

INTERDIMENSIONAL CORRELATIONS IN THE SUSTAINABILITY OF SMALLHOLDER COFFEE FARMING: A CASE STUDY OF PULOSARI VILLAGE, PANGALENGAN DISTRICT, BANDUNG REGENCY**Risma Namira Aulia***

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Corresponding author: risma19003@mail.unpad.ac.id**ABSTRACT**

Smallholder coffee farming depends on the interaction of economic, ecological, social, technological, and institutional conditions. Understanding these relationships is therefore essential for developing interventions that are both relevant to farmers and effective at the system level. This study examined the strength of the associations among sustainability dimensions and identified the dimension most closely associated with the overall sustainability index for smallholder coffee farming in Pulosari Village, Pangalengan District, Bandung Regency. A quantitative cross-sectional survey was conducted with 190 coffee farmers. Sustainability was assessed using 103 indicators grouped into five dimensions: economic, ecological, social, technological, and institutional. Interdimensional relationships were analysed using Pearson's correlation coefficient at the 1% significance level. All pairwise correlations were positive and statistically significant ($p < 0.001$). The strongest association was found between the technological and institutional dimensions ($r = 0.866$),

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whereas the weakest was observed between the ecological and institutional dimensions ($r = 0.429$). The technological dimension also had the strongest correlation with the overall sustainability index ($r = 0.920$), followed by the institutional dimension ($r = 0.894$). Its combination of the lowest index score (46.82) and the strongest association with the overall index identifies technology as the principal leverage point. The findings suggest that technological improvement should be pursued alongside institutional strengthening rather than introduced as a stand-alone intervention.

1. INTRODUCTION

Indonesia is the world's fourth-largest coffee producer after Brazil, Vietnam, and Colombia (International Coffee Organization, 2021). More than 95% of national coffee production comes from smallholder plantations (Badan Pusat Statistik, 2022), meaning that the long-term viability of Indonesia's coffee sector is closely tied to the sustainability of small-scale farming. Bandung Regency is one of West Java's main Arabica coffee-producing areas, with approximately 13,000 hectares under cultivation and annual production exceeding 5,000 tonnes. Despite this potential, farmers continue to face structural barriers to adopting more sustainable practices.

The concept of agricultural sustainability has expanded beyond the three classical pillars introduced by Brundtland (1987). Through the Sustainability Assessment of Food and Agriculture Systems framework, FAO (2014) incorporated governance as an additional dimension. In Indonesian agriculture, technology is also frequently treated as a distinct dimension because of its central role in farm transformation (Mariyono, 2019; Sudarko et al., 2020). These five dimensions do not operate independently; together, they form an interconnected farming system.

Nevertheless, many studies of farm sustainability in Indonesia stop at reporting separate index scores for each dimension and do not statistically examine how those dimensions are related. Without a clear understanding of this relational structure, intervention priorities may be fragmented and resources may be directed towards measures that have limited wider effects. Rasihen et al. (2021) argue that sustainability assessment is most useful when it reveals the sensitive factors that require improvement. This study addresses that gap by examining the pattern and strength of relationships across sustainability dimensions.

Accordingly, this study aimed to: (1) analyse the strength of the relationships among the sustainability dimensions of smallholder coffee farming in Pulosari Village; and (2) identify the dimension most closely associated with the overall sustainability index as a basis for setting intervention priorities.

2. METHODS

The study was conducted in Pulosari Village, Pangalengan District, Bandung Regency, West Java. The location was selected purposively because Pangalengan is a major highland Arabica coffee-producing area with a substantial concentration of smallholder farmers.

A quantitative cross-sectional design was used. The sample comprised 190 coffee farmers, determined using the [Slovin formula/Krejcie and Morgan (1970)] at a 95% confidence level and a 5% margin of error. Primary data were collected through structured interviews using a questionnaire containing 103 indicators across five sustainability dimensions: economic (24 indicators), ecological (20 indicators), social (24 indicators), technological (24 indicators), and institutional (11 indicators). Each indicator was measured on a five-point Likert scale.

