Research on World Agricultural Economy
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RESEARCH ARTICLE

Predicting Agriculture Sustainability in Subak Pulagan as World Cultural Landscape of Bali: Bayesian Networks Approach

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Abstract: Subak is a farmers' organization as an institution managing rice farming irrigation in Bali which has been around for thousands of years. Subak reflects the philosophical concept of *Tri Hita Karana* which unites the spirit world, the human world and nature. Subak Pulagan is one of five sites in Bali designated by United Nations Educational, Scientific and Cultural Organization (UNESCO) as a world cultural landscape. The aim of this research is to identify key factors for agricultural sustainability in Subak Pulagan in terms of various institutional (people), profit and environmental (planet) components. The analysis technique uses a Bayesian network, where data was previously collected through Focus Group Discussion (FGD). The results of the analysis show that the opportunity for agricultural sustainability in Subak Pulagan is quite high. If we look at the three pillars of sustainability, if 'profit' is in maximum condition, it can provide the greatest opportunity to realize sustainable agriculture. If viewed from institutions (the role of government and the role of Subak), the possibility of sustainable agriculture will increase if these two institutions are also optimized. So farmer welfare (profit component) must be pursued, including through agricultural institutions. Incentive assistance through the transmission of land and building taxes, fertilizer, access to capital, and agricultural insurance are forms of incentives that the government can pursue.

Keywords: Sustainable agriculture; World cultural heritage; Subak Pulagan; Bayesian Belief Network; Institutional economics

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Received: 19 June 2024; **Received in revised form:** 10 July 2024; **Accepted:** 11 July 2024; **Published:** 15 August 2024

Citation: Suasih, N.N.R., Mustika, M.D.S., Pratiwi, A.A.M., et al., 2024. Predicting Agriculture Sustainability in Subak Pulagan as World Cultural Landscape of Bali: Bayesian Networks Approach. *Research on World Agricultural Economy*. 5(3): 1–13. DOI: https://doi.org/10.36956/rwae.v5i3.1135

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1. Introduction

Agriculture represents an important sector for economic growth, employment, and poverty reduction [1]. Moreover, increasing agricultural productivity in developing countries is necessary to reduce hunger and poverty, especially in the face of rapidly rising food prices [2]. Various aspects of agricultural activities, apart from having economic value, also have cultural value, so that agriculture is seen as a caretaker of cultural heritage [3]. So in every decision made regarding agriculture, farmers will always consider cultural beliefs [4].

Xenophon (a Greek philosopher), stated that "Agriculture is the mother and protects all the cultures" [5]. When agriculture runs well, other cultures around it would become prosperous, and when it was abandoned, then all the other cultures would be destroyed [6]. The Subak system in Bali, Indonesia, is one of the agricultural-cultural institutions deeply ingrained in Balinese society, especially the irrigation system. Subak embodies the philosophy of "Tri Hita Karana", which emphasizes harmony between people, nature, and the divine [7]. The Tri Hita Karana philosophy is in line with the theory of eco-centrism, which is an environmental ethics theory that criticizes the dichotomy between humans and nature, and considers the two as one unit [8].

For Balinese, agriculture (especially lowland rice) has become a cultural root (way of life) [9]. When viewed from an economic perspective, the agricultural sector has an important role in the economy of the Balinese people, one of which is the second largest contributor to Bali's Gross Regional Domestic Income (GRDP). In 2023, the agricultural sector in a broad sense will contribute 13.73% percent of Bali's total GRDP. The results of the 2023 Bali agricultural census show that the food crop subsector is the most dominant agricultural business subsector in Bali, reaching 39.11% [10]. This increasingly shows that Subak, which is an agricultural institution primarily in rice fields, plays an important role.

The uniqueness and philosophy of Subak in Bali has made Subak recognized by the UN through UNESCO as a World Cultural Heritage or World Cultural Heritage (WCH) since 29 June 2012. The determination of Subak as WCH is included in the cultural landscape category entitled "The Cultural Landscape of Bali Province: The Subak System as a Manifestation of the Tri Hita Karana Philosophy" (Cultural Landscape of Bali Province: Subak System as a Manifestation of the Tri Hita Karana Philosophy). There are two WCH rules that must be used as guidelines in managing and utilizing the WCH area, namely the authenticity rule while maintaining authenticity, and the sustainability rule by ensuring sustainability [11].

The designation of Subak as a WCH coincides with several areas in Bali which are interconnected. These areas are an inseparable unit in the Balinese Cultural Landscape which has an area of ± 19,500 ha [12,13], with details presented in Figure 1.

