directly tested in these criteria, the validation of the model with stakeholders serves as a critical step to ensure that the model accurately represents real-world dynamics (Jarvis & Kelley, 2021). By involving stakeholders in the validation process, the model can be refined to better match the actual behavior of the system it represents. The matrix in Figure 4 classifies stakeholders into one of the following groups (Reed et al., 2009; Permani et al., 2023):

(1) Stakeholders with low involvement and low influence: The strategy is to monitor and provide information to these stakeholders about what will or has been done.
(2) Stakeholders with low involvement and high influence: The strategy is to convince these stakeholders that the planned or ongoing program has good objectives and results.
(3) Stakeholders with high involvement and low influence: Involve these stakeholders in the program so that it provides better benefits than before.
(4) Stakeholders with high involvement and high influence: The strategy is to collaborate with these stakeholders so that the program can run well.

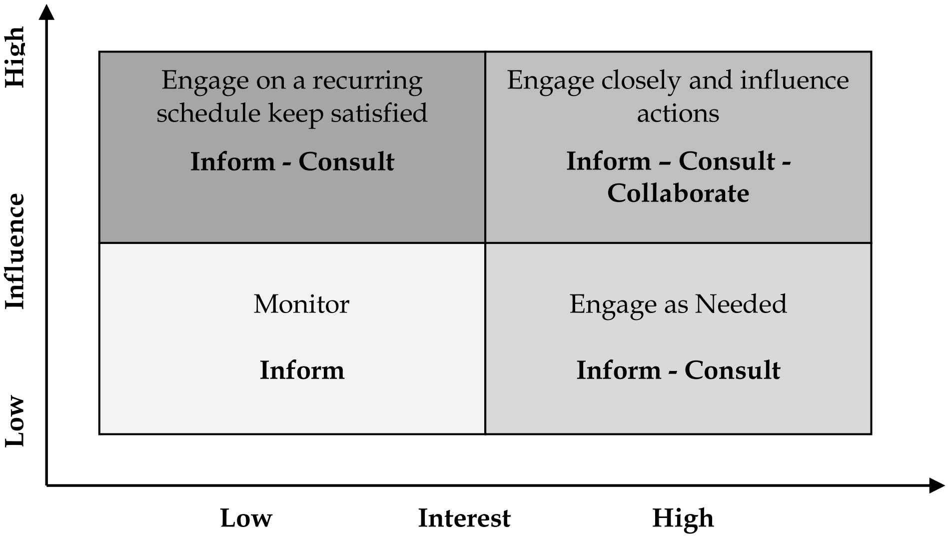

Figure 4.
Mapping stakeholders by strengths, influences, and concerns or interests
Source: Adapted from Reed et al. (2009); Permani et al. (2023)

RESULT AND DISCUSSION

Overview of Shallot Farmers in Garut Regency

The champion shallot farmers in Garut Regency are mentored by the Indonesian Ministry of Agriculture, with an area of approximately 3,500 hectares dedicated to shallot cultivation, and a harvest area reaching 3,200 hectares. Bayongbong Sub-district serves as the production center, with 1,500 hectares of land planted with shallots. The average productivity is 12 tons of dried shallots or 18 tons of fresh shallots per hectare, with a harvest time of around 60 days. This information indicated that shallot cultivation in Garut has high efficiency because the productivity is higher than the average productivity in Indonesia which is 10,05 tons/ha (Pusdatin, 2023).

Garut Regency has significant potential to support national food security through the Horticultural Food Estate program, with farmers contributing to both the local economy and national food supply. Garut Regency, contributing 18.11 percent to West Java's agricultural output and ranking as the third highest producer in the region (Pusdatin, 2023), owes its significance in chili and shallot cultivation to its favorable agro-climatic conditions. The region's specific altitude and consistent rainfall patterns create an optimal environment for high agricultural productivity (Saidah et al., 2020; Luckyardi et al., 2022).

Most of the production is sold, while a small portion is used as seeds for the next season. Farmers have warehouses to store and dry shallots, with a storage period of 2-3 months and a shrinkage rate of 30%, often storing produce when prices are low to delay sales until prices improve. The commonly cultivated varieties are Tuk Tuk and Bali Karet (Batu Ijo), with an average productivity of 8-9 tons/ha for dried shallots and 18 tons/ha for fresh shallots.

The selling price of fresh shallots ranges from IDR 6,000 to IDR 10,000 per kg, dried shallots from Rp 12,000 to Rp 20,000 per kg, and shallot seeds from Rp 25,000 to Rp 30,000 per kg. Planting is done on dry land (fields) during the rainy season and on paddy fields during the dry season, with production costs of 120-140 million IDR/ha in the dry season and 90 million IDR/ha in the rainy season. The champion shallot farmers have a shared storage warehouse with a capacity of 80 tons, managed by nine farmer groups with an average of 25 members per group. These champion farmer groups play a role in maintaining the stability of shallot supply and prices in West Java Province.

