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Farmer Perspectives on the Economic, Environmental, and Social Sustainability of Environmental Conservation Agriculture (ECA) in Namobuddha Municipality, Kavre, Nepal

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Abstract: The adoption of environmental conservation agriculture (ECA) in Nepal is aligned with the country's goal to achieve carbon neutrality by 2045, as ECA practices have been proven to effectively reduce greenhouse gas emissions. Nepal's agricultural sector faces numerous challenges, including labor shortages, climate change impacts, and the necessity for environmentally friendly farming methods, making the adoption of ECA practices even more crucial. Thus, this paper explored farmer perspectives on the sustainability of ECA practices in the Namobuddha municipality, Nepal, which is renowned as a leading hub of organic farming. A cross-sectional survey was conducted, together with key informant interviews and onsite observations. By analyzing various farmer perspectives, the study presents an analytical framework that highlights the economic, environmental, and social pillars of ECA's sustainability. The findings underscore the significance of economic viability for farmers, as damages to crops and farm products negatively drive their perception of ECA sustainability. Conversely, factors such as increased agriculture-related income, favorable prices, and sustainable productivity positively shape farmers' perceptions. In terms of environmental sustainability, farmers prioritize enhancing the local and global environment, viewing their farming methods as climate-smart and actively working towards reducing greenhouse gas emissions. The study emphasizes the importance of strategic communication to effectively convey the benefits of ECA to rural communities. Overall, this research contributes to filling the knowledge gap concerning farmers' perceptions of ECA sustainability. The insights gained from this study have the potential to inform policy decisions and promote the widespread adoption of environmentally friendly farming practices in Nepal.

Keywords: environmental conservation agriculture; organic farming; sustainable agriculture; farmer decision-making; sustainability pillars; economic sustainability; environmental sustainability; social sustainability



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1. Introduction

Agriculture plays a vital role in Nepal's economy, since it employs a significant portion of its population while contributing to its overall food security [1]. However, Nepal's agricultural sector faces multifaceted challenges, such as labor shortages, feminization, youth exodus, and input-intensive farming practices [2,3]. Furthermore, the country's susceptibility to climate change impacts, including unpredictable rainfall patterns, rising temperatures, and frequent extreme weather events, poses a substantial threat to its agricultural productivity and food systems [4]. In addition to climate change, ensuring the sustainability of environmentally friendly farming methods is crucial for the long-term viability of agriculture in Nepal [5]. Recognizing the importance of addressing these challenges, the adoption of environmental conservation agriculture (ECA) practices has gained

traction globally [6,7]. ECA encompasses a diverse range of strategies and technologies that aim to enhance agricultural productivity, increase resilience to climate change, and mitigate its adverse effects. However, for ECA to effectively contribute to sustainable agriculture in Nepal, it is imperative to understand the perceptions of farmers regarding the sustainability of these practices.

ECA has a more flexible and wide-ranging use than Conservation Agriculture (CA), which focuses on three main principles: crop rotation, residue retention, and no-till [8]. ECA includes a wide range of farming practices, such as eco-farming (using environmentally friendly methods in accordance with consumer agreements or local government regulations), organic farming, and specialized farming (which uses less pesticide and fertilizer than conventional methods). This all-encompassing strategy enables farmers to be more supported widely. Through direct payment programs, Japan has successfully reduced about 140,000 tons of greenhouse gas emissions yearly as a result of implementing ECA practices [9]. Given this success, it is vital for Nepal to prioritize the promotion of ECA adoption among its farmers as part of the country's commitment to achieving carbon neutrality by 2045 [10].

Farmers are the stewards and decision makers of their farming operations [11]. This is why farmers' perceptions play a pivotal role in the successful adoption and continued implementation of ECA techniques. Their understanding, beliefs, and attitudes toward environmentally friendly farming methods determine their willingness to embrace change and adapt to new agricultural practices. Therefore, gaining insights into farmers' perceptions of the sustainability of ECA becomes paramount for the successful implementation of climate-resilient and environmentally friendly agricultural systems in Nepal [12].

While several studies have examined the impact of climate change on Nepal's agriculture and the potential of ECA practices [5,13], a substantial research gap remains regarding farmers' perceptions and their role in the adoption of sustainable farming methods.

Understanding the factors that shape farmers' perceptions, encompassing their knowledge, attitudes, socio-economic conditions, and resource accessibility, will enable policymakers and agricultural practitioners to tailor strategies that promote the uptake of ECA practices among Nepalese farmers. Therefore, this paper endeavored to bridge the existing knowledge gap by conducting a study on the elements that drive the perceptions of Nepalese farmers regarding the sustainability of ECA.

The Sustainability of ECA

Environmental conservation agriculture (ECA) is an agricultural production system that aims to enhance productivity while conserving the environment [9]. It has been promoted as a sustainable alternative to conventional agriculture practices that are associated with environmental degradation, soil erosion, and biodiversity loss. Studies have shown that ECA practices can improve soil health and reduce erosion, leading to increased soil fertility and water availability [14]. For instance, a meta-analysis conducted by Bai et al. (2019) corroborated the efficacy of ECA practices in bolstering soil organic carbon (SOC) sequestration, effectively transforming croplands into potent carbon sinks. Among the ECA practices, biochar applications were the most effective in increasing SOC content, followed by cover crops and conservation tillage [15]. In addition to soil health benefits, some ECA practices can also lead to increased crop productivity and profitability. The Consultative Group on International Agricultural Research (CGIAR) reports that ECA is capable of sustainably increasing farm incomes and contributing to food security and development [16]. Furthermore, this leads to better rural communities and improved social ties between consumers and producers.

However, the adoption of ECA practices is not without challenges. Studies have shown that farmers face various constraints in adopting ECA practices, such as limited access to essential resources that can hinder their acceptance and adoption of ECA [17,18]. There are also policy and institutional barriers, such as inadequate regulations, policies, and insufficient support for the implementation of ECA. The lack of awareness and knowledge about

the benefits of ECA and its potential in mitigating climate change poses another significant challenge. Moreover, difficulties in accessing appropriate technology and infrastructure further hinder ECA adoption [19].