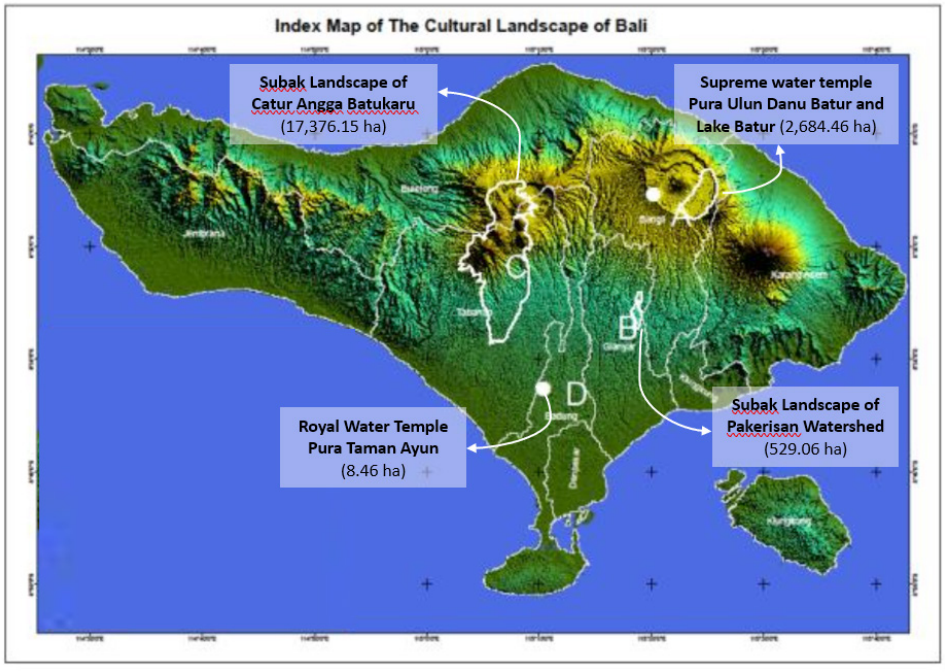


Figure 1. Index map of the cultural landscapes of Bali [12,13].

There are three subaks located in the Subak Landscape of Pakerisan Watershed area, in Gianyar Regency, namely Subak Pulagan, Subak Kulub Atas, and Subak Kulub Bawah. This Subak landscape area has become increasingly famous internationally after being designated as a WCH site. The local community (including farmers) gave a flat response to the title. They hope that the government will pay attention to the condition of farmers and agriculture in Subak Pulagan because the title of world heritage status has consequences for preserving Subak, including not changing the function of agricultural land. The government needs to consider fully subsidizing the payment of Land and Building Tax as a form of appreciation for the efforts of Subak members in preserving Subak. Apart from that, the provision of subsidies or other assistance should be adjusted to the needs and conditions of the subak, such as fertilizer subsidies which should be organic fertilizer [14]. If farmers' welfare can be realized, it is certainly a guarantee for agricultural sustainability, subak preservation, and preventing the conversion of agricultural land.

One effort to improve farmer welfare is through farmer empowerment [15]. Farmer empowerment is a form of community capacity development with the nuances of improving the quality of human resources through providing agricultural information from the central to rural levels, and involving participation and leadership of farmer groups [16]. There are four criteria for implementing community empowerment, namely: (1) human development; (2) business development; (3) community development; and (4) institutional development [17]. Specifically, Subak is related to institutional development, where achieving capacity and effectiveness will support human, business and environmental development [17,18].

The aim of this research is to identify key factors for agricultural sustainability in Subak Pulagan in terms of various institutional (people), economic (profit), and environmental (planet) components through a participatory approach. In particular, this research also presents the causal relationship between the three elements of sustainable agriculture, including institutions, and their impact in realizing sustainable agriculture. The institutions referred to here refer to New Institutional Theory which focuses on the influence of institutions on human behavior through rules, norms, cultural cognitive that are built and perceived by actors [19].

Considering that the integration of uncertainty arising from interactions between human systems and the environment is crucial [20], this research uses the Bayesian Belief Network (BBN) tool. BBN is able to identify institutional drivers and their interactions visually, so that it can be used by stakeholders in formulating comprehensive scenarios to understand the ins and outs of sustainable agriculture.

2. Materials and Methods

2.1 Bayesian Networks (BN)

This research uses a Bayesian Networks (BN) approach, which is also known as Bayesian Belief Network (BBN) or causal probabilistic networks to assess the agricultural sustainability level at Subak Pulagan as a World Cultural Heritage landscape. BBN has several advantages, including: (1) problems are easier to understand; (2) building models does not require a lot of effort and time; (3) new variables can be added as the structure of the network is built; (4) incomplete data samples can be corrected by adding or integrating probabilities with all possible values of the variable [21,22].

A Bayesian Network consists of two components: a qualitative component represented by a directed acyclic graph (DAG) showing the relationships among variables, and a quantitative component consisting of probabilities of the variables in the form of conditional probabilistic tables (CPT) [23]. The basic structure of the BN which involves three variables is illustrated in Figure 2.

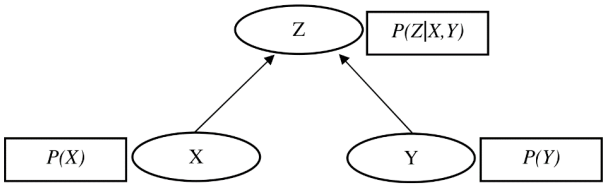


Figure 2. Simple structure of a BN (DAG) [23].

Simply, variable *X* and variable *Y* are known as 'parents variables' for variable *Z*, and variable *Z* is known as the 'child variable'. Probabilities in a Bayesian Network could be simplified by the DAG structure of the BN, where the probability distribution of any variable is solely dependent on its parents. The probability distribution in a BN with *n* nodes (X_1, ..., X_n) can be written as [23]:

$$P(X_1, ..., X_n) = \prod_{i=1}^{n} P\left(X_i \middle| P_a(X_i)\right) \quad (1)$$

where $Pa(X_i)$ is the set of the probability distributions corresponding to the parents of node X_i. For Figure 2, the above equation can be formulated as [23]:

$$P(Z) = P(Z|X,Y) \times P(X) \times P(Y) \quad (2)$$

2.2 Identifying Variables

The BBN modeling procedure begins by identifying variables, followed by defining the network structure and probability rules [24]. In identifying variables, the BN framework is used, as shown in Figure 3.