Stakeholder Analysis of CAS Technology Utilization

Stakeholder mapping was conducted using the interest (relevance)-influence (power) matrix (Reed et al., 2009; Goodman & Thompson, 2017; Permani et al., 2023). It is important to evaluate the relevance (interest) and influence (power) of each stakeholder concerning the implementation program of the CAS model for shallot commodities in Garut Regency if the program is implemented. Relevance refers to the extent to which stakeholders are related to the CAS program and shallots. The implementation of CAS technology in shallots involves various stakeholders.

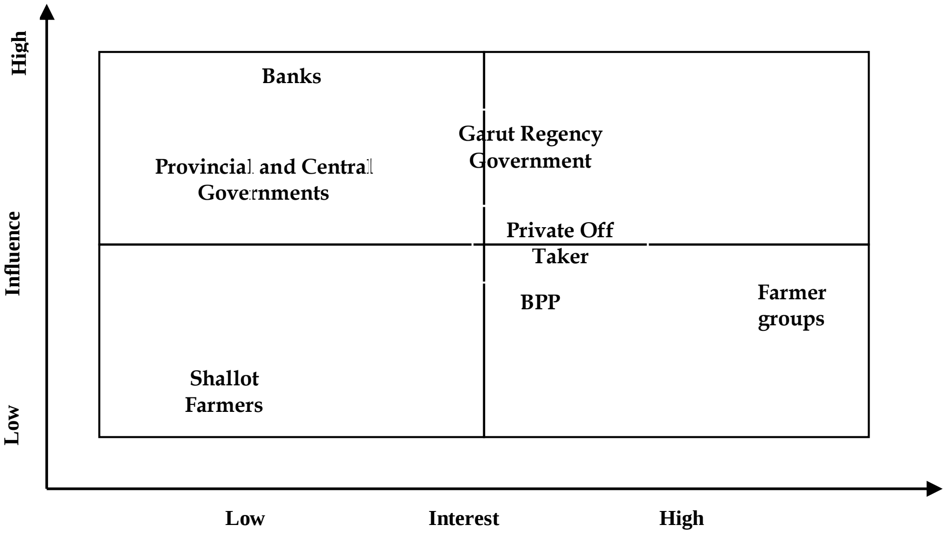

Figure 5.
Mapping of stakeholders involved in the implementation of CAS
Source: FGD and interviews (2023)

Based on the results of the desk study, focus group discussions (FGD), and interviews with stakeholders in Garut Regency, it is clear that a diverse range of stakeholders, each with varying levels of involvement and power, are engaged in the implementation of CAS. Despite the involvement of multiple parties, including government bodies and private sector actors, it is anticipated that there will be no significant conflicts or overlaps in their roles. This is due to the distinct and complementary functions assigned to each stakeholder, which are carefully delineated to ensure effective collaboration. The specific roles and responsibilities of each stakeholder are outlined below to illustrate how their contributions are coordinated to support the successful implementation of CAS without any potential discord.

1. Shallot farmers, although highly involved in shallot production, have low power in decision-making and implementation of the CAS program. Crucial in the production chain but limited in decision-making and technology implementation. Their influence is minimal despite their significant efforts in cultivation and harvest.

2. Farmer groups are vital in implementing CAS technology, bridging the gap between innovation and practical application. They have high interest, but low power. Their involvement in knowledge-sharing and collaboration with research institutions and government agencies positions them as key drivers of sustainable storage solutions. The shallot farmer group aids farmers in facilitating needs from purchasing production facilities to post-harvest handling and marketing (Asriadi & Husain, 2022).

3. The Agricultural Extension Office (BPP) has medium involvement and relatively low power in implementing the CAS program. Acts as a knowledge disseminator and educator, participating in training and workshops. Despite their instrumental role, their influence on policy formulation is limited. Their medium involvement includes active participation in training, workshops, and field demonstrations to promote CAS adoption. Collaborating with farmer groups, research entities, and government agencies, BPP enhances post-harvest management practices. Their role as a knowledge transfer facilitator highlights the network of stakeholders in agricultural development.

4. The Garut Regency Government has a significant role with moderate involvement and high power in shaping policies to bolster shallot development, including the CAS program. As the local governing body for agricultural policies, they set guidelines and allocate resources to support CAS adoption. Their proactive measures include strategic planning, subsidies, infrastructure development, and capacity-building programs. Collaborating with agricultural extension services, research

institutions, and private stakeholders, they promote knowledge exchange and innovation. Their high regulatory power ensures policies align with broader agricultural goals and address local challenges in shallot production. Through effective governance and stakeholder engagement, they advance sustainable agriculture and strengthen farmers' resilience, contributing to the long-term viability of the shallot industry.

5. Private off takers are pivotal in advancing shallot development and adopting CAS. As key market players, they influence market dynamics and technological adoption with moderate power, driving demand and pricing strategies. Their involvement spans the supply chain, including procurement, distribution, quality assurance, and market access, shaping the competitiveness and sustainability of shallot farming. Collaborating with government agencies, research institutions, and farmer groups, they enhance CAS adoption through partnerships and investments in storage solutions. This improves post-harvest management and product quality, supporting the growth and resilience of shallot farming. Private off takers are key enablers of sustainable growth and technological advancement in the shallot industry.

