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Sustainability analysis of watermelon farming in *Subak Intaran Barat*, Bali

Ida Bagus Purna Wijaya
Graduate Program in Agribusiness, Faculty of Agriculture, Udayana University, Denpasar, Indonesia
Corresponding Email: guspurna91@gmail.com

Dwi Putra Darmawan
Graduate Program in Agribusiness, Faculty of Agriculture, Udayana University, Denpasar, Indonesia

Widhianthini
Graduate Program in Agribusiness, Faculty of Agriculture, Udayana University, Denpasar, Indonesia

***Abstract*---**This study aims to analyze the multidimensional sustainability status of watermelon farming in *Subak* Intaran Barat, identify sensitive attributes influencing sustainability, and formulate adaptive and sustainable development scenarios. The study adopts a descriptive quantitative approach using the Multiaspect Sustainability Analysis (MSA) method. Sustainability is assessed across five main dimensions: economic, social, ecological, institutional, and technological aspects. Data were collected through in-depth interviews with key informants, field observations, and document analysis. The analysis was conducted to determine the sustainability index, sustainability status position, and the most influential sensitive attributes affecting changes in the sustainability status of watermelon farming. The results are expected to indicate that the sustainability of watermelon farming in *Subak* Intaran Barat is not solely determined by economic profitability, but also by the strength of *Subak* institutions, farmers' social participation, ecological pressures resulting from urbanization, and limitations in the adoption of agricultural technology. Dominant sensitive attributes are predicted to be related to price fluctuations, land conversion, *Subak* member participation, irrigation water-use efficiency, and access to technological innovations. Based on these findings, several development scenarios are formulated, emphasizing institutional

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strengthening, improved farming efficiency, and the integration of local wisdom values with the demands of modern agriculture.

***Keywords*---**sustainability, watermelon farming, *Subak*, MSA, semi-urban agriculture.

Introduction

Agriculture remains a central pillar of Indonesia's national economy, particularly in rural areas, by ensuring food security, providing employment, and maintaining ecological balance. However, rapid globalization and urbanization have generated serious challenges, including land conversion, price volatility, climate change, and declining farmer regeneration. In Bali, agricultural sustainability is closely linked to the traditional irrigation system *Subak*, which was recognized by UNESCO in 2012 as a World Cultural Heritage system. Beyond irrigation, *Subak* represents the Tri Hita Karana philosophy, which emphasizes harmony between humans and God (*parahyangan*), among humans (*pawongan*), and with nature (*palemahan*). Despite its high cultural and ecological value, *Subak* currently faces strong pressures from modernization, population growth, and the expansion of settlements and tourism areas.

In this context, the development of high-value horticultural crops such as watermelon has emerged as an adaptive strategy to strengthen farm resilience and economic sustainability. Denpasar City is one of Bali's strategic agricultural areas for watermelon production. Provincial data show that watermelon output in Bali fluctuated from 24,562 tons in 2022 to 19,330 tons in 2023 (Databoks, 2024), reflecting instability that is also evident at the local level. One of the areas most affected is *Subak* Intaran Barat, located in Sanur Kauh Village, South Denpasar District. Covering approximately 83 hectares, this area represents a green enclave amid rapid coastal urbanization. To sustain their livelihoods, farmers have diversified their activities by cultivating watermelon during the dry season because of its relatively high economic value, short planting cycle, and suitability for dry conditions. Nevertheless, such production fluctuations raise concerns regarding the long-term sustainability of watermelon farming, which is highly dependent on production stability and external pressures.

Although watermelon farming is financially profitable, with an average net income of IDR 4,483,200 per hectare and an R/C ratio of 2.30 (Malur et al., 2019), its sustainability is threatened by multiple structural challenges. Urban expansion in Sanur has accelerated land conversion, and according to BPS (2021), approximately three hectares of *Subak* land in Denpasar are converted annually. Farmers also face limited access to capital and extreme price volatility. Under normal conditions, watermelon prices range from IDR 6,000 to 8,500 per kilogram, but during peak harvest periods, prices may fall to IDR 2,500 per kilogram (Teropong Media, 2023), severely affecting income stability and reducing farmers' willingness to maintain cultivation.