This research data was collected through focus group discussions (FGD) which were carried out in the Subak Pulagan area. The discussion involved 10 stakeholders in Subak Pulagan, namely farmers (as Subak members), Subak administrators, local government, and agricultural extension workers. The selection of FGD participants was based on their involvement and activities in the development and management of Subak Pulagan. The FGD aims to determine the variables that determine the sustainability of Subak Pulagan and understand the structure of the BN network. The determining variables were identified from two different sources, namely information sourced from secondary data (village reports and other publications) and input from stakeholders (FGD participants). Stakeholders are assigned to adjust and add variables based on their point of view in managing Subak Pulagan using predetermined variable categories. After reaching an agreement regarding the variables determining the sustainability of Subak Pulagan, the FGD participants were asked to determine the network or relationship between variables and assess the probability of each variable. Input from FGD participants will be consolidated and confirmed repeatedly to form the BN network structure.

2.3 BN Structure and Conditional Probabilistic Tables (CPT)

Identified variables in Table 1 then were constructed to a DAG BN Structure as shown in Figure 4. Sustainable agriculture as objective variables is a product of four main components, namely the role of subak, farmers regeneration, fertilizer, and cropping pattern.

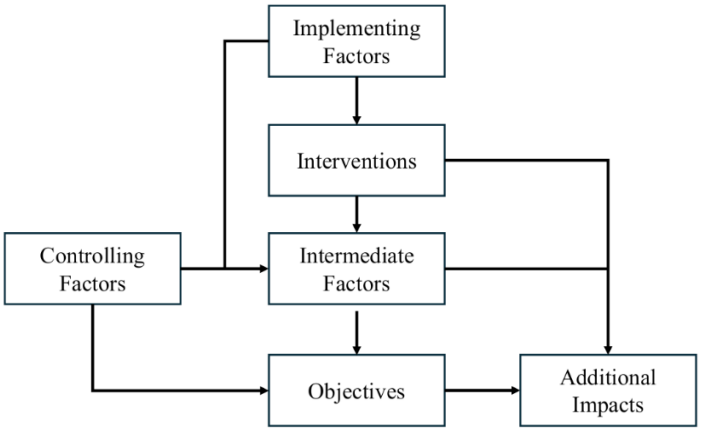


Figure 3. Interaction of BN variables [20,25].

Table 1. Variable Categories, Variable Nodes, and Node States.

Variable Categories	Description	Variable Nodes (Node States)	Dominant Theme	Node States
Objectives	The things that wish to affect through the system.	Sustainable agriculture	P1, P2, P3	Yes, No
Interventions	The things that wish to implement in order to achieve the objectives.	Role of subak	P1	High, Low, Medium
		Financial incentive	P2	Yes, No
Intermediate factors	Factors which link objectives and interventions.	Farmers regeneration	P1	Yes, No
Controlling factors	Factors that cannot be changed by intervening at the scale that are considered but controlled.	Climate change	P3	Normally, Extremme
		Role of government	P1	High, Medium, Low
Implementation factors	Factors which directly affect whether the intervention can be successfully implemented both immediately and in the future.	Cropping pattern	P3	Monoculture, Polyculture
		Fertilizer	P3	Organic, Anorganic
Additional impact	Factors which are changed as a result of interventions that do not affect anything else in the environmental system.	Farmer terms of trade	P2	High, Medium, Low

Note: P1 = People; P2 = Profit; P3 = Planet

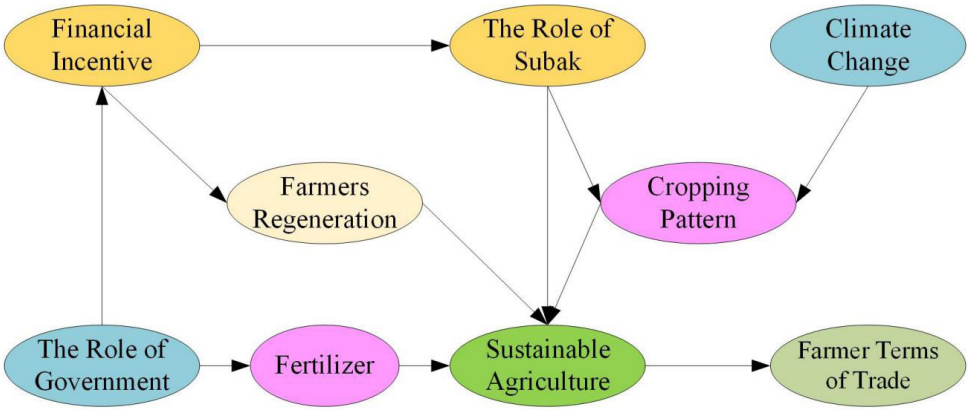


Figure 4. DAG of BN structure of sustainable agriculture in Subak Pulagan.

After the BN structure had been constructed, the stakeholders then were asked to elicit the probability of each node based on node states (in Table 1). The probabilities were put in CPT using GeNIe Acamedic (Version 4) to fill out prior probabilities for BN structure [20].

3. Results

3.1 Strength Analysis

The structure of BN of prior probabilities for agriculture sustainability in Subak Pulagan can be seen in Figure 5, which shows the current value of CPT obtained from stakeholders' elicitation.

The next stage in Bayesian Network analysis is analyzing power using influence diagrams to understand potential cause-and-effect relationships between variables. The width of the arc represents the strength of each connection between parent and child nodes [26].

Based on Table 2, it is observed that the most significant impact is the role of government on financial incentives with an average score of 0.4 and a maximum of 0.6, followed by the significant impact of the role of government also on fertilizer with an average score of 0.267 and a maximum of 0.400.