Beyond the aforementioned challenges, it is also imperative to understand farmers' perceptions of the sustainability of ECA practices, as these perceptions significantly shape their continued adoption of these techniques. Accordingly, this paper undertakes a comprehensive analysis of the elements that positively or negatively drive farmers' perceptions concerning the sustainability of ECA. This is to address the primary aim of this research, which was to identify the elements that drive farmers' perception of ECA sustainability. Based on our findings, we have developed an analytical framework elucidating the three fundamental pillars underpinning ECA's sustainability, along with an interpretation of their intersections. We believe that this framework will serve as a valuable resource for future scholars engaged in ECA research endeavors.

2. Study Area and Methods

The primary aim of this research was to identify the elements that drive farmers' perception of ECA sustainability. Therefore, the Namobuddha municipality was chosen as the research site due to its prominence as a key center for organic farming in Nepal (Figure 1). It comprises eleven wards, with an estimated population of 29,519 people as of the 2011 census [12]. It is adjacent to Kathmandu Valley and is at the heart of the Kavrepalanchok district in the Bagmati province. It is characterized by diverse ethnic communities, and agriculture is the backbone of livelihoods, with a majority of households engaged in commercial cultivation of vegetables and cultivating various crops for self-consumption [20]. Meanwhile, the National Center for Organic Farming plays a key role in producing various farm products like hill mangos, kiwis, and oranges. These are marketed in farmers' markets all over Kathmandu. Furthermore, animal husbandry also augments farmers' income, with products such as milk and curd being produced from raising buffaloes and cattle. The center is located between the Patleket and Phulbari villages in the northern mountain region of Namobuddha. Marketing is efficient due to the strategic location of Namobuddha near national highways, nearly 52 km east of the city capital, Kathmandu.

Namobuddha has diverse terrain, with altitudes varying from 748 m in the southern region to 2029 m in the northern area. Consequently, winters are considerably colder at higher elevations, while even the valleys experience a chill due to natural fog rising from the rivers. Despite the mid-winter cold, the climate for the rest of the year tends to be warm and subtropical. In June, the municipality experiences its highest average temperature, reaching 25 °C, while January is the coldest month, with temperatures dropping to 11 °C. The annual average precipitation is around 1154 mm, with the majority occurring during July (300 mm) and August (264 mm), coinciding with the monsoon season. Conversely, winter experiences minimal precipitation, with approximately 152 dry days annually. The soil type is predominantly red-brown, reflecting Namobuddha's location in the Mahabharat midhills in central Nepal.



Figure 1. Map of the Namobuddha municipality showing wards marked ★ included in the study.

2.1. Sampling Design and Data Collection

Multiple methods were used to collect data for this research, such as surveys at the household level, FGDs, key informant interviews, and observations at the research area. Clustered random sampling was used to choose the municipality, and four wards were selected (2, 4, 7, and 10) based on the presence of farmers practicing ECA, which included 2462 households. The sample size was calculated using the formula provided by Arkin and Colton (1963) [21]:

$$n = \frac{NZ^2 * p(1 - p)}{Nd^2 + Z^2 * p(1 - p)}$$

where

n = sample size;

N = total number of households (2462);

Z = confidence level (at 95% level, Z = 1.96);

p = estimated population proportion (0.5, this maximizes the sample size);

d = error limit of 5% (0.05).

From this pool of households, 333 were chosen at random for the survey. Data collection was conducted using a semi-structured questionnaire, which had been pretested in comparable areas prior to the actual survey. The questionnaire sought to gather detailed information on farmers' personal attributes, land use, crop production, livestock management, and strategies for mitigating climate variability, as well as the influence of local and higher-level institutions and policies on these practices. It also aimed to assess the impact of these factors on crop yields, farm income, and overall livelihoods.

Face-to-face interviews were carried out with either the head of the household or the primary person responsible for farming activities. Eight researchers used the KoboToolbox to collect data for eight days in February 2022. These researchers received one day of training and were instructed to follow ethical guidelines for surveys involving human

participants. All participants provided informed consent, and strict measures were taken to comply with COVID-19 safety protocols.

The research methodology received approval from the research ethics board of Hiroshima University (see full details on the Institutional Review Board Statement below). Due to incomplete responses, 30 questionnaires were excluded from the analysis, resulting in a final sample of 303.

2.2. Analytical Methods Employed

The purpose of the research was to identify the positive and negative drivers of farmers' perception of ECA's sustainability. To achieve this goal, the farmers were asked to rate their perceptions of ECA's economic, environmental, and social sustainability using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). This rating served as the dependent variable in all regression analyses. A Spearman correlation was employed to examine the variables that had positive and negative associations with the dependent variable. The significant drivers of ECA's sustainability among Namobuddha farmers were identified using ordinal logistic regression, and the odds ratio, model fit, and goodness-of-fit were evaluated using SPSS v.27. The analyzed factors included the farmers' perceptions of climate variability effects, socio-demographic variables, and ECA-related variables. To further support our findings, chi-square automatic interaction detection (CHAID) decision tree analysis and correspondence analyses were conducted to validate the significant variables that emerged.

3. Results

3.1. Socio-Demographic and Farm-Related Data of Farmers in Namobuddha Municipality

Typically, studies that involve farmers have a higher number of male participants. However, in this study, Supplementary Table S1 shows that among the 303 household head farmers surveyed, there were slightly more women (52.5%) than men. The majority of farmers surveyed were between 41 and 60 years old (43.9%), belonging mostly to the Bahun (53.5%) and Janajati (30.4%) ethnic groups. More than one-third of the farmers had no formal education (35.6%), and a similar number had primary education (32.0%). In terms of farming experience, most had 10–40 years of experience, with the highest percentage (26.1%) having 10–20 years of experience. The majority of farmers practiced mixed farming or self-farming with hired laborers (86.5%), with almost half practicing conventional farming (49.2%) and slightly more than half practicing environmental conservation agriculture (ECA). Within the ECA group, the majority practiced special farming (49.5%), a method that uses fewer chemicals and pesticides than conventional farming, while a small percentage practiced organic farming (1.3%).