6. Both provincial and central governments exert significant influence with low direct involvement in the CAS program's policymaking. As key regulatory bodies, they shape the framework for CAS and other agricultural innovations through policy formulation and resource allocation. Although not deeply involved in daily operations, they set strategic directions, provide incentives, and ensure adherence to national standards and environmental regulations. Collaborating with local administrations, research institutions, and industry stakeholders, they align policies with regional needs to enhance the program's effectiveness and sustainability. By leveraging their authority, provincial and central governments support the scalability and long-term viability of CAS, aiming to improve food security, reduce post-harvest losses, and enhance agricultural competitiveness.

7. Banks provide crucial capital loan assistance for CAS investment, making it more affordable and accessible for farmers. Thus, they have high power, but low direct interest to use CAS. Their financial support enhances agricultural sustainability and productivity. Collaborating with extension services, government agencies, and industry stakeholders, banks tailor financial products to meet farmers' needs, driving agricultural innovation and sustainable development, thereby contributing to food security and economic growth.

Identification Of Problems In Shallot Production And Marketing In Garut Regency

Based on the results of FGD and interview as well as the desk study, farmers in Garut Regency face several problems that affect farm productivity and income. The main problems faced by shallot farmers include price fluctuations, low productivity, high production costs, non-optimal storage management, and the lack of availability of modern storage technology.

Shallot Price Fluctuations

One of the main problems faced by shallot farmers in Garut Regency is the fluctuation of their commodity prices. The price of shallots tends to rise and fall drastically throughout the year, which can result in financial losses for farmers. These significant price fluctuations are often beyond farmers' control and can significantly affect their income. From 2022 to 2023, Figures 6 show that the price of shallots in the Kramat Jati wholesale market changes a lot and follows an unpredictable pattern. For example, in 2022, the price of shallots hit an all-time high of IDR 62,000 in July, while in 2023, the price hit an all-time low of IDR 17,000 in the same month. The average price stayed about the same, at IDR 26,000 to IDR 28,000.

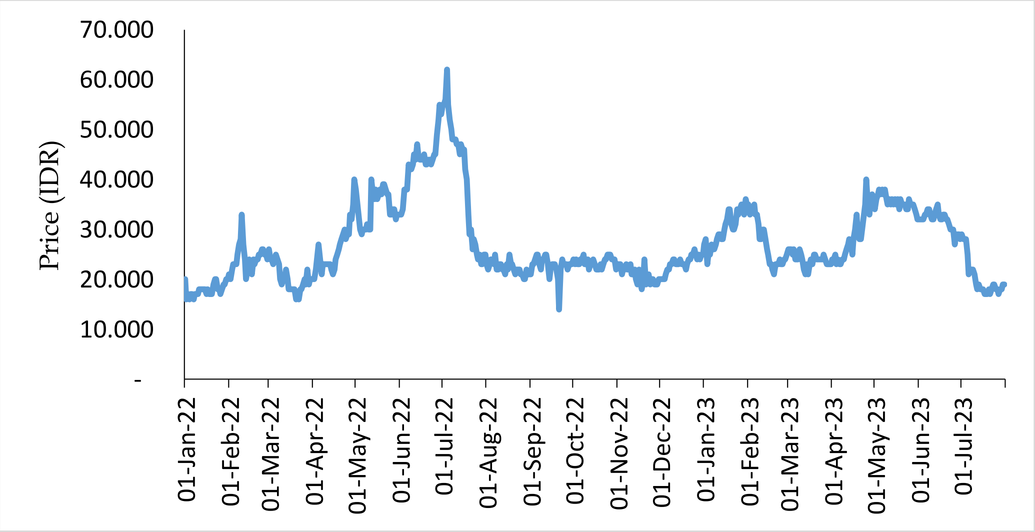

Figure 6.
Trend in the price of shallots at the wholesale level in 2022 - 2023
Source: Kramat Jati Market (primary data, 2023)

Farmers face high market price fluctuations and price uncertainty every year. If farmers are price takers, price changes at the farm level are highly dependent on price changes at the wholesale level. The relatively asymmetric transmission of shallot prices due to the market information gap causes price increases at the consumer level to not be accompanied by the same increase at the producer level (Magfiroh et al., 2017). This has a negative impact on farmers' income. At the time of the study (2023), the lowest average price of dried shallots at the farm level was IDR 12,000, and the highest average price was IDR 20,000. With these prices, the farmer's share compared to the price in the wholesale market was 70–71%. The price of dried shallots is twice the price of wet shallots. Some farmers in Garut Regency sell dried shallots, while others sell wet shallots.

Low Productivity

Shallot productivity in Garut Regency is still low, at 18 tons/ha for wet bulbs and 8–9 tons/ha for dried shallot production. Farmers often face problems in optimizing their production, such as proper seed selection, efficient farming techniques, and pest and disease management. This low productivity reduces yields and farmers' income.

High Production Costs

The production cost of shallots in Garut Regency is relatively high, between IDR 83 million/ha in the rainy season in upland areas and IDR 107 million/ha in the dry season in paddy fields, excluding post-harvest costs. Farmers incur high costs, especially for land rent in paddy fields, seeds, fertilizers, pesticides, and labor. Even if the seeds are from their own crops, the cost of these seeds must be considered because it reduces farm income from selling shallots that are used for seed purposes. These costs can reduce the profit earned from selling shallots.