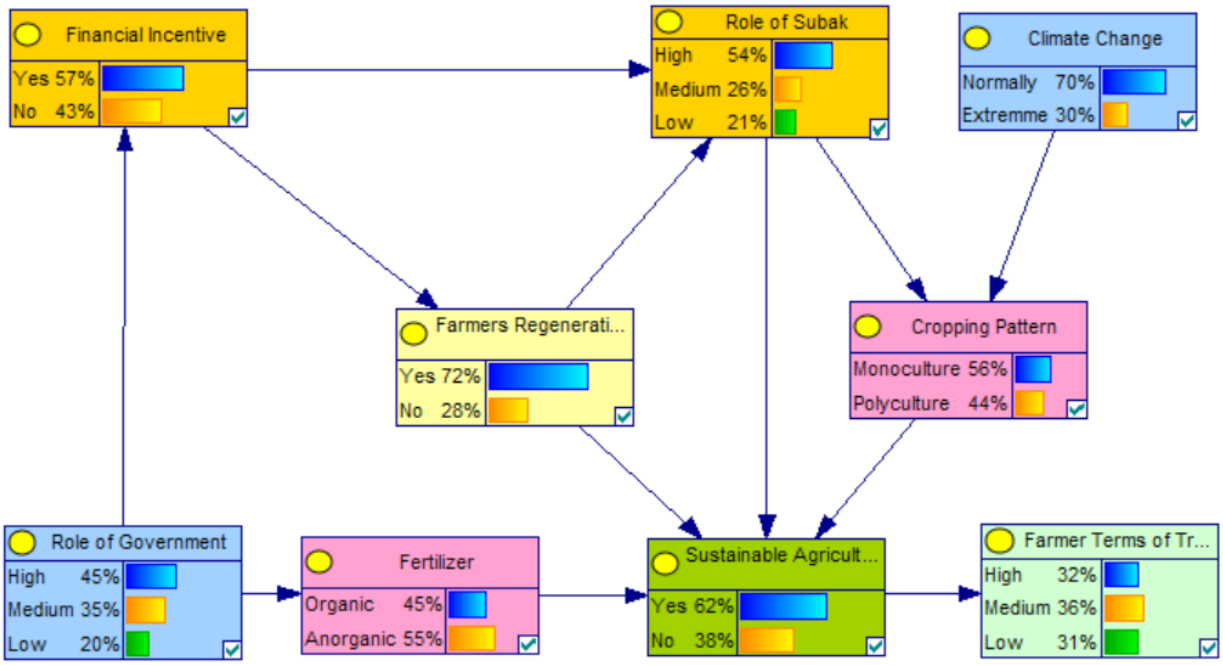


Figure 5. Structure of BN with prior probabilities.

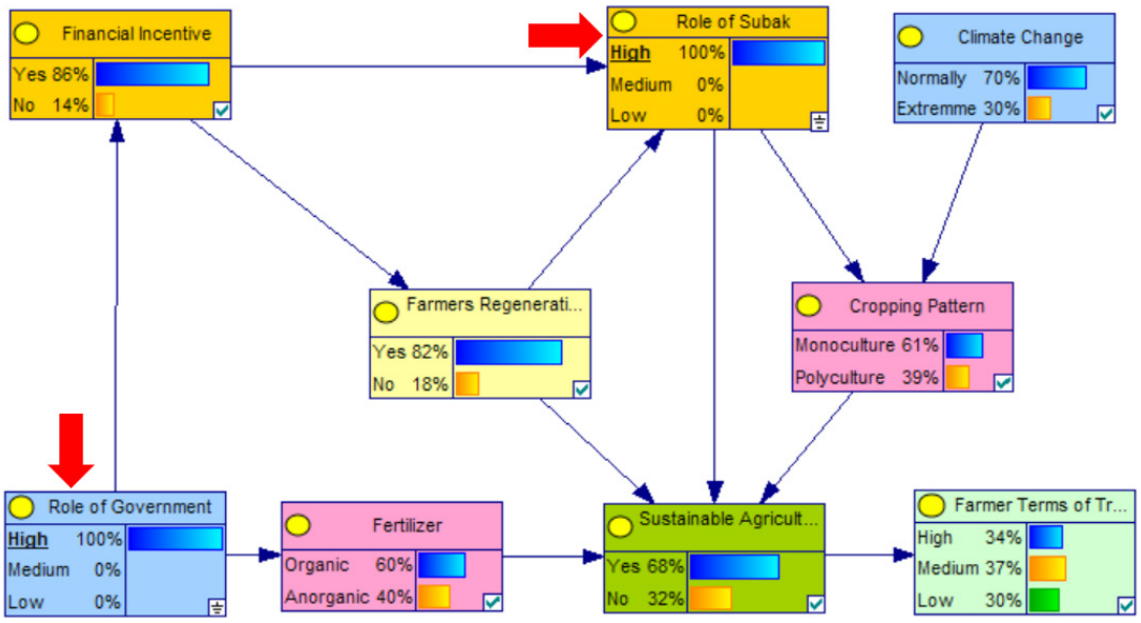
Table 2. Score of Strength between Parent and Child Nodes in the BN Structure.