3.2. Perception and Knowledge of Climate Variability and ECA among Farmers

A majority of the farmers (87.5%) agreed that climate variability had affected their farming in the last decade (Supplementary Table S2), with the top effects being drought (93.4%), heavy rain and floods (63.4%), and damage to crops (33.3%). To adapt, farmers are improving pest and disease management (48.5%), changing planting times and seasons (31.4%), and planting high-yielding crop varieties (25.7%).

Regarding the interest in ECA, over two-thirds (67%) of the farmers expressed interest, while almost one-third (28.7%) were unsure. However, more than half (59.1%) were unsure if their farming methods were climate-smart, and almost 70% stated that the government or NGOs do not promote ECA. Furthermore, over half (52.8%) of the farmers did not want to learn about or discuss ECA, while almost 40% expressed their interest in doing so. A majority of the farmers (62%) were unsure if ECA is sustainable or not, and almost half (44.9%) were unsure if ECA can reduce greenhouse gases, sustain productivity and income, and enhance resilience and adaptive capacity.

Despite the uncertainty, most farmers (83.2%) said they would practice ECA, with self-health (80.2%), supplying better food (44.2%), and higher prices (28.7%) being the

primary reasons. To further investigate this, we performed a Spearman correlation to check if the ECA-related variables exhibited the same relationship when correlated with 'will practice ECA'. All the variables had a significant positive correlation with 'will practice ECA' (Supplementary Table S3). The correlation results provided indicate that despite the initially reported low desire to discuss or learn about ECA among some farmers, there was a significant positive correlation between this variable and the intention to practice ECA. This suggests that those who express interest in learning or discussing ECA are also more likely to express a willingness to practice it.

The farmers also expected local industry/economy promotion (53.8%), decreased climate hazards (46.9%), and increased agriculture-related income (23.4%) from ECA. The middlemen/traders (71.3%) were the most common selling place for ECA products, followed by the hat bazar or local market (39.6%). However, most farmers (90.1%) did not receive a higher price for their ECA products, and many (69%) were dissatisfied with the price. Additionally, farmers do not receive subsidies for ECA farming, according to the majority (90.1%), and 65% of them believed that subsidies were not unhelpful in ECA.

Regarding future plans, a significant majority (89.8%) intended to continue farming over the next 5 to 10 years. Among them, over one-third (40.9%) planned to maintain their current land area while increasing their focus on ECA farming. Additionally, when questioned about ECA's potential to empower women, more than two-thirds (69.3%) affirmed this belief.

3.3. Spearman Correlation of Farmers' Perception of ECA's Sustainability with Socio-Demographic and ECA-Related Variables

Six variables were found to be associated with farmers' perception of ECA sustainability (Table 1). These were caste/ethnicity, plan to continue farming for the next 5 to 10 years, ECA interest, desire to discuss or learn more about ECA, perception that ECA can empower women, and intent to practice ECA. All of these also appeared to be significantly associated with farmers' perception of ECA sustainability in the ordinal regressions in the following section.

Table 1. Spearman correlation of farmers' perception of ECA's sustainability with socio-demographic and ECA-related variables.

Variable	Estimate	Significance
Gender	0.008	0.885
Age	0.027	0.637
Caste/Ethnicity	−0.123	0.033 *
Education	0.014	0.806
Years of farming experience	0.047	0.417
Farming type	0.020	0.733
Will continue farming for the next 5 to 10 years	0.144	0.012 *
ECA interest	0.369	0.000 **
Desire to discuss or learn more about ECA	0.139	0.016 *
Perception that farming method is climate-resilient or climate-smart	−0.091	0.112
Perception that ECA can achieve sustainable income and productivity, improve adaptive capacity and resilience, and reduce greenhouse gases	0.069	0.231
Perception that ECA can empower women	0.245	0.000 **
Government/NGOs promote ECA	0.014	0.804
Receives premium price for ECA products	−0.076	0.188
Price satisfaction for ECA products	−0.072	0.208
Will practice ECA	0.268	0.000 **
Subsidy is helpful in ECA farming	−0.095	0.097

* Significant at $p < 0.05$ level; ** significant at the $p < 0.01$.

3.4. Relationship of Farmers' Perception of ECA Sustainability with Variables Related to Climate Variability, ECA, and Socio-Demographic Characteristics, Using Ordinal Logistic Regression

Numerous drivers emerged as significant in shaping farmers' perception of the sustainability of ECA (Table 2). Firstly, a positive driver was identified under the perceived effects of climate variability, which was changes in season/duration. This means that when farmers observed changes in the season or its duration, they were more likely to have a positive perception on ECA's sustainability. Another positive driver was the pursuit of self-health, as farmers recognized the benefits of ECA on their health. Additionally, the expectation of increased income from agriculture was also a positive driver.

There were five drivers under reasons on why it was good to switch to ECA, listed in decreasing order of odds ratio. The first was the intent to have good or higher prices for their produce, followed by meeting the growing demands of consumers. The remaining drivers were related to the farmers' desire for improved self-health, the need to improve their local and global environment, and the need to build consumer trust.

Table 2. Relationship of farmers' perception of ECA sustainability with variables related to climate variability, ECA, and socio-demographic characteristics, using ordinal logistic regression.