From an institutional perspective, *Subak* Intaran still maintains the traditional organizational structure led by a *Pekaseh* (Windia & Dewi, 2005). However, institutional challenges have intensified in urban contexts. Declining farmer participation and weak regeneration, caused by young people shifting to the tourism sector, reduce collective engagement in *Subak* activities (Sudarmika, 2015). Technically, irrigation channels are increasingly disrupted by urban development, while dual authority between customary institutions and formal government agencies often creates governance confusion (Sutawan, 2008). Despite these constraints, *Subak* Intaran retains strong social and cultural capital that can be strengthened through institutional innovation, such as developing Subak-based business units, digitalizing land and water data, and building partnerships with non-agricultural stakeholders.

Beyond its challenges, *Subak* Intaran Barat also holds significant potential. Infrastructure development, including farm roads and jogging tracks, not only supports agricultural activities but also opens opportunities for ecotourism aligned with the concept of multifunctional agriculture. Nevertheless, the sustainability of watermelon farming cannot be understood solely from an economic standpoint. Field observations and previous studies indicate that sustainability is shaped by interconnected economic, social-cultural, ecological, institutional, and technological dimensions. Price volatility, declining social participation, land conversion, institutional rigidity, and limited adoption of modern farming technologies interact in complex ways within the *Subak* system.

Therefore, a multidimensional assessment is essential to capture this complexity. This study aims to evaluate the sustainability status of watermelon farming in *Subak* Intaran Barat, identify sensitive attributes that constrain or support sustainability, and provide evidence-based recommendations. The findings are expected to support adaptive strategies that strengthen *Subak* as a dynamic socio-ecological system and contribute to the achievement of the Sustainable Development Goals, particularly those related to food security, sustainable cities, and environmental conservation.

Methods

This study adopts a mixed-method approach, combining qualitative inquiry that is subsequently quantified to capture the multidimensional nature of sustainability in watermelon farming within *Subak* Intaran Barat. This approach is employed to ensure that sustainability assessment is not limited to numerical indicators but also reflects farmers' perceptions, social dynamics, institutional practices, and ecological realities. Primary data were collected through questionnaires, in-depth interviews, field observations, and focus group discussions involving purposively selected key informants, including active watermelon farmers, *Subak* leaders (*pekaseh* and *prajuru*), agricultural extension officers, and representatives of relevant agricultural institutions. Quantitative data derived from structured questionnaires were used to measure sustainability indicators across five dimensions—economic, social-cultural, ecological, institutional, and technological—while qualitative data supported contextual interpretation and reduced the risk of numerical bias. Secondary data were obtained from official statistics, institutional reports, and previous studies to strengthen triangulation and contextual validity.

Data analysis was conducted using the Multiaspect Sustainability Analysis (MSA) approach, supported by the Exsimpro application, which is adapted from the RAPFISH framework for agricultural sustainability assessment. MSA was applied to generate sustainability indices for each dimension, determine overall sustainability status, identify sensitive (leverage) factors, and simulate future development scenarios. The analysis involved data normalization, index construction, aggregation of sustainability scores, and classification into sustainability categories. Model robustness was ensured through sensitivity analysis and random iteration validation, with tolerance thresholds set at a maximum deviation of ±0.5 from the modal value and an overall error margin not exceeding 10%. Sensitivity analysis was further employed to identify key leverage factors influencing sustainability outcomes, while scenario simulations were used to evaluate potential policy interventions and development pathways. The results of the analysis were presented through a combination of formal techniques (tables, graphs, and radar diagrams) and interpretative narratives to provide a comprehensive and policy-relevant understanding of the sustainability of watermelon farming in an urbanizing *Subak* system.