Parent	Child	Average	Maximum
Climate Change	Cropping Pattern	0.233	0.300
Cropping Pattern	Sustainable Agriculture	0.083	0.100
Farmer Regeneration	Role of Subak	0.198	0.265
Farmer Regeneration	Sustainable Agriculture	0.075	0.100
Fertilizer	Sustainable Agriculture	0.075	0.100
Financial Incentive	Farmer Regeneration	0.200	0.200
Financial Incentive	Role of Subak	0.198	0.265
Role of Government	Financial Incentive	0.400	0.600
Role of Government	Fertilizer	0.267	0.400
Role of Subak	Cropping Pattern	0.133	0.300
Role of Subak	Sustainable Agriculture	0.063	0.150
Sustainable Agriculture	Farmer Terms of Trade	0.265	0.265

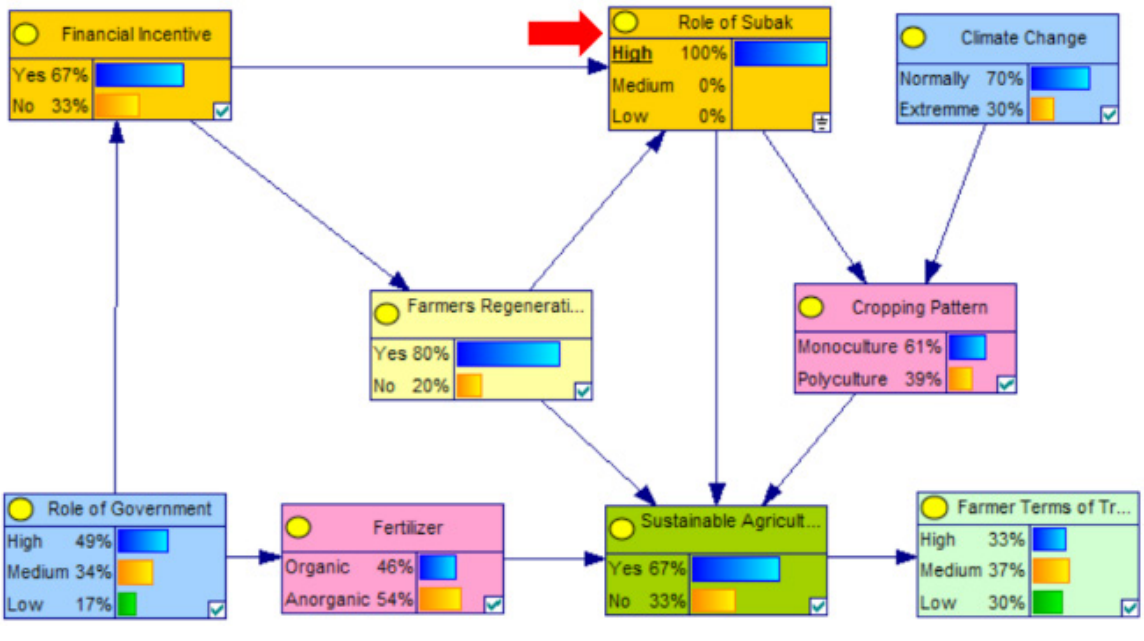
3.2 Institutional Role Analysis

To analyze key institutional factors in predicting sustainable agriculture in Subak Pulagan, the key institutional factors referred to are the role of government and the role of Subak. The analysis involved setting two arcs as target nodes with a probability value of 100% or making them as "evidence", simultaneously (Figure 6a) and partially (Figure 6b,c).

Figure 6 shows that by maximizing institutional roles (subak and government), the prediction of sustainable agriculture will be 68%, where previously it was 62% (Figure 5). Partially, if only the role of subak is maximized, then the prediction for sustainable agriculture will be 67%. Meanwhile, if the role of government is maximized, then the prediction for sustainable agriculture will be 64%. So, to optimize sustainable agriculture, institutional roles must be optimized simultaneously.



(a)



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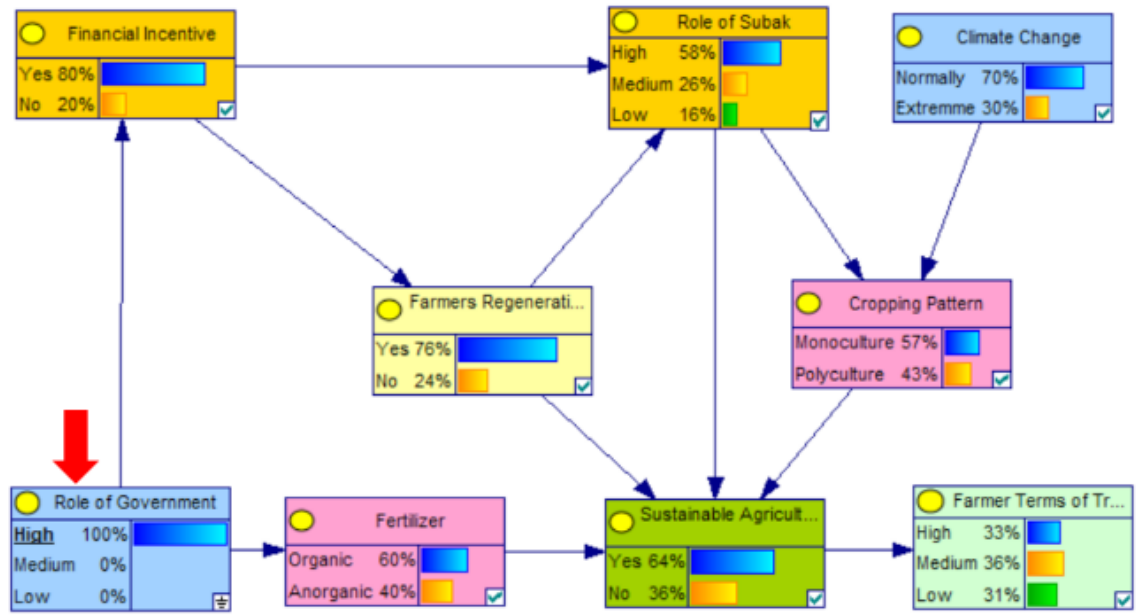