Variable	Estimate	Odds Ratio	Significance
Effects of climate variability			
Heavy rain, flood	−0.264	130.21%	0.094
Rise of sea temperature, extreme hot days	0.051	95.03%	0.779
Cyclone, typhoons, hailstorm	−0.178	119.48%	0.310
Change in distribution of plants/crops	0.222	80.09%	0.310
Change in season/duration	0.397	67.23%	0.023 *
Melting of glaciers, sea-level rise	−0.796	221.67%	0.538
Drought	0.099	90.57%	0.708
Damage to houses/buildings	−0.242	127.38%	0.541
Damage to land/farmland	−0.039	103.98%	0.803
Damage to crops/farm products	−0.335	139.79%	0.025 *
Reason to practice ECA			
To build trust with consumers	0.286	75.13%	0.244
To improve local and global environment	−0.312	136.62%	0.321
Self-health	0.521	168.37%	0.004 **
Good/higher price	0.185	83.11%	0.233
To meet growing demand of consumers	0.028	97.24%	0.884
To supply better food to all	0.093	91.12%	0.494
To decrease the cost of chemicals and pesticides	0.293	74.60%	0.053
Recommended by NGO, cooperatives, agricultural officer, local government, etc.	−0.523	168.71%	0.681
Incentives or subsidies from the government	−0.027	102.74%	0.944
Appropriate policy support and market facilities	0.04	96.08%	0.96
Expected impact of ECA			
Climate variability mitigation	−0.007	100.70%	0.992
Agro-biodiversity conservation	0.074	92.87%	0.796
Control water quality	−0.456	157.78%	0.037
Ground water conservation	0.16	85.21%	0.597
Quality improvement of agricultural products	−0.11	111.63%	0.61
Decrease in climate hazards	−0.268	130.73%	0.056
Increase in agriculture-related income	0.487	61.45%	0.005 **
Local industry/economy promotion	0.302	73.93%	0.034
Locality stabilization and promotion of people's lives	−0.225	125.23%	0.43

Table 2. Conf.

Variable	Estimate	Odds Ratio	Significance
Reason why it is good to switch to ECA			
To build trust with consumers	0.811	44.44%	0.002 **
To improve local and global environment	0.693	50.01%	0.02 *
Self-health	0.596	55.10%	0.001 **
Good/higher price	0.578	178.25%	0.000 **
To meet growing demand of consumers	0.42	152.20%	0.049 *
To supply better food to all	0.304	73.79%	0.052
To decrease the cost of chemicals and pesticides	−0.197	121.77%	0.244
Recommended by NGO, cooperatives, agricultural officer, local government, etc.	−0.769	215.76%	0.557
Incentives or subsidies from the government	−0.775	217.06%	0.078
ECA-related variables			
ECA interest	−0.177	119.36%	0.113
Desire to discuss or learn more about ECA	0.566	56.78%	0.000 **
Perception that farming method is climate-resilient or climate-smart	0.151	85.98%	0.041 *
Perception that ECA can achieve sustainable income and productivity, improve adaptive capacity and resilience, and reduce greenhouse gases	0.709	49.21%	0.003 **
Perception that ECA can empower women	−0.215	123.99%	0.240
Government/NGOs promote ECA	0.087	91.67%	0.436
Receives premium price for ECA products	−0.009	100.90%	0.975
Price satisfaction for ECA products	−0.103	110.85%	0.349
Will practice ECA	0.292	74.68%	0.021 *
Subsidy is helpful in ECA farming	−0.001	100.10%	0.987
Socio-demographic variables			
Gender	0.097	90.76%	0.505
Age	0.11	89.58%	0.494
Caste/Ethnicity	−0.242	127.38%	0.007 **
Education	0.128	87.99%	0.164
Years of farming experience	0.046	95.50%	0.603
Farming type	0.013	98.71%	0.948
Will continue farming for the next 5 to 10 years	0.879	41.52%	0.000 **

** significant at $p < 0.01$; * significant at $p < 0.05$. Link function: complementary log–log $f(x) = \log(-\log(1 - x))$.

In terms of ECA-related variables, four drivers were significant, again listed in decreasing order of odds ratio. These were the perception that the farming method is climate-resilient or smart, the intention to practice ECA, the desire to discuss or learn more about ECA, and the belief that ECA can contribute to sustainable income and productivity, improve adaptive capacity and resilience, and reduce greenhouse gases.

Finally, among socio-demographic variables, farmers' intention to continue farming for the next five to ten years emerged as a positive driver. On the other hand, only two negative drivers were identified: damage to crops/farm products due to climate variability and caste/ethnicity, under socio-demographic variables. This means that when farmers experienced damage to crops/farm products, they were more likely to have a negative perception on ECA's sustainability. For caste/ethnicity, this is investigated further in the Discussion section (under Section 4.3.2), where we perform a correspondence analysis between caste/ethnicity and ECA sustainability.

Overall, farmers' perception of ECA sustainability was influenced by multiple drivers, both positive and negative, that span climatic, economic, and socio-demographic factors. These findings suggest the need for targeted interventions that address the diverse drivers of ECA adoption and encourage its widespread adoption.

3.5. Decision Tree of Namobuddha Farmers with Regards to Their Perception of ECA's Sustainability

To gain a better understanding of which variables are the most influential predictors of farmers' perception of ECA sustainability, we conducted chi-square automatic interaction detection (CHAID) (Figure 2). The results show that ECA interest emerged as the strongest predictor, a finding that is consistent with the Spearman correlation and ordinal logistic regression analyses. Specifically, ECA interest was found to be significant at the $p < 0.01$ level in both analyses, highlighting its importance in predicting farmers' perception of ECA sustainability. Interestingly, the remaining predictors that emerged were caste and ethnicity and damage to crops/farm products, which were both identified as negative drivers in the ordinal regression analyses.