Losses During the Storage Process

One of the main problems in shallot storage in Garut Regency is the high level of losses during the storage process. Shallots are often stored in traditional conditions, such as stacked in para-para or inadequate storage sheds. During storage, shallots can experience shrinkage of up to 10% per month, which means farmers lose a significant portion of their harvest. The longer the storage period, the higher the risk of shrinkage and deterioration due to poor storage conditions (mold growth, hollowing, etc.), and the higher the risk of losing sales revenue.

Limited Capacity of Government-Assisted Warehouses

Although the Central Government of the Republic of Indonesia, through the Ministry of Agriculture, has provided a shallot storage warehouse to Garut Regency, its use is still subpar. The warehouse has a limited capacity of around 80 tons, which is often insufficient for large-scale shallot storage needs. As a result, farmers must take turns using the warehouse, with shallots staying in the warehouse for at most two weeks. The warehouse management is self-help among farmer group members, who pay the cost of a security guard every month.

Lack of Modern Storage Technology

Modern storage technology, such as CAS, is not yet available in the Garut Regency. Although plans to build a CAS facility have been discussed, the investment required is very high. It is estimated that the investment for one CAS unit with a capacity of 150 metric tons could reach IDR 2.4 billion. This lack of modern storage technology limits farmers' ability to maintain the quality of their shallots during storage. However, the high cost of this investment should be further assessed to determine if it provides commensurate benefits to farmers and CAS managers if the program is implemented at the farm level or if alternative schemes and policies should be considered.

Identification of Problems in Shallot Production and

The dynamic hypothesis model framework for CAS technology implementation involves two levels of stakeholders. The first level includes shallot farmers who are interested in utilizing storage technology and are willing to pay some storage costs. The second level consists of warehouse managers who are interested in the feasibility of CAS technology storage services. These warehouse managers operate at the farmer group or farmer group association (Gapoktan) level with limited support from the local government. Given that CAS technology requires high investment and operational costs, it is necessary to assess its feasibility. CAS technology, while effective in extending the shelf life of fruits and vegetables, presents significant challenges in terms of investment and operational costs (Thompson, 2018). The dynamic hypothesis posits that CAS technology is feasible to implement with a certain minimum saving cost and capacity that can be utilized. Feasibility depends significantly on the farmers' ability to pay the storage costs and the prevailing selling price. Currently, farmers can only contribute IDR 200/kg per fortnight for storage in warehouses, equating to IDR 1,000/kg per month.

Simulation Model Formulation and Results

At this stage, a simulation model of the feasibility of using Controlled Atmosphere Storage (CAS) for the welfare of shallot farmers in Garut Regency was developed. The model simulation showed how the adoption of CAS technology could potentially improve the income and overall welfare of shallot farmers in the region. For the model simulation to reflect the real conditions and constraints faced by shallot farmers in Garut Regency, assumptions were made based on data collected from field FGDs and interviews, as well as desk studies of various publicly available data, such as BPS production cost data.

The SFM for this study includes two critical sub-models: (1) the shallot income model at the farmer level and (2) the CAS management model at the warehouse manager level. The latter could represent farmer groups or other management institutions, whether private or governmental. This dual model approach allows for detailed analysis of both individual farmer incomes and broader management practices and efficiencies at the warehouse level.

Based on the data collected, several key parameters were identified and included. These parameters include production costs, prices of shallots in different forms (wet and dry), storage costs, and the different climatic conditions affecting shallot cultivation (rainy season upland and dry season lowland paddy fields). By simulating different scenarios, the model aims to capture the different conditions under which shallots are grown in the Garut Regency and the potential impact of CAS on farmers' incomes under these different conditions.

The scenarios developed for the simulation consider four main combinations: (1) wet shallot during the wet season (upland), (2) wet shallot during the dry season (lowland), (3) dry shallot during the wet season (upland) and (4) dry shallot during the dry season (lowland). Each scenario presents a unique set of challenges and opportunities for growers. For example, wet shallots are more susceptible to spoilage and therefore benefit more from CAS, which can extend shelf life and reduce post-harvest losses. On the other hand, dry shallots, which already have a longer shelf life, may not see a significant impact from CAS, but the technology could still provide benefits in terms of quality preservation and market timing. In Indonesia, shallots are commonly cultivated in both lowland and upland regions. Despite this, most of the production areas are situated at low elevations (Sopha et al., 2023).

The reliability of the simulation results was reinforced by a thorough validation process of the assumptions regarding input costs and prices. The values used in the simulation are based on survey data from statistical sources and have been cross-verified with data from farmer groups in Garut, ensuring that they accurately reflect real-world conditions. To further validate these assumptions, a sensitivity analysis was performed, examining how variations in storage costs and product prices—key factors influencing the implementation of CAS—affect the technology's overall feasibility. This analysis highlights the robustness of CAS across different scenarios and demonstrates how fluctuations in critical variables can impact its viability. Incorporating this analysis offers a clearer understanding of the technology’s performance and adaptability under varying conditions, thereby enhancing the reliability of the simulation results.