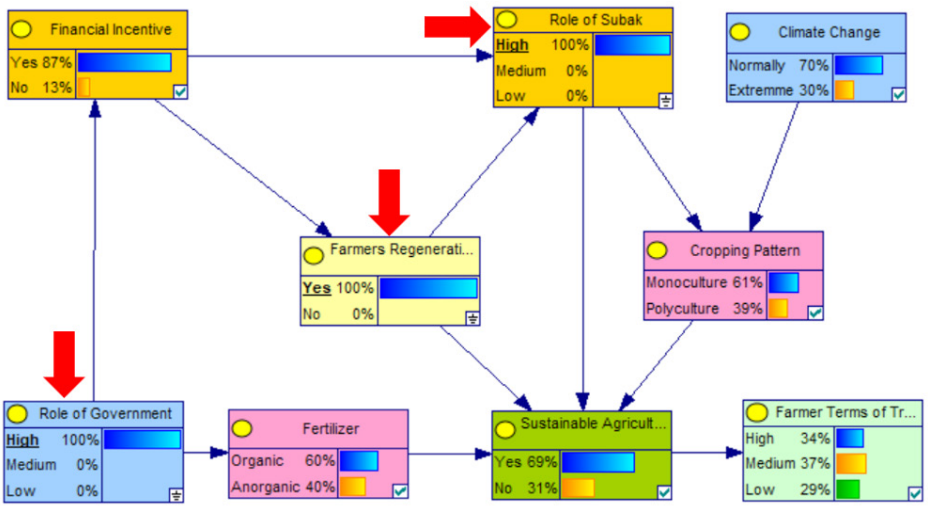
(**c**)

Figure 6. BN structure with institutional role as evidence variables. (**a**) Role of Subak and role of government 'simultaneously' as evidence variables; (**b**) Role of Subak as evidence variables; (**c**) Role of government as evidence variables.

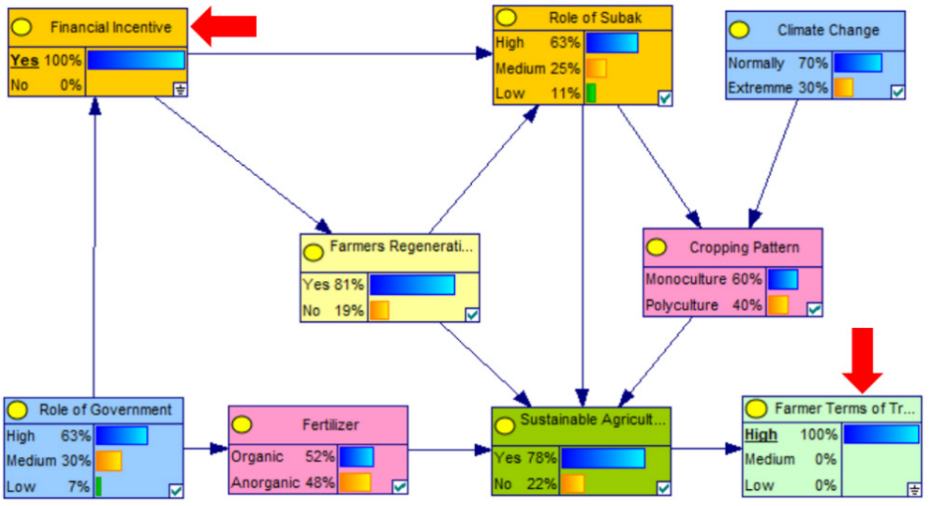
3.3 Sustainability Component Analysis

As explained in Table 1, variables have been categorized into sustainability components, i.e., people, profit, and planet (3P). We should know the comparison if the variables (nodes) according to these components are maximized with a probability value of 100%.

Figure 7a shows that with a probability value of 100% on the 'people' component nodes, the impact on the probability value of sustainable agriculture is 69%. Furthermore, if the probability nodes of the 'profit' component are maximized to 100%, then the probability value of sustainable agriculture will be very high, namely 78%. Furthermore, if the ones optimized with a probability value of 100% are 'planet' nodes then the probability value of sustainable agriculture will be 71%.



(a)



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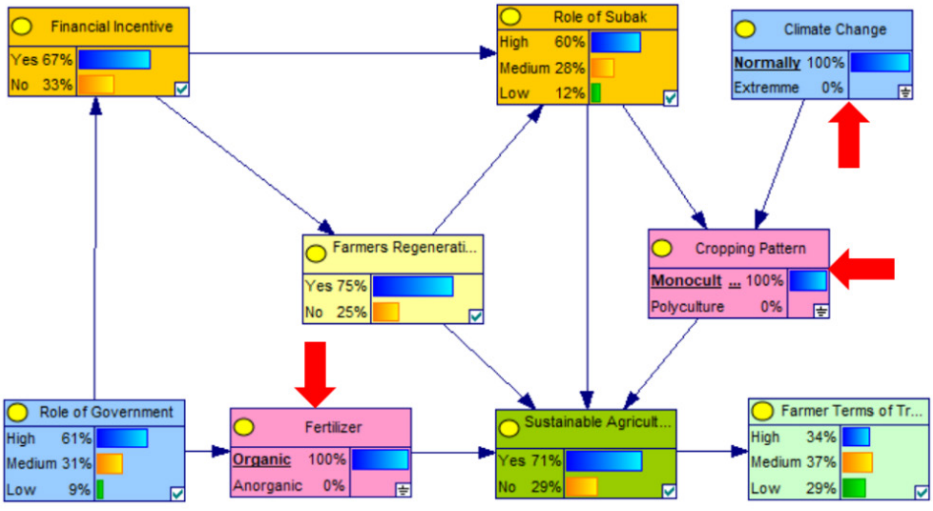

(c)

Figure 7. BN Structure with sustainability component as evidence variables. (**a**) 'People' as evidence variables; (**b**) 'Profit' as evidence variables; (**c**) 'Planet' as evidence variables.