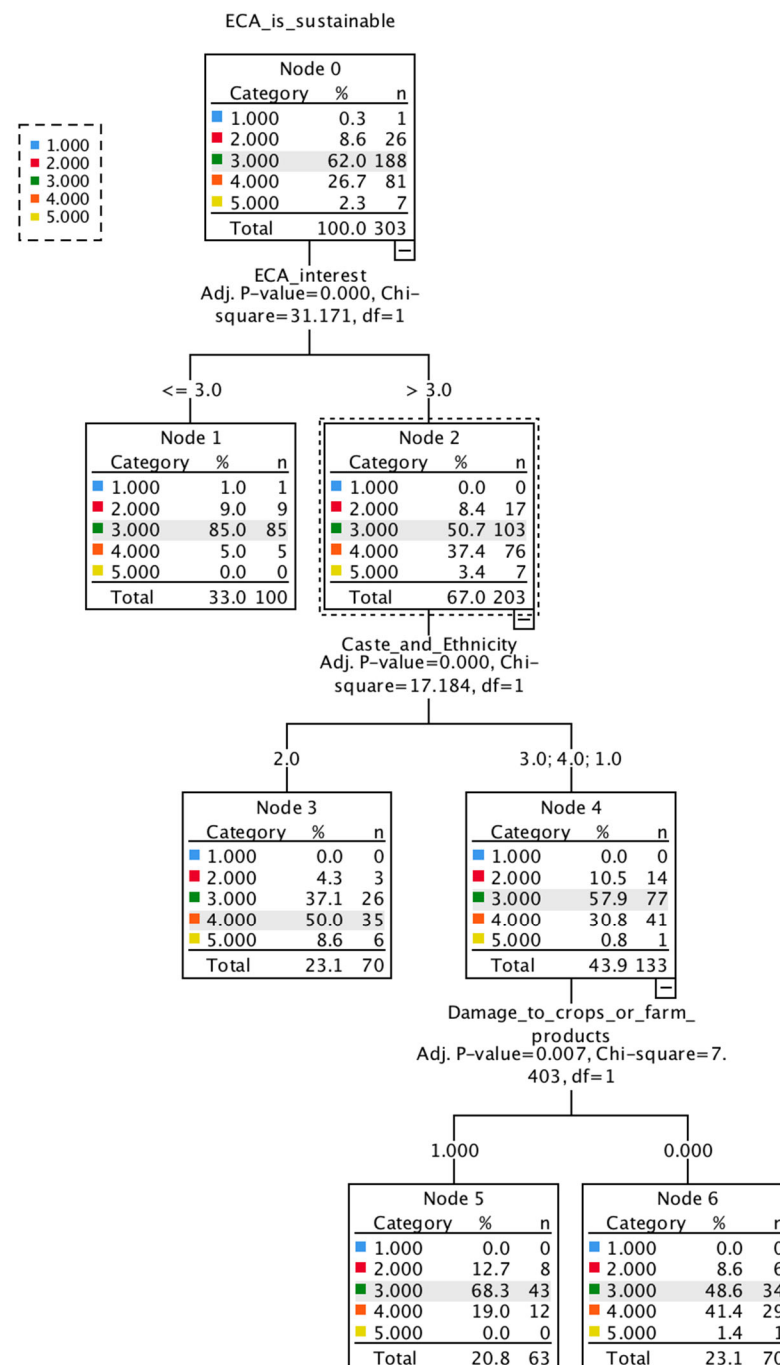


Figure 2. CHAID decision tree diagram of ECA sustainability's predictors.

4. Discussion

Despite the vast body of research conducted on farmers' adoption of environmentally friendly farming practices and their impact on climate change, limited attention has been paid to exploring the factors that contribute to farmers' perception of ECA sustainability in Nepal. Given that farmers' perception could potentially determine their adoption and continued practice of ECA, understanding these factors is essential. ECA adoption is particularly crucial, as it has been demonstrated to decrease greenhouse gas emissions while providing economic, environmental, and social benefits to farmers [9]. This study aimed to bridge this research gap by identifying the positive and negative drivers of farmers' perception of ECA sustainability, which are presented and summarized in Figure 3, classified under the three pillars of ECA sustainability. We discuss each of these pillars in light of our findings, and in Section 4.4, we further explore the intersections of the three pillars to deepen the discussion.

Effect of climate variability

- Damage to crops/farm products (-)

Expected impact of ECA

- Increase agriculture-related income (+)

Reason why it's good to switch to ECA

- Good/higher price (+)

ECA-related variable

- Perception that ECA can achieve sustainable income and productivity, improve adaptive capacity and resilience, and reduce greenhouse gases (+)

Effect of climate variability

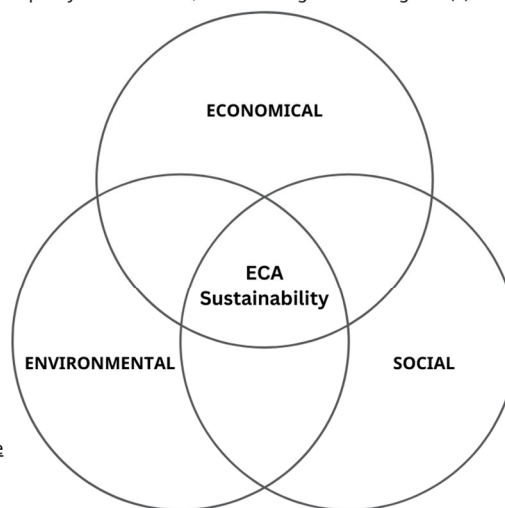
- Change in season/duration (+)

Reason why it's good to switch to ECA

- To improve local and global environment (+)

ECA-related variables

- Perception that farming method is climate resilient or climate smart (+)
- Perception that ECA can achieve sustainable income and productivity, improve adaptive capacity and resilience, and reduce greenhouse gases (+)



Reason to practice ECA

- Self-health (+)

Reasons why it's good to switch to ECA

- To build trust with consumers (+)
- Self-health (+)
- To meet growing demand of consumers (+)

ECA-related variables

- ECA interest (+)
- Desire to discuss or learn more about ECA (+)
- Perception that ECA can achieve sustainable income and productivity, improve adaptive capacity and resilience, and reduce greenhouse gases (+)
- Will practice ECA (+)

Socio-demographic variables

- Caste/Ethnicity (-)
- Will continue farming for the next 5 to 10 years (+)

Figure 3. Pillars of ECA sustainability based on the findings of the study.

4.1. Economic Sustainability of ECA

ECA is a set of farming practices that address climate change while increasing productivity and resilience [9]. The literature suggests that ECA can contribute to food security, reduce greenhouse gas emissions, and increase farmers' income [19]. However, to ensure the long-term sustainability of ECA, it is crucial to ensure its economic viability for farmers [22]. Indeed, several studies have already emphasized that farm income can increase farmers' adoption of agricultural technologies [23,24]; therefore, ECA practices should not lead to financial losses or negatively impact farmers' income. For instance, in the study conducted by Maharjan et al. (2022) among ECA farmers in Fujioka, Japan, they reported that making profit is among the top priorities of farmers, aside from making positive contributions to environmental conservation [6]. The paper also emphasized the importance of balancing environmental conservation and profitability to ensure the sustainability of a farming method.