Result and Discussion

Sustainable Factors

The results of the Multiaspect Sustainability Analysis (MSA) indicate that watermelon farming in Subak Intaran Barat falls within the sustainable category, with an average sustainability index of 57.45. This score suggests that the farming system remains relatively viable and functional despite increasing urbanization pressures in the coastal area of Denpasar. Among the five assessed dimensions, the economic, socio-cultural, ecological, and technological aspects were classified as sustainable, while the institutional dimension was rated low sustainable, positioning it as the main limiting factor for overall sustainability.

The economic dimension achieved the highest sustainability index at 64.29, indicating that watermelon farming still provides relatively adequate financial benefits to farmers. Key determinants supporting economic sustainability include farm income, land productivity, cost efficiency, and watermelon selling prices. Nevertheless, sharp price volatility, the dominance of collector-based marketing channels, and limited access to formal financing continue to weaken farmers' bargaining power. Differences between land-owning farmers and sharecroppers further shape income stability, as limited land tenure and restricted capital reduce sharecroppers' capacity to expand farming operations sustainably. These findings underscore that economic sustainability is not only determined by profitability, but also by land tenure structure, marketing arrangements, and access to financial resources.

From an ecological perspective, the sustainability index of 57.14 shows that watermelon cultivation practices in Subak Intaran Barat are functionally sustainable, although not yet optimal for long-term conservation. Key ecological concerns include continued reliance on chemical fertilizers, low adoption of organic inputs, and relatively intensive pesticide use. Farmers' concerns about increased weed growth associated with organic fertilizers and potential yield losses often reinforce dependence on chemical inputs. At the same time, crop residue management practices, the use of plastic mulch, and irrigation governance through the subak system contribute positively to ecological stability. This implies that strengthening balanced fertilization strategies and implementing integrated pest management are critical to reducing pressure on soil quality and surrounding ecosystems.

The socio-cultural dimension recorded a sustainability index of 61.86, reflecting relatively strong social capital embedded within Subak Intaran Barat. Farmers' generally moderate education levels, long-standing experience in watermelon cultivation, and family involvement in farming activities contribute meaningfully to socio-cultural sustainability. Participation in farmer groups, adherence to *awig-awig* (customary rules), and engagement in religious rituals further strengthen social cohesion and collective coordination. However, challenges persist in the form of declining youth participation and limited frequency of agricultural training, both of which may hinder farmer regeneration and slow innovation adoption. Overall, the socio-cultural dimension aligns with the *people* pillar in the Triple-P framework, yet requires continuous capacity-building through structured training and youth empowerment initiatives.

The institutional dimension emerged as the weakest component, with a sustainability index of 42.86, indicating a low sustainable condition. Although *awig-awig* remains important for governing shared resources and sustaining social order, it has not been fully adapted to the operational needs of modern watermelon farming, particularly in relation to marketing, financing, and horticulture-specific coordination. Government support programs funded through both national (APBN) and municipal (APBD) budgets provide production inputs, but their impacts tend to be short-term due to top-down planning and limited integration with local needs. Extension services, agricultural cooperatives, and formal financial institutions have also not operated optimally in supporting farmers. These findings highlight that strengthening sustainability requires more participatory, adaptive, and locally integrated institutional arrangements within the subak system.

The technological dimension achieved a sustainability index of 61.11, suggesting that farmers have adopted basic cultivation technologies at a reasonably sustainable level. The use of improved varieties and relatively accessible seed availability are among the most supportive technological factors. Subak-based overflow irrigation also delivers ecological advantages through energy efficiency and equitable water distribution. Nevertheless, major constraints include weak farm recordkeeping practices, limited use of digital marketing tools, and the absence of collective management for agricultural machinery and equipment. As a result, farm decision-making remains insufficiently data-driven, and farmers' bargaining position in marketing remains weak. This indicates that the optimization of practical and digital technologies—particularly in recordkeeping and market access—offers substantial potential to enhance economic sustainability and farm efficiency.