Table 1. Some assumptions and parameters used in the Stock and Flow Model (SFM) of the feasibility of CAS implementation in Garut Regency

Sub-model	Parameter	
Shallot Farmer (per hectare per season)		
A. Income		
Production of wet shallots		
Upland (ton/ha)	13.5	
Lowland (ton/ha)	18	
Production of dry shallots		
Upland (ton/ha)	7.5	
Lowland (ton/ha)	10	
Average price of wet shallots (IDR/kg)	9,000	
Average price of dry shallots (IDR/kg)	16,000	
B. Production Cost Structure (000 IDR/ha)	Upland	Lowland
1. Seeds	23,992	25,367
2. Fertilizers	6,607.5	9,514.08
3. Pesticides/Fungicides/Insecticides	9,512.9	13,698.6
4. Fuel	811	1,167
5. Electricity	77	110.88
6. Protective Nets	29.4	42
7. Mulch	681.4	681.4
8. Containers, Polybags, Sticks, Ropes	628.8	628.8
9. Labor	28,654.7	41,290
10. Land Rent	7,550.9	7,550.9
11. Other Expenses	4,935	7,106
C. Storage Cost Structure		
Storage cost (IDR/kg)	200	
CAS Manager (per year of operation)		
1. Warehouse with CAS Income		
Warehouse storage capacity (ton)	80	
Warehouse occupancy rate (%)	60	
Minimum CAS rental price (IDR/kg)	2,000	
2. Investment Costs (IDR)		
Shallot warehouse	1,400,000,000	
CAS	2,400,000,000	
Warehouse land	3,000,000,000	
CAS supporting equipment	50,000,000	
3. Operational Costs (IDR/year)		
Variable operational costs	120,000,000	
Fixed operational costs	132,000,000	

Source: FGD, interviews, BPS data, and Kramat Jati Main Market (2023)

The Shallot Farming Income Model

The shallot farming income model in Garut Regency comprises three key components: the revenue model, the production cost model, and the storage cost model. These models are designed to evaluate various shallot farming systems, including the cultivation of wet and dried shallots in both upland and lowland rice fields. The incorporation of data from focus group discussions (FGDs), interviews, and publicly accessible sources, such as Statistics Indonesia, enables a comprehensive analysis of the feasibility of controlled atmosphere storage (CAS) technology for shallot farmers in the region. Simulations of these models were conducted over 20 years, reflecting the business life expectancy of CAS implementation at the manager level. This long-term perspective allows for a thorough assessment of the potential financial and logistical benefits of adopting CAS technology for shallot farmers. The results from these simulations provide valuable insights for policymakers and stakeholders, helping to inform decisions that could enhance the income stability and overall welfare of shallot farmers in the Garut Regency.

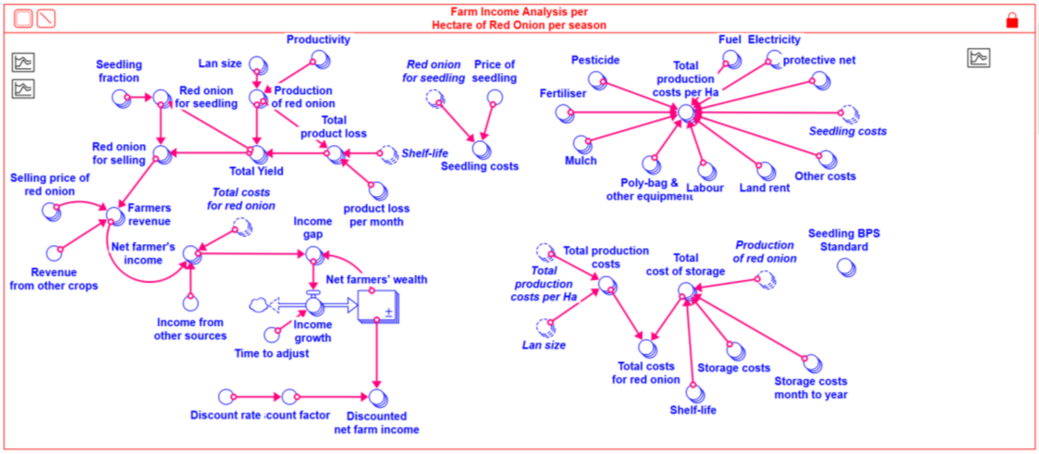

Figure 7.
Stock and Flow Model of Shallot Farming Income
Source: Developed By Authors (2023)

For the revenue model, parameters such as the average yield of wet shallots (13.5 tons/ha for upland and 18 tons/ha for lowland) and dry shallots (7.5 tons/ha for upland and 10 tons/ha for lowland) were used, along with their respective average prices (IDR 9,000/kg for wet shallots and IDR 16,000/kg for dry shallots). The production cost model incorporates a comprehensive array of expenses, including seeds, fertilizers, pesticides, and labor, among other costs. These costs are generally higher in lowland areas compared to upland areas. The total production cost is estimated to be IDR 86.49 million per hectare in upland regions, whereas it is estimated to be IDR

107.91 million per hectare in lowland regions. These estimated average costs for shallot cultivation in upland and lowland areas are comparable to those in other regions of Indonesia (e.g. Rahayu et al., 2019).