The findings of our study indicate that damages to crops/farm products negatively drive farmers' perception of ECA sustainability. Nearly 89% of the farmers in this study reported that their farming was affected by climate variability in the last ten years, with

drought, heavy rain and flood, and damages to crops/farm products being the top climate variability effects experienced by the farmers. Climate variability-induced crop damage can result in significant losses to farmers, which affects their income and livelihoods. This could potentially lead to farmers losing confidence in sustainable farming practices and reduce their willingness to adopt ECA. This further highlights the importance of knowledge dissemination among farmers to teach them ECA's climate variability mitigation capabilities, as was also recommended in earlier studies [6,25].

Our findings show that increase in agriculture-related income, good/higher price, and sustainable income and productivity were identified as positive drivers of farmers' perception of ECA sustainability. These are all critical to ensuring that ECA practices remain financially viable and profitable in the long term. Farmers need to generate enough income to maintain their livelihoods, invest in their farms, and respond to changes in the climate. This aligns with the sentiments of other studies, stating that while giving priority to environmentally friendly farming methods may be beneficial in the long run, its sustainability may be hindered when farmers are resource-constrained and experience income reduction due to less agricultural productivity [26,27]. Therefore, economic sustainability is a critical component of ECA that could potentially affect farmers' adoption of ECA practices.

4.2. Environmental Sustainability of ECA

Another important pillar of ECA's sustainability is how it contributes to environmental conservation and climate variability mitigation [28]. Previous studies have already demonstrated that ECA is important to adopt because it could reduce greenhouse gas emissions, improve soil health, and eliminate input-intensive farming practices, among others [14,29]. These highlight the importance of incorporating environmental conservation and climate variability mitigation into the framework of sustainable agriculture.

Our research findings indicate that farmers are more inclined to perceive ECA as sustainable when they prioritize the improvement of their local and global environment. They also feel the same way when they perceive their farming method as climate-smart or climate-resilient, or as capable of reducing greenhouse gases. Moreover, our study supports the notion that farmers who experience changes in seasons or duration are more likely to perceive ECA as sustainable.

These findings underscore the significant value that farmers place on ECA and its climate variability mitigation potential. Consequently, it is crucial to communicate the benefits of ECA effectively to rural communities, as previous studies have identified a knowledge gap among farmers regarding ECA [6]. To bridge this gap, it is essential to intensify efforts in disseminating information about the capacity of ECA to conserve the environment and reduce greenhouse gas emissions. By emphasizing the environmental advantages of ECA, farmers can better understand its importance and make informed decisions in adopting sustainable agricultural practices.

4.3. Social Sustainability of ECA

The third important pillar of ECA sustainability is its social aspect, for this is where social inequalities are addressed and cultural heritages are preserved, which promotes community well-being and resilience and rural livelihoods. By incorporating the social dimension into agricultural practices, we can create a more sustainable and equitable food system that benefits both consumers and producers. Studies have also shown that a sense of community, self-identity, and other psychological factors are important in determining farmers' adoption of farming practices. In this study, farmers who ascribe importance to building trust with consumers and meeting their demands, improving their self-health, and enhancing their adaptive capacity and resilience, as well as those who are planning to continue farming for the next five to ten years, are more likely to perceive ECA as sustainable.

4.3.1. ECA Interest

Among our findings in the social pillar, two factors stood out. First is ECA interest, which emerged as a positive driver and the best predictor in the CHAID analysis for determining farmers' perception of ECA sustainability. Interest is important in adopting ECA because it motivates farmers to learn about these practices and to implement them. When farmers are interested in sustainable farming practices, they are more likely to seek out information about them and to adopt them on their farms. This can lead to a range of benefits, including improved soil health, reduced use of chemical inputs, and increased crop yields. Moreover, interested farmers are more likely to participate in farmer-to-farmer knowledge sharing networks and other learning platforms, which can enhance their capacity to implement sustainable farming practices effectively. In our study, farmers who were interested in ECA were those who were older and had more years of education and farming experience. Interestingly, those who perceived stronger climate variability effects were also those who had higher ECA interest, based on the Spearman correlation ($p = 0.366$). We also found in another Spearman correlation test that farmers who had higher ECA interest also perceived ECA to be capable of empowering women ($p = 0.240$). In connection to this, farmers who had more desire to discuss or learn about ECA and those who wanted to practice ECA were those who perceived that ECA is sustainable.

4.3.2. Caste/Ethnicity

The second element that stood out is caste/ethnicity, which emerged as a negative driver and the second-best predictor for determining farmers' perception of ECA sustainability. To further understand its relationship with ECA sustainability, we conducted a correspondence analysis, as shown in Figure 4. Our findings show that Bahuns were the ones who perceived ECA as not sustainable (as the 1 and 2 red circles in the plot represent 'strongly no' and 'no'). Interestingly, Bahuns also represented more than half of the respondents of the study (53.5%). Meanwhile, Janajatis, the second largest majority of farmers in our sample (30.4%), broadly perceived ECA as sustainable. To explain this stark difference between the caste/ethnicity groups and their ECA sustainability perception, we referred to our key informant interviews. Experts reported that Bahuns usually farm individually, own higher landholdings among the other caste/ethnicity groups, and are more focused on commercial farming. The study of Joshi and Maharjan [30] agrees with this finding, reporting that Bahuns do indeed have higher landholdings and better irrigation coverage, coupled with higher access to production resources that results in higher crop yields. They also reside mostly in roadside areas, and their focus is more on easy/fast income earning. Hence, this may urge them to practice conventional farming using chemical fertilizers and pesticides as frequently as needed. Meanwhile, Janajatis usually farm collectively, have comparatively smaller landholdings, and are characterized to be more attached to nature, their spirituality, and their culture. The study of Gartaula et al. [31] confirms this, describing Janajatis as having a rich cultural life and often conducting rituals and festivities. These show that the social aspect of farmers is also relevant in determining strategies to promote ECA's sustainability to rural communities.