Overall, the findings demonstrate that sustainability in Subak Intaran Barat's watermelon farming system is multidimensional and cannot be interpreted solely through an economic lens. Socio-cultural strength and the adoption of basic technologies support sustainability, yet institutional weaknesses constitute the primary constraint. Therefore, institutional strengthening of the subak, closer alignment of government programs with local priorities, continuous capacity-building through farmer training, and improved adoption of marketing and recordkeeping technologies are essential strategies for sustaining watermelon farming in Bali's semi-urban agricultural landscape.

Sensitive Factor

Based on the Multiaspect Sustainability Analysis (MSA) of watermelon farming in Subak Intaran Barat, Sanur Kauh Village, sensitive attributes were identified through sensitivity leverage analysis across five sustainability dimensions: ecological, economic, socio-cultural, institutional, and technological. The results indicate that each dimension contains key attributes that significantly influence changes in the sustainability index and therefore represent priority areas for policy intervention and farmer assistance.

Within the ecological dimension, seven sensitive attributes were identified, with the use of plastic mulch ranked as the highest priority, followed by pesticide application during the growing season (alongside crop residue and waste management). Field observations show that the adoption of plastic mulch remains uneven among farmers. Farmers who apply plastic mulch benefit from improved weed suppression, enhanced soil moisture retention, and greater fertilizer efficiency; however, adoption is constrained by higher initial costs and entrenched conventional farming practices (Sari et al., 2020; Nugroho & Setyawan, 2021). At the same time, plastic mulch poses long-term ecological risks due to poorly managed post-harvest plastic waste, which may degrade soil quality if residues accumulate (Nugroho & Setyawan, 2021).

Pesticide use is still dominated by synthetic chemical inputs, often applied preventively and at relatively high frequencies. Such practices may increase production costs and exert negative environmental pressures, including soil and water contamination (Prasetyo et al., 2020; Sari & Widodo, 2021). The implementation of Integrated Pest Management (IPM) remains limited, largely due to insufficient technical knowledge, limited extension support, and farmers' concerns about yield losses when reducing pesticide use (Putri et al., 2022). Overall, ecological sustainability requires strengthened guidance on environmentally friendly cultivation practices, including the adoption of alternative mulching materials, improved waste management, rational pesticide use, and increased application of organic fertilizers. The latter remains limited despite strong evidence that balanced integration of organic and inorganic fertilizers improves soil quality and long-term productivity (Widyastuti et al., 2020; Prasetyo et al., 2022), in line with national policy on organic fertilizer use (Ministry of Agriculture Regulation No. 70/2011).

In the economic dimension, seven sensitive attributes were identified, with harvest marketing and selling price of watermelon emerging as the two most influential factors. Marketing remains largely conventional, dominated by sales through local collectors at the farm gate. This system is preferred for its speed, simplicity, and reduced risk of post-harvest losses; however, it places farmers in a weak bargaining position and allows a larger share of margins to accrue to intermediaries (Saptana et al., 2020). Limited adoption of value-adding practices—such as sorting, grading, and proper packaging—means that prices are primarily determined by volume rather than quality (Rahman et al., 2022).

Watermelon prices in Subak Intaran Barat range from IDR 5,000 to 7,500 per kilogram and fluctuate substantially due to seasonal supply variations, synchronized harvest periods, and an oligopsonistic market structure (Saptana et al., 2020). Although these prices may appear profitable, rising input costs often erode farmers' margins, resulting in unstable incomes (Putri & Handayani, 2021). Consequently, improving market access, diversifying marketing channels, and implementing quality standards are essential strategies for strengthening farmers' bargaining power and ensuring more stable and sustainable economic outcomes.
For the socio-cultural dimension, the most sensitive factors are the social system within watermelon farming and farmers' activeness in farmer groups. The social system is shaped by interactions among farmers, family members, subak institutions, and farmer groups, which collectively support production activities through cooperation, labor sharing, and information exchange (Suharyanto et al., 2020; Wulandari & Rahman, 2021). However, increasing commercialization of farming activities has led to a gradual decline in traditional mutual assistance, replaced by hired labor systems that may weaken social cohesion (Nugraha & Lestari, 2021).