The storage cost model addresses the costs associated with storing shallots using CAS technology. This includes the storage cost of IDR 200/kg and the investment costs for CAS infrastructure, which amounts to significant capital expenditure, such as IDR 1.4 billion for the shallot warehouse and IDR 2.4 billion for the CAS unit itself.

Based on the simulation results (Figure 8.), it appears that, given the activities currently carried out by farmers, selling dry shallots, especially in the dry season (from planting in rice fields), provides higher income opportunities compared to net sales in the rainy season, assuming that the average price throughout the year is stable at IDR 16,000/kg. When storage costs are increased from IDR 200/kg to three times as much (IDR 600/kg), farmers' income decreases (for paddy fields) and becomes negative (for field crops). When the price decreases by just IDR 1,000/kg, farmers' income immediately doubles, and even field farmers selling wet shallots can incur losses. This indicates that shallot farmers' income is very sensitive to price changes and increasing storage costs, as well as research conducted by Salmiah (2020), Suswadi (2022), and Arafah (2022). The selling price of dried shallots at the farm level of IDR 14,000 is not feasible for farmers, while based on FGDs, the lowest price can reach IDR 12,000/kg.

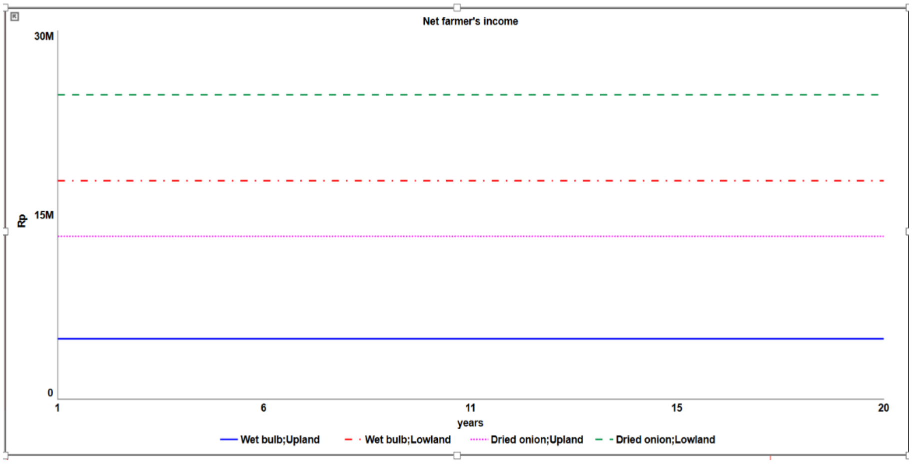

Figure 8.
Simulation Results of Shallot Farming Income
Source: Processed by the Authors from Primary Data (2023)

However, considering the time value of money, such as inflation or rising input prices, the income and economic welfare of farmers over the next 20 years will inevitably change. The time value of money affects the real price discounted rate, incorporating a discount factor that reduces the present value of future income (Chandra & Bahner, 1985). The projections as shown in Figure 9, the projections illustrate a significant decrease in real net income for shallot farmers if these economic factors are not addressed.

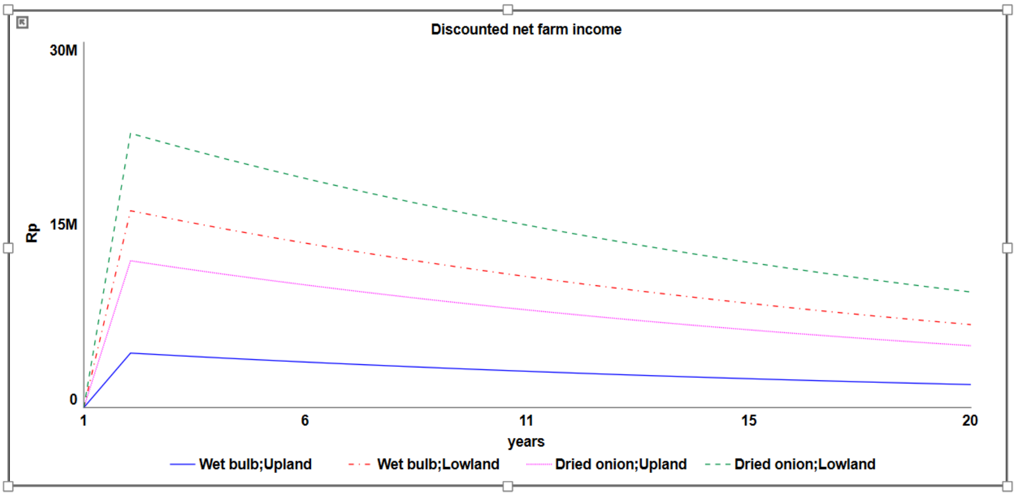

Figure 9.
Discounted Shallot Farming Income
Source: Processed by the Authors from Primary Data (2023)

As input costs increase over time, these factors significantly impact the economic sustainability of shallot farming. If current conditions persist, simulations indicate a decline in farmers' income and economic welfare. Increased costs for production inputs like seeds, fertilizers, and pesticides, coupled with inflation, erode the purchasing power of farmers, making it increasingly difficult to cover costs and maintain profitability. Inflation further erodes the purchasing power of farmers, making it harder for them to cover their (Algieri, et al., 2024).