Raw scores were converted to indices on a scale of 0 to 100 using the following normalisation formula: $\text{index} = ((\text{mean score} - 1) / 4) \times 100$. Indicator indices were aggregated into dimension indices, which were subsequently combined to obtain the overall sustainability index. Index categories followed the FAO (2014) classification: 0-20, unsustainable; 20-40, less sustainable; 40-60, moderately sustainable; 60-80, sustainable; and 80-100, highly sustainable.

Instrument reliability was assessed using Cronbach's alpha, with 0.70 as the minimum acceptable threshold (Ghozali, 2018). Relationships among dimensions were analysed at the respondent level using Pearson's product-moment correlation coefficient. Assumptions of normality, linearity, and homoscedasticity were examined before the analysis was performed (Field, 2018; Schober et al., 2018). The strength of association was classified following Sugiyono (2019): 0.00-0.20, very weak; 0.21-0.40, weak; 0.41-0.60, moderate; 0.61-0.80, strong; and 0.81-1.00, very strong. Two-tailed significance tests were conducted at the 1% and 5% levels.

3. RESULTS AND DISCUSSION

Sustainability Indices by Dimension

The overall sustainability index for smallholder coffee farming in Pulosari Village was 55.78 (SD = 10.83), placing it in the moderately sustainable category. The five dimensions, however, did not perform equally, as shown in Table 1.

Table 1. Sustainability indices by dimension for smallholder coffee farming (n = 190)

Dimension	Index	SD	Alpha	Category
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Social	64.49	8.44	0.801	Sustainable
Ecological	61.74	9.69	0.822	Sustainable
Institutional	53.46	15.15	0.852	Moderately sustainable
Economic	52.38	12.81	0.874	Moderately sustainable
Technological	46.82	17.53	0.956	Moderately sustainable
Overall index	55.78	10.83	-	Moderately sustainable

Source: Primary data analysis ([year]). Note: SD = standard deviation; Alpha = Cronbach's alpha coefficient.

Cronbach's alpha exceeded the 0.70 threshold for every dimension, ranging from 0.801 to 0.956. The instrument was therefore considered reliable, and the aggregation of indicator scores into dimension indices was statistically defensible.

Interdimensional Correlations in Sustainability

Pearson correlation analysis across the five dimensions produced coefficients that were uniformly positive and statistically significant at the 1% level ($p < 0.001$). The correlation matrix is presented in Table 2 and visualised in Figure 1.

Table 2. Pearson correlation matrix across sustainability dimensions (n = 190)

Dimension	Economic	Ecological	Social	Technological	Institutional
Economic	1.000	0.561**	0.622**	0.695**	0.638**
Ecological	0.561**	1.000	0.694**	0.522**	0.429**
Social	0.622**	0.694**	1.000	0.619**	0.684**
Technological	0.695**	0.522**	0.619**	1.000	0.866**
Institutional	0.638**	0.429**	0.684**	0.866**	1.000

Source: Primary data analysis ([year]). Note: ** significant at the 1% level (two-tailed).

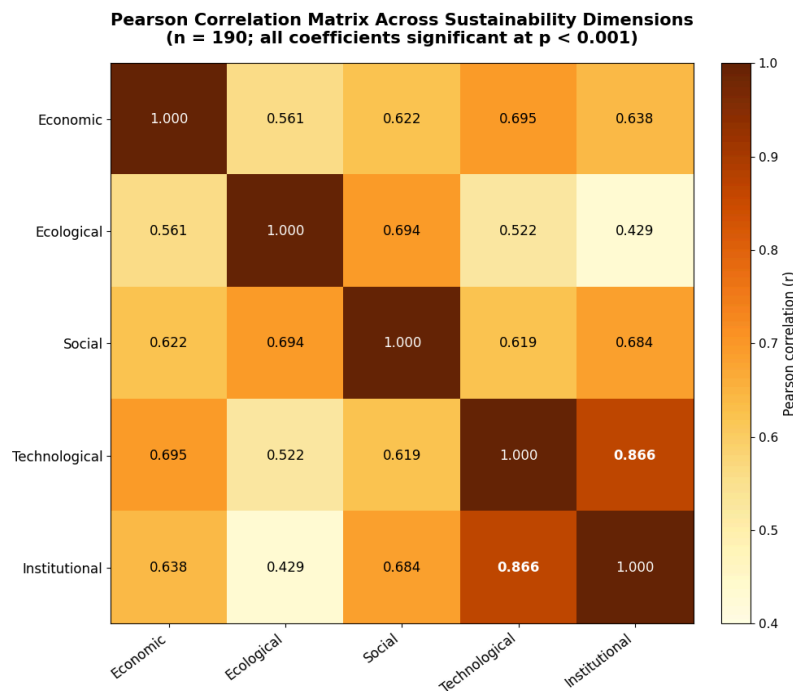


Figure 1. Heat map of the Pearson correlation matrix across sustainability dimensions

Three main findings emerge from Table 2 and Figure 1.