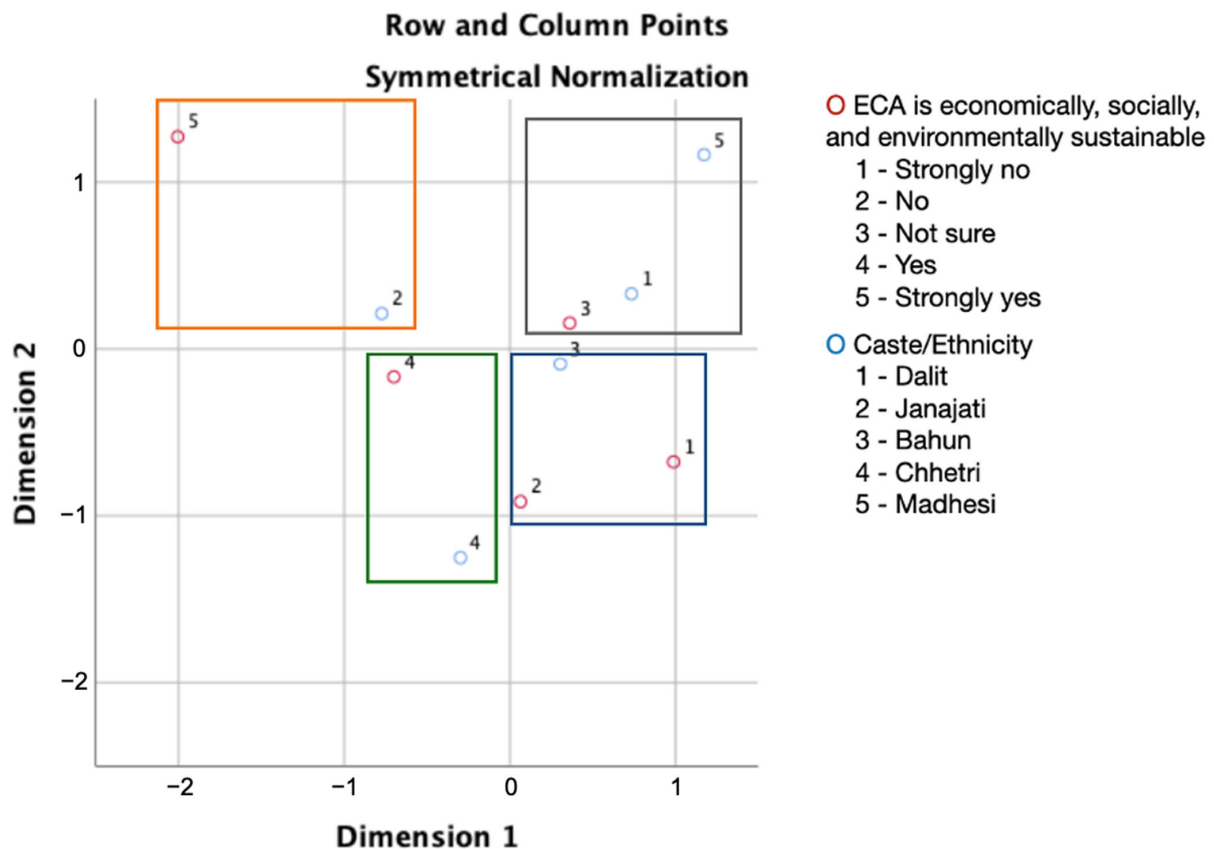


Figure 4. Biplot of ECA sustainability and caste/ethnicity.

4.4. Intersections of the Pillars of ECA Sustainability

Figure 5 provides a comprehensive overview of our findings, showcasing the interconnections between the economic, social, and environmental pillars of ECA sustainability. Understanding farmers' perceptions of ECA sustainability is of utmost importance, as it plays a significant role in shaping their future adoption of ECA practices.

The first pillar, economic sustainability, enables farmers to embrace new and innovative practices that enhance productivity, minimize environmental impact, and build resilience to climate variability. This pillar intersects with the social dimension by ensuring profitability, which allows farmers to cater to consumers' growing demands. Additionally, economic sustainability enables farmers to meet the financial and nutritional needs of their farms and families, ensuring the continuity of farming for future generations [32]. Consequently, farmers are able to sustainably produce healthy food, benefiting both consumers and producers. Meanwhile, this pillar intersects with the environmental dimension by promoting productivity while employing climate-smart and environmentally friendly farming methods. Simultaneously, ECA practices reduce greenhouse gas emissions, leading to improved environmental conditions and reduced crop and product damage—an aspect identified as a negative driver in our study.

The second pillar focuses on the social aspect of ECA sustainability, which intersects with the environmental dimension by mitigating climate variability and enhancing consumer trust and acceptance. It empowers farmers to contribute to the betterment of their local and global environments, strengthening their adaptive capacity and resilience [33,34]. Furthermore, since ECA practices can effectively reduce greenhouse gas emissions, they enable farmers to continue their agricultural activities in the years to come.