4. Discussion

4.1 The Role of Institutions in Subak Pulagan

The results of the BBN analysis show the important role of institutions in agricultural sustainability in Subak Pulagan. Simply, the institutional system of Subak organization is sustainable water resource management in Bali. Farmer institutions in Bali are farmer institutions located in local institutional areas in the form of membership or collaboration organizations. This institution includes a broad understanding, namely, apart from including the definition of farmer organizations, it also includes the rules of the game or rules of behavior that determine patterns of action and social relations, including social unity as a concrete form of the institution itself [27]. Subak is the oldest farmer's institution in Bali, and the Subak organizational institution is a cultural heritage [28].

The Subak system as a social institution can at least play several important functions (multi-functional roles). Subak functions are classified into internal and external functions. The internal function of Subak is to carry out ritual activities, distribute irrigation water, handle conflicts, and maintain irrigation networks and other physical buildings. Meanwhile, the external function of subak is as a buffer or supporter of food security, cultural preservation, environmental conservation, and support for traditional values in a sustainable manner [29]. Irrigation systems that are socio-culturally based, such as Subak, do have weaknesses such as the inability to resist external intervention [28]. Subak in Bali continues to experience weakening in function as a result of the rapid development of the tourism sector and population growth in Bali [30]. The weakening of subak functions can be divided into two types, namely macro and micro functions. Macro weakening is the result of population growth and tourism development which causes the conversion of agricultural land. Meanwhile, micro weakening is caused by low farmer regeneration and the change of farmer professions [31].

The results of this research found that government and Subak institutions are simultaneously important for realizing sustainable agriculture in Subak Pulahan, in line with research by Suasih et al. [32] which specifically examined the influence of the government's role on the welfare of farmers in Subak Pulagan, with the role of Subak as a moderator. The results of the research found that the role of subak significantly strengthens the influence of the government's role on farmers' welfare.

As explained in New Institutional Theory, there are three components in institutions, namely regulative, normative and cognitive cultural aspects. Figure 8 presents these three aspects in agricultural institutions, namely the government and Subak.

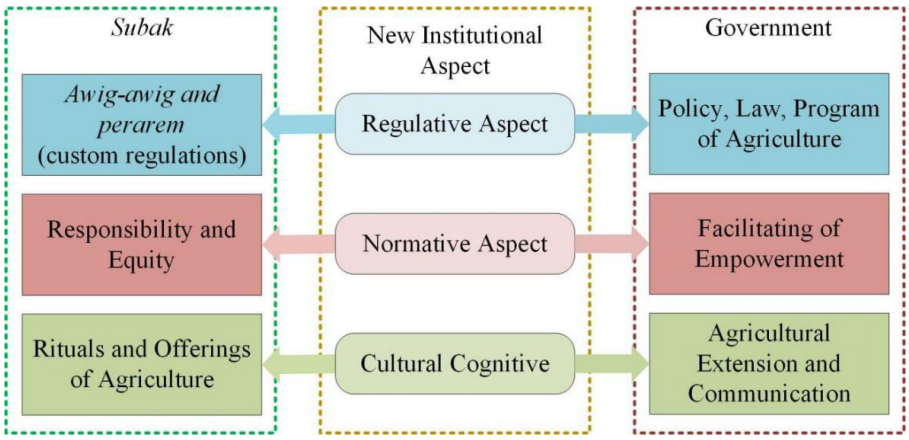

Figure 8. Institutional aspects of agricultural institutions (government and Subak).

4.2 Sustainable Condition in Subak Pulagan

The designation of Subak as a World Cultural Heritage (WCH) is a matter of pride for the Balinese people in particular, and the Indonesian people in general [1]. However, behind this pride, it is actually also a very big challenge for the Balinese people, because Bali is one of the important tourist destinations in the world. This is a challenge, because there is an obligation for the Balinese people to preserve the subak system, which has been designated as WCH, amidst the high rate of conversion of agricultural land to non-agricultural land.

The research results of Sarita et al. [14] regarding farmers' perceptions of the designation of Subak Pulagan as a World Cultural Heritage found that this prediction was well received by farmers, where the

farmer's hope is that the community and Subak members will increase awareness about preserving Subak by suppressing land conversion. Suasih [33] and Prastyadewi et al. [34] emphasized that Subak Pulagan farmers consider agricultural land as 'tetamian/cecatu' or it is called the inheritance of the land from ancestors to posterities. So as long as subak and people's perception of agricultural land remains, it will support sustainable agriculture.

One of the results of this research is to emphasize the importance of the 'profit' aspect as a component of sustainable agriculture. Attention to the welfare of farmers in particular and rural communities is crucial in realizing sustainable agriculture. Rural communities tend to have economic activities in the agricultural sector. So the sources of income for rural communities can be differentiated into on-farm, off-farm and non-farm sector income [34]. Apart from income of the farming sector (on-farm) and the off-farm sector, the non-farm sector also needs to be utilized, such as developing agricultural tourism, either in the form of eco-tourism, agro-tourism, or packaged as a tourist village (Figure 9).