Active participation in farmer groups enhances access to training, extension services, government support programs, and collective problem-solving mechanisms. Such participation strengthens farmers' social capital and facilitates the adoption of agricultural innovations (Suryani et al., 2022; Suharyanto et al., 2020). From a sustainability perspective, farmer group participation reflects the "people" dimension of sustainable agriculture, emphasizing social stability, participation, and adaptive capacity (Lagiman, 2021).

Within the institutional dimension, the role of agricultural cooperatives and access to financial institutions were identified as the most sensitive factors. Although a farmers' cooperative previously existed in Subak Intaran Barat, it failed to operate sustainably due to weak governance, low member discipline, and repayment problems, preventing it from effectively supporting input provision, financing, and collective marketing. In theory, well-functioning cooperatives can reduce production costs through collective procurement and strengthen farmers' bargaining power, thereby stabilizing incomes (Saptana & Ashari, 2019; Wibowo et al., 2021).

Access to formal financial institutions remains limited due to administrative requirements, collateral constraints, and low financial literacy among farmers (Ashari & Saptana, 2018). In the absence of an effective cooperative acting as a financial intermediary, farmers tend to rely on personal savings or informal credit sources, which carry higher economic risks. Therefore, revitalizing farmer cooperatives and integrating them with formal financial institutions—supported by transparent management and collective monitoring mechanisms—are critical for improving access to capital and strengthening institutional sustainability (Wibowo & Haryanto, 2021).

In the technological dimension, the most sensitive factors are irrigation technology and farm record-keeping practices. Irrigation in Subak Intaran Barat relies primarily on traditional subak systems based on gravity-fed surface flow (overflow), which are energy-efficient and aligned with local wisdom. However, these systems provide limited control over water volume and timing, leading to nutrient leaching and waterlogging during the rainy season and uneven distribution during the dry season (Suputra et al., 2020; Putra & Wijaya, 2021).

Farm record-keeping remains rudimentary and irregular, with most farmers relying on memory rather than systematic documentation of inputs, costs, and yields. This limits their ability to accurately assess production costs, evaluate profitability, and make data-driven decisions. In addition, inadequate records restrict access to formal credit and government support programs, where farm data are often a key administrative requirement (Rahman & Susanti, 2020; Prasetyo et al., 2021). Consequently, improving irrigation management and promoting systematic farm record-keeping are essential steps toward enhancing efficiency, professionalism, and the long-term sustainability of watermelon farming in Subak Intaran Barat.

Scenarios for Improving Sustainability Status

Scenario development was conducted to ensure that ecological, economic, socio-cultural, institutional, and technological dimensions can be improved in a balanced way. The scenarios were constructed using the most sensitive attributes as driving factors, assuming that Scenario 1 is feasible through optimization of existing resources within 3–5 years, while Scenario 2 reflects longer-term improvements requiring >5 years. The sustainability values under each scenario are summarized in Table 1.

Table 1. Sustainability Values Under Scenarios

No	Dimension	Existing	Scenario 1	Scenario 2
1	Ecology	57.14	71.43	92.86
2	Economy	64.29	78.57	92.86
3	Socio-cultural	61.86	76.14	88.14
4	Institutional	42.86	64.29	85.71
5	Technology	61.11	72.22	92.56
	Total average	57.45	72.53	90.43
	Sustainability status	**Sustainable**	**Sustainable**	**Very sustainable**

Primary Data, 2025

Overall, the system improves from 57.45 (Sustainable) to 72.53 (Sustainable) under Scenario 1 and to 90.43 (Very sustainable) under Scenario 2. Scenario effectiveness can be assessed using the ratio ΔS2S/ΔS1S, where Scenario 2 is considered more effective if it is at least twice Scenario 1; otherwise Scenario 1 is regarded as more implementable (Paulus et al., 2023). The results indicate Scenario 2 is generally more effective for ecology, economy, institutional, and technology, while socio-cultural improvements are comparatively more feasible under Scenario 1.