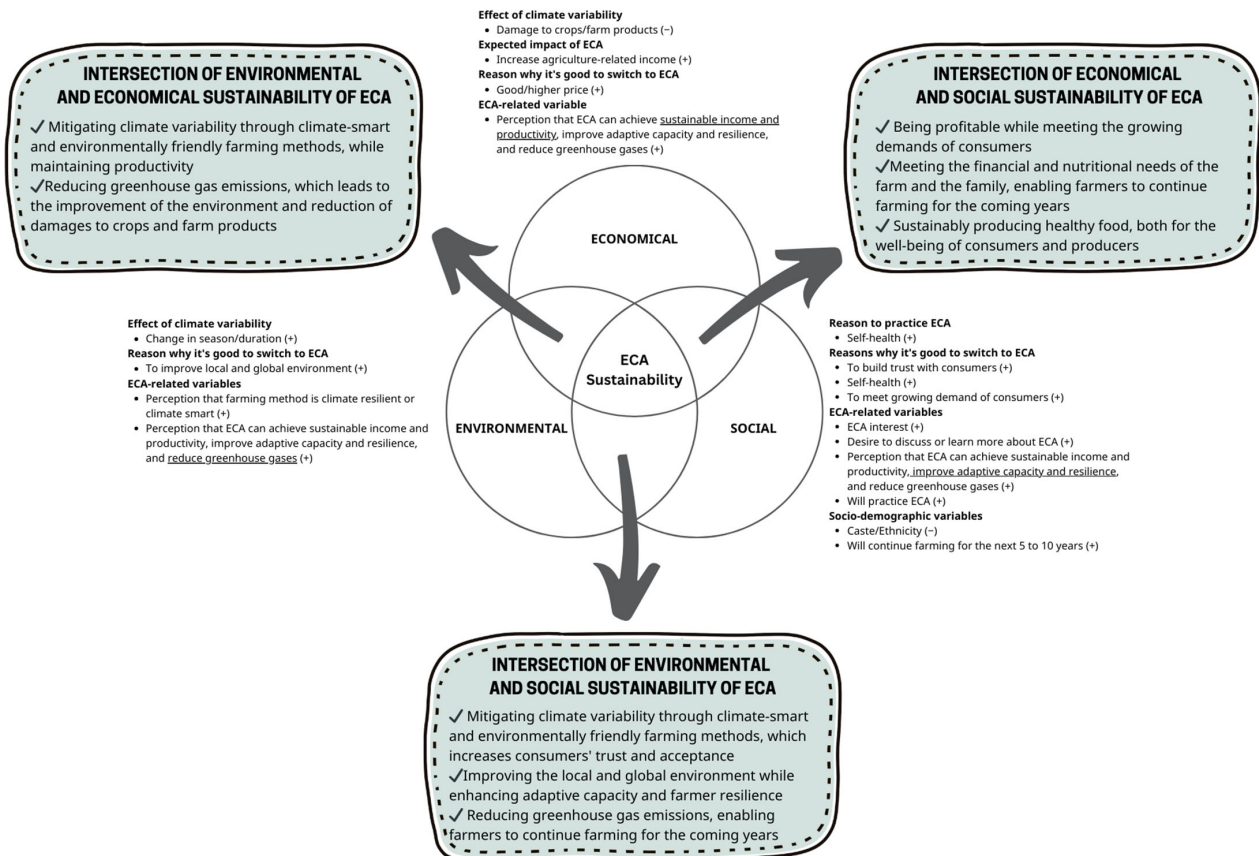


Figure 5. Intersections of the pillars of ECA sustainability.

The third pillar encompasses the environmental aspect of ECA sustainability, which serves as one of the main motivations for farmers to adopt ECA practices [35]. When balanced alongside the social and economic pillars, it leads to improved food security and resilient agricultural systems that enable farmers to adapt to changing climate conditions.

5. Conclusions

As Nepal sets its sights on becoming carbon-neutral by 2045, the implementation of ECA within rural communities becomes increasingly important, since it has been proven to effectively reduce greenhouse gas emissions and minimize input-intensive farming practices, according to MAFF (2020) [9]. However, our research has revealed that the adoption of ECA practices faces various challenges, including limited access to inputs and credit, cultural and social barriers, and the trade-offs between environmental sustainability and social equity. To overcome these challenges and ensure the long-term sustainability of ECA practices, it is imperative to implement targeted policies and programs. These should focus on improving access to inputs and increasing profit for farmers, addressing cultural and social barriers through community engagement and awareness programs, and reconciling the tensions between environmental conservation and social equity goals. Additionally, collaboration between government agencies, non-governmental organizations, and local communities will be crucial in promoting the adoption of ECA and fostering sustainable agricultural practices.

Furthermore, our paper has identified several key factors that determine farmers' perception of ECA sustainability, both positively and negatively. By understanding these factors, policymakers and agricultural practitioners can develop more effective strategies to promote the adoption of ECA practices and address the underlying barriers to implementation. Additionally, our framework illustrating the intersections of the pillars of

ECA sustainability provides a valuable tool for future researchers studying ECA and its contributions to agricultural sustainability.

In conclusion, overcoming the challenges associated with ECA adoption will require concerted efforts from all stakeholders and a holistic approach that considers the complex interplay between environmental, social, and economic factors. Through collaborative action and targeted interventions, Nepal can harness the full benefits of ECA and pave the way towards a more sustainable and resilient agricultural future.

6. Recommendations

In light of our findings, we propose the implementation of strategic initiatives to disseminate ECA knowledge among farmers, recognizing the pivotal role of interest in ECA in shaping perceptions of its sustainability. Building on the insights gleaned from our research and in alignment with the recommendations of previous ECA studies [6,29], efforts should focus on developing tailored educational programs and outreach activities aimed at increasing farmers' awareness and understanding of ECA practices.

Moreover, future research endeavors could delve deeper into specific aspects identified in our findings, such as exploring the potential for ECA practices to empower women farmers. By examining the intersectionality of gender dynamics and agricultural practices, researchers can uncover valuable insights into the role of ECA in promoting gender equality and women's empowerment in rural communities.

Furthermore, expanding the scope of the research to encompass additional districts in Nepal, coupled with a larger dataset, would provide a more comprehensive understanding of farmers' perception of ECA. This broader geographic coverage would enable researchers to capture the diversity of experiences and perspectives among farmers across different regions, thereby enriching our understanding of the factors influencing ECA adoption and sustainability.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su16114523/s1>, Table S1: Socio-demographic characteristics of the sampled farmers in Namobuddha, Kavre, Nepal; Table S2: Climate variability and ECA-related variables of the sampled farmers in Namobuddha, Kavre, Nepal; Table S3: Spearman correlation of farmers' intention to practice ECA with ECA-related variables.

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