Adopting Controlled Atmosphere Storage (CAS) technology could mitigate some of these effects by reducing post-harvest losses and allowing farmers to store their produce until market conditions are more favorable (Thompson et al., 2018). However, without adjustments for inflation and input price increases, the long-term economic welfare of farmers remains at risk. Policymakers must consider these economic dynamics when planning interventions to support the agricultural sector in the Garut Regency and similar regions across Indonesia.

The CAS Management Business Feasibility Model

The feasibility model for CAS warehouse management is comprised of two principal components. The inflow and outflow are the two main components of the model (Figure 10). Inflow encompasses the receipt of cash revenues from the provision of CAS storage services. These revenues are determined by the storage fees charged to service users, which may include farmers or food industries/traders. Additionally, the volume of storage utilized by these users affects the inflow of revenues. Outflow encompasses both investment costs and operational costs, which are further divided into fixed and variable expenses.

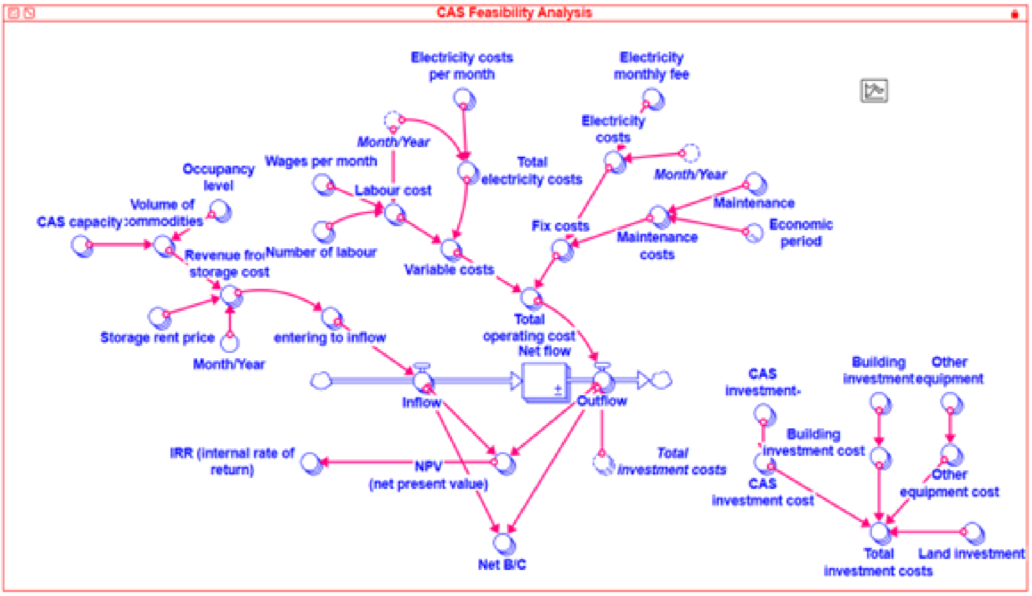

Figure 10.
Stock and Flow Model of Shallot Storage Service Business Feasibility
(Conventional and CAS)

Source: Processed by the Authors from Primary Data (2023)

The volume of storage is contingent upon the capacity of the available CAS warehouse. The conventional warehouse (building) has a capacity of 80 tons of shallots when arranged in a five-layer "para-para" configuration. In contrast, the CAS technology model offers more efficient storage capabilities. Consequently, the feasibility model evaluates two scenarios: The two scenarios to be evaluated are as follows: (1) The conventional storage method (without CAS); (2) The enhanced storage method utilizing CAS technology.

In the conventional scenario, the warehouse relies on traditional storage techniques, which may lead to higher post-harvest losses and reduced quality over time. In the context of the CAS scenario, the technology is designed to preserve the quality and extend the shelf life of the stored produce, with the potential to generate higher revenues and more favorable economic outcomes for both warehouse managers and farmers. This dual-scenario approach provides a comprehensive assessment of the potential benefits and challenges associated with the adoption of CAS technology in the context of shallot farming in the Garut Regency.

Figure 11. shows that both the CAS model and the conventional model will be feasible if the storage cost is at least IDR 2,000/kg (CAS) and IDR 1,000/kg (conventional), with a minimum annual capacity utilization of 60%. This is because prices change throughout the year and shallots are available during the harvest season. However, the payback period can only be achieved after year 9 for CAS and after year 8 for the conventional method, indicating the significant investment needed for CAS. When the storage cost is reduced to IDR 600/kg according to the minimum profit limit for farmers (conventional) and IDR 1,500/kg (CAS), the use of CAS technology and conventional warehouse management for 20 years becomes unfeasible. Research conducted by Maharijaya et al. (2015) states that shallot storage with a cooling warehouse is feasible to operate throughout the year (leased for storage of other commodities) with a payback period of 9 years and storage costs of 350 IDR/kg.