Ecological improvement focuses on reducing environmental pressure while maintaining productivity. Scenario 1 (<5 years) prioritizes expanding plastic mulch adoption and improving pesticide management; Scenario 2 (>5 years) strengthens ecological performance further through mulch adoption, crop-residue/waste management, and greater use of organic fertilizer, supported by extension and collective management to mitigate post-harvest mulch waste. Evidence from horticulture studies suggests mulch can improve soil microclimate and fertilizer efficiency (Nurhayati et al., 2021) and may reduce weed pressure and pesticide needs (Siregar & Harahap, 2020), while inadequate waste management can create long-term environmental risks (Wibowo et al., 2022).

Table 2. Scenario for Improving Ecological Sustainability Status

Scenario	Attribute	Good	Real	Scenario 1	Scenario 2
1	Use of plastic mulch	2	0	1	–
1	Pesticide use during the growing season	2	1	2	–
2	Use of plastic mulch	2	0	–	2
2	Management of crop residue/plant waste	2	1	–	2
2	Use of organic fertilizer	2	1	–	2

Primary Data, 2025

These interventions are aligned with the projected improvement of the ecological sustainability index from 57.14 (existing) to 71.43 (Scenario 1) and 92.86 (Scenario 2) (Primary data, processed, 2026), indicating that long-term ecological gains depend on combining field-level practices (mulch, organics) with risk controls (threshold-based pesticide use) to reduce residues and protect subak water/soil functions (Prasetyo et al., 2020; Putri et al., 2022). Consistent medium-to-long-term application of soil–water conservation practices (≥5 years) is expected to support nutrient retention and soil biological activity, reinforcing the pathway to very sustainable ecological status (Suryani & Abdurachman, 2019).

Economic sustainability is driven primarily by market structure and financing constraints. Scenario 1 (<5 years) targets improved harvest marketing (moving beyond dependence on collectors) and stronger access to formal capital (e.g., group-based credit), while Scenario 2 (>5 years) aims to maximize performance through higher selling value/price outcomes and more stable productivity per hectare, supported by quality management (sorting/grading), collective marketing, and reinvestment capacity. Evidence suggests uncoordinated horticultural chains weaken farmer margins (Hidayati et al., 2020), while collective marketing can strengthen bargaining position and reduce transaction costs (Wibowo & Sumarno, 2021), and formal credit access supports timely input use and technology adoption (Saptana & Ashari, 2019).

Table 3. Scenario for Improving Economic Sustainability Status

Scenario	Attribute	Good	Real	Scenario 1	Scenario 2
1	Marketing of watermelon harvest	2	0	1	–
1	Access to capital (credit/loans)	2	1	2	–
2	Selling value/price of harvest	2	0	–	2
2	Productivity per season per 1 ha within the *subak*	2	1	–	2

Primary Data, 2025

The scenario logic positions marketing and financing as the short-term levers that unlock longer-term outcomes (price/value and productivity). With sustained implementation, the economy index increases from 64.29 (existing) to 78.57 (Scenario 1) and 92.86 (Scenario 2) (Primary data, processed, 2026), implying that long-run economic resilience depends on institutionalized market access, cost-aware farm management, and productivity stabilization through improved cultivation practices (Sutarya et al., 2019; Kariyasa & Sinaga, 2020), supported by financing and financial literacy to reduce reliance on informal loans (Ashari, 2018; Susilowati et al., 2020).

Socio-cultural sustainability is anchored in subak-based social capital. Scenario 1 (<5 years) prioritizes strengthening the social system of farming and increasing farmer activeness in farmer groups, as these mechanisms accelerate knowledge exchange, cooperation, and coordinated action. Scenario 2 (>5 years) focuses on increasing training participation frequency and leveraging farming experience as collective knowledge through participatory learning, which strengthens adaptive capacity amid market and production risks. Empirical literature emphasizes that trust, networks, and collective action are decisive for smallholder resilience (Suharyanto et al., 2018), and active farmer groups function as learning and coordination platforms (Hidayat & Saptana, 2019).