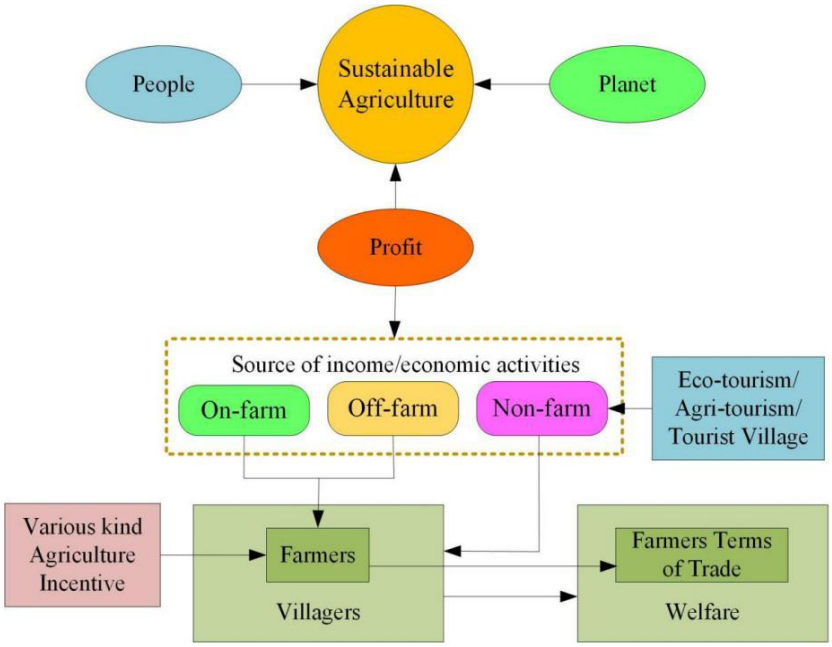

Figure 9. Model of profit improvement as one of sustainable agriculture component.

It is hoped that the title of World Cultural Heritage for subak in Bali will provide benefits, especially for local communities around the area. Research by reference [34] states that in the Jatiluwih tourist area as part of the WCH of Bali Province, the number of tourist visits has increased quite significantly since it was designated as a WCH by UNESCO in 2012. The increase in tourist visits to Jatiluwih has made a significant contribution to the income of the Jatiluwih community.

Tourism in Subak Pulagan has now begun to be developed as part of the Tampaksiring Tourism Village, like the research results of reference [35] which states that Subak Pulagan is suitable for agrotourism development, and of course under the coordination of Tampaksiring Village. The Gianyar Regency Government has also designated Tampaksiring Village as a tourist village, with the Subak Pulagan landscape as one of its tourist destinations.

5. Conclusions

The results of the analysis show that the opportunity for agricultural sustainability in Subak Pulagan is high. When viewed from the three pillars of sustainability, if the 'profit' is in maximum condition, it can provide the highest opportunity to realize sustainable agriculture, where indicators from the profit aspect are financial incentives and farmer terms of trade. This research specifically captures the role of agricultural institutions, in this case, Subak and the government. The results of the analysis with BBN show that the probability of sustainable agriculture will increase if these two institutions are also optimized. In line with the New Institutional Theory, institutions indeed influence behavior through rules, norms, and cognitive culture.

Bearing in mind that Subak Pulagan has the title of World Cultural Heritage which has consequences for the sustainability of Subak, farmer welfare (profit com-

ponent) must be pursued, including through agricultural institutions. Incentives through land and building tax exemptions, fertilizer assistance, access to capital, and agricultural insurance are forms of incentives that the government can pursue. Subak also needs to actively maintain agricultural socio-cultural activities and ensure that there are no conflicts that will change the function of agricultural land or disrupt irrigation and rice cultivation activities.

Agriculture and tourism in Bali are like a symbiotic mutualism, so the potential of Subak Pulagan as part of the Tampaksiring Tourism Village needs to be optimized. Therefore, further research, apart from taking agricultural topics, can also be directed at developing sustainable tourism in Subak Pulagan so that it leads to the welfare of farmers and the local community.

Author Contributions

Ni Nyoman Reni Suasih formulates research objectives and develops the overall research design. Made Dwi Setyadhi Mustika compiles the research background, linked to previous research and empirical conditions. Anak Agung Manik Pratiwi carries out mapping of previous research to formulate research gaps and formulates research conclusions. Made Sinthya Aryasthini Mahaendrayasa prepares a breakdown of the research methodology stages and provides an interpretation of the results of data analysis. I Gusti Ayu Prili Saraswati carries out data collection and field coordination. Ni Made Nami Krisnayanti performs data input and analysis.

Funding

This research was funded by Institute for Research and Community Services of Udayana University, grant number B/255.21/UN14.4.A/PT.01.03/2024.

Acknowledgments

We thank Institute for Research and Community Services of Udayana University, all farmers in Subak Pulagan for sharing their stories and insights of agriculture and the philosophy of Subak during the field research. We would also like to show our gratitude to Prof. Akhmad Fauzi, who introduced BBN analysis to us.

Data Availability

The main data from this research were obtained from the results of the Focus Group Discussion, and supported by data from the document "Cultural Landscape of Bali Province: the Subak System as a Manifestation of the Tri Hita Karana Philosophy" which can be accessed at the link https://whc.unesco.org/en/list/1194/.

Conflict of Interest

All authors disclosed no any conflict of interest.

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