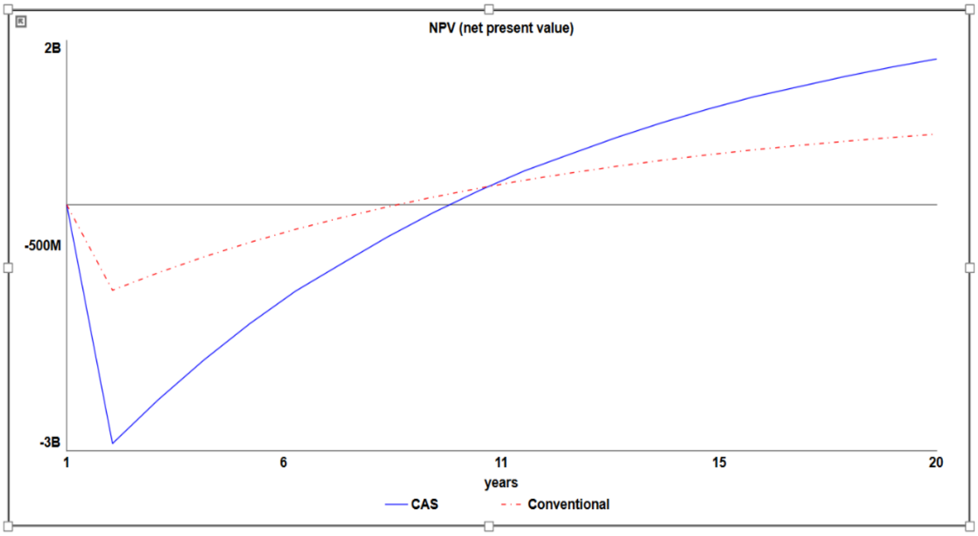

Figure 11.
Business Feasibility Results of CAS Management in Garut Regency
Source: Processed by the Authors from Primary Data (2023)

The application of controlled atmosphere storage (CAS) represents a significant advancement in post-harvest technology. This is because the composition of the gas within the storage environment exerts a considerable influence on the shelf life of stored products. The controlled-atmosphere storage (CAS) method is employed to preserve harvested fruits and vegetables, thereby preventing spoilage during the storage, transportation, and distribution processes (Arshad et al. 2023). However, CA storage is capital-intensive and expensive to operate, hence it is more appropriate for those foods that are agreeable to long-term storage (Bodbodak & Moshfeghifar, 2016). The most significant implication of these findings is the necessity of striking a balance between the advantages of storage technology and the constraints of economic reality.

For CAS technology to become a long-term solution, strategies must be developed to reduce operational costs and increase capacity utilization. This could entail the implementation of policy interventions, subsidies, or cooperative models to provide support to farmers and storage operators. Moreover, the integration of storage solutions for multiple commodities could enhance economic returns and reduce payback periods, as indicated by the research of Maharijaya et al. (2015) Consequently, while CAS technology has the potential to enhance agricultural storage, its implementation must be carefully managed to ensure economic sustainability.

CONCLUSION AND SUGGESTION

Conclusion

The implementation of CAS technology at the farmer group level presents significant challenges due to the high investment and operational costs involved, particularly for groups with limited production volumes and financial resources. As noted by Bodbodak & Moshfeghifar (2016), the selection of appropriate functions and devices for generating and maintaining Controlled Atmosphere (CA) depends on the type of horticultural produce stored and the specific storage conditions required. Since CA storage is capital-intensive and expensive to operate, it is more suited to products that can benefit from extended storage periods.

Successful adoption of CAS is contingent upon substantial financial support from both private-sector investors and government entities. Moreover, achieving sustained year-round occupancy levels is crucial for the economic viability of the venture. Relying solely on seasonal demand poses inherent risks, particularly if prices fluctuate above the average annual price.

System dynamics modeling can effectively illustrate how changes in various parameters impact behavior and provide feedback on income and net present value (NPV). However, the accuracy of this feasibility model depends on assumptions that may not be universally applicable across different times and geographical locations. Therefore, it is essential to adapt the CAS implementation strategy to the specific circumstances and evolving economic conditions to ensure its long-term viability and maximize the benefits for shallot farmers in Garut Regency and similar regions. Incorporating specific cost figures and case studies of similar implementations could further enhance the argument by providing concrete examples and demonstrating the practical application of CAS technology.

Suggestion

The adoption of CAS technology is particularly suited for stakeholders in the food industry who require a consistent year-round supply of shallots. These entities typically possess greater financial resources, enabling them to afford higher rental fees than individual farmers. CAS technology not only serves as a strategic buffer stock for governmental purposes but also presents commercial potential through leasing to industry players, thereby enhancing overall investment returns. This dual role supports its utilization in bolstering food security initiatives while simultaneously generating economic benefits through improved operational efficiency and revenue streams in the agricultural sector.

To operationalize this potential, it is crucial for local government policy to explicitly facilitate business models that attract and encourage private companies to participate in the program, such as through a cluster strategy. This could include creating a favorable business environment for investments, ensuring access to financing, and providing infrastructure.

Additionally, policies should promote private sector involvement in capacity-building initiatives for farmers, ensuring they are equipped with the necessary skills and resources to contribute effectively to the program. By fostering such a supportive ecosystem, the adoption of CAS technology can be maximized, benefiting both the agricultural sector and broader economic development.

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