Table 3. Scenario for Improving Socio-Cultural Sustainability Status

Scenario	Attribute	Good	Real	Scenario 1	Scenario 2
1	Social system in watermelon farming	2	0	2	–
1	Activeness in farmer groups	2	1	2	–
2	Frequency of participation in agricultural training	2	1	–	2
2	Experience in watermelon farming	3	1	–	2

Primary Data, 2025

This sequencing indicates that socio-cultural gains can be achieved relatively quickly through participation and group strengthening, while long-term reinforcement depends on continuous learning and institutionalization of local experience. The socio-cultural index is projected to improve from 61.86 (existing) to 76.14 (Scenario 1) and 88.14 (Scenario 2) (Primary data, processed, 2026), supporting the interpretation that short-term social activation (Scenario 1) is a practical pathway, while long-term capacity building sustains higher performance (Suharyanto et al., 2019; Susilowati, 2021).

Institutional sustainability is constrained by weak cooperative performance and limited integration with formal finance and public programs. Scenario 1 (<5 years) prioritizes revitalizing the farmer cooperative (governance, rules, accountability) and strengthening the role of financial institutions as sustainable financing partners while cooperative functions recover. Scenario 2 (>5 years) expands institutional support through stronger finance partnerships and more consistent, capacity-oriented government programs funded by APBD (Denpasar City) and APBN (via Bali Province), aligned with farmer empowerment mandates. Prior research highlights that cooperative durability depends on member compliance and professional management (Susilowati et al., 2019), and sustained finance–farmer relationships support long-term farm development (Saptana & Ashari, 2019).

Table 4. Scenario for Improving Institutional Sustainability Status

Scenario	Attribute	Good	Real	Scenario 1	Scenario 2
1	Farmer cooperative institution	2	0	1	–
1	Role of financial institutions	2	1	2	–
2	Role of financial institutions	2	0	–	2
2	Government assistance funded by Denpasar City APBD	2	1	–	2
2	Government assistance funded by Bali Province (APBN)	2	1	–	2

Primary Data, 2025

Institutional improvement is projected to rise from 42.86 (existing) to 64.29 (Scenario 1) and 85.71 (Scenario 2) (Primary data, processed, 2026), indicating that short-term gains require immediate governance repairs and financing access, while long-term gains depend on stable multi-actor support (finance + structured government programs). This direction is consistent with the policy logic of sustained farmer protection and empowerment frameworks and the need for transparent, accountable program implementation at local and provincial levels, alongside continued institutional strengthening (Saptana et al., 2018; Ashari, 2018; Susilowati et al., 2020).

Technological sustainability in Subak Intaran Barat is primarily limited by unmanaged surface-flow irrigation and weak farm management practices. Scenario 1 (<5 years) targets gradual improvements in irrigation control (simple gates, scheduling, tertiary channel repairs) and adoption of basic farm record-keeping, while Scenario 2 (>5 years) advances toward more controlled irrigation infrastructure and more structured (potentially semi-digital) records, complemented by marketing technology and digital tools for coordination/sales to reduce dependence on intermediaries. Literature indicates unmanaged surface irrigation can reduce water-use efficiency and productivity (Sutrisno et al., 2020), while record-keeping improves decision quality and access to support programs (Haryono & Saptana, 2018; Saptana et al., 2020).

Table 5. Scenario for Improving Technological Sustainability Status

Scenario	Attribute	Good	Real	Scenario 1	Scenario 2
1	Irrigation technology	2	0	1	–
1	Farm record-keeping	2	0	1	–
2	Irrigation technology	2	0	–	2
2	Farm record-keeping	2	1	–	2
2	Use of marketing technology	3	1	–	2
2	Use of digital tools for coordination/sales	2	1	–	2

Primary Data, 2025

Technological sustainability is projected to increase from 61.11 (existing) to 72.22 (Scenario 1) and 92.56 (Scenario 2) (Primary data, processed, 2026), implying that early improvements in irrigation discipline and record-keeping create the management foundation for more advanced, market-facing technology adoption. Over the long term, digital coordination and marketing tools can improve price transparency, shorten chains, and strengthen farmer bargaining power when integrated with farmer institutions (Saptana & Rachman, 2019; Susilowati et al., 2021), reinforcing the transition to a very sustainable technological profile.

Conclusion

The sustainability assessment of watermelon farming in Subak Intaran Barat indicates that the farming system is currently **moderately sustainable**, yet it remains vulnerable due to imbalances across sustainability dimensions. The **economic dimension** appears relatively stronger, as watermelon farming provides short-term profitability and competitive market value; however, this strength is highly sensitive to price volatility and harvest-season fluctuations. In contrast, the **socio-cultural and institutional dimensions** face notable challenges, including declining farmer participation, weak regeneration of young farmers, and the limited effectiveness of subak institutions in supporting horticultural activities. Meanwhile, the **ecological and technological dimensions** require serious attention due to intensive chemical input use, inadequate management of agricultural waste, predominantly manual irrigation systems, and limited adoption of farm record-keeping and digital technologies.

Sensitive attributes influencing sustainability are distributed across all analyzed dimensions. In the **ecological dimension**, the use of plastic mulch, management of crop residues, and pesticide application practices are critical determinants of soil fertility and ecosystem balance. The **economic dimension** is strongly affected by harvest marketing systems and farmers' access to capital, which directly influence income stability. The **socio-cultural dimension** is shaped by farmer activeness in farmer groups and accumulated farming experience, while the **institutional dimension** depends heavily on the presence and performance of farmer cooperatives and the role of financial institutions. In the **technological**

dimension, irrigation technology, systematic farm record-keeping, and the use of digital technologies for coordination and marketing emerge as key attributes governing efficiency and adaptability of watermelon farming in semi-urban areas.
The sustainability development scenarios demonstrate that a **phased implementation strategy** can significantly enhance the overall sustainability status of watermelon farming. **Short-term strategies (<5 years)** prioritize strengthening social systems, increasing farmer group participation, improving harvest marketing and access to capital, and adopting basic technologies such as farm record-keeping and simple irrigation improvements. In contrast, **long-term strategies (>5 years)** emphasize cooperative institutional strengthening, optimization of financial institutions and government support programs, adoption of more advanced irrigation technologies, digitalization of marketing systems, and conservation-based ecological management. Implementation of these scenarios is projected to elevate the sustainability index to the **very sustainable** category, while reinforcing Subak Intaran Barat as an adaptive, resilient, and contextually relevant agricultural system amid increasing urbanization pressures in Denpasar City.

Recommendation

Based on the sustainability improvement scenario analysis, enhancing the sustainability status of watermelon farming in Subak Intaran Barat, Sanur Kauh Village, should be pursued through a **phased and adaptive implementation of priority sustainability scenarios**. The **ecological and institutional dimensions** are more effectively improved through **Scenario 2**, as these dimensions require structural changes and longer time horizons. Key actions include consistent adoption of plastic mulch, improved management of crop residues and agricultural waste, strengthening farmer cooperative institutions, and optimizing the role of financial institutions and government assistance programs. These interventions are inherently long-term and demand sustained commitment, institutional coordination, and policy support to achieve durable sustainability outcomes.

In contrast, the **economic, socio-cultural, and technological dimensions** are more effectively enhanced through **Scenario 1**, given that improvements in these areas can be implemented in the short term. Priority actions include increasing farmer group activeness, improving harvest marketing systems, strengthening farmers' access to capital, introducing basic farm record-keeping practices, and optimizing existing simple irrigation technologies. The strategic combination of short-term (Scenario 1) and long-term (Scenario 2) interventions is expected to generate synergistic effects, leading to a substantial increase in the overall sustainability index and supporting the long-term viability of watermelon farming in Subak Intaran Barat amid ongoing urbanization pressures.

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