The strongest relationship was found between the technological and institutional dimensions ($r = 0.866$; $p < 0.001$), indicating a very strong association. Farmers' technological capacity is closely connected to the strength of the institutions that support them, particularly cooperatives and agricultural extension services. Farmers with better access to cooperative services also tend to have better access to technology. This finding supports Sudarko et al. (2020), who describe institutions as enablers of agricultural technology adoption, and is consistent with North's (1990) argument that formal institutions can reduce the transaction costs associated with adopting innovation.

The correlation between the economic and technological dimensions was strong ($r = 0.695$; $p < 0.001$). This relationship suggests that economic capacity and technological capability tend to develop together. Investment in technology requires access to capital, while technology can, in turn, support productivity and farm income. Interventions that focus on only one of these dimensions without considering the other may therefore produce limited results.

The weakest relationship was observed between the ecological and institutional dimensions ($r = 0.429$; $p < 0.001$), although the association remained moderate and statistically significant. This pattern may indicate that ecological practices

already used by farmers, including composting, waste management, and climate awareness, are still shaped largely by practical experience and locally inherited knowledge. These practices have not yet been fully connected to formal institutional support, such as sustainability certification or government extension services. The finding points to an opportunity to build stronger links between institutional services and farmers' existing ecological practices through regenerative agriculture programmes and certification schemes.

Correlations between Individual Dimensions and the Overall Sustainability Index

To identify the dimension most closely associated with variation in the overall sustainability index, Pearson correlations were calculated between each dimension index and the overall index. The results are presented in Table 3.

Table 3. Correlation of each dimension with the overall sustainability index

Dimension	Index	r with overall index	Interpretation
Technological	46.82	0.920**	Very strong; largest association with variation in the overall index
Institutional	53.46	0.894**	Very strong; an important support for the overall index
Economic	52.38	0.837**	Very strong; closely associated with the overall index
Social	64.49	0.819**	Very strong; substantial association with the overall index
Ecological	61.74	0.708**	Strong; the smallest association among the five dimensions

Source: Primary data analysis ([year]). Note: ** significant at the 1% level (two-tailed).

Table 3 shows that the technological dimension had the strongest association with variation in the overall sustainability index ($r = 0.920$), followed by the institutional dimension ($r = 0.894$). Technology also recorded the lowest dimension index (46.82). Taken together, its low performance and strong relationship with the overall index position the technological dimension as the principal leverage point. Improvement in this dimension would be expected to show the closest association with improvement in the overall index, making technology a strategically important focus for intervention.

Implications of the Findings

The pattern of relationships has three practical implications. First, technology modernisation should not be implemented separately from institutional strengthening, given the very strong relationship between the two dimensions ($r = 0.866$). Revitalising cooperatives as integrated

service hubs may create wider benefits for technology access and adoption. Second, the strong relationship between the economic and technological dimensions ($r = 0.695$) suggests that limited capital accompanies technological disadvantage; inclusive financing should therefore be designed alongside the provision of equipment and technical support. Third, the more modest link between ecological practices and formal institutions ($r = 0.429$) suggests that farmers' existing ecological strengths have not yet been fully translated into market value, for example through sustainability certification.

It is important to emphasise that correlation coefficients describe the strength of association and do not establish cause-and-effect relationships (Cohen, 1988; Hair et al., 2019). The findings should therefore be interpreted as evidence of interconnection rather than causality. Establishing the direction of causal relationships would require a longitudinal or experimental research design.

4. CONCLUSION

All correlations among the sustainability dimensions of smallholder coffee farming in Pulosari Village were positive and statistically significant at the 1% level, indicating that the five dimensions function as an interconnected system. The strongest relationship was between the technological and institutional dimensions ($r = 0.866$), while the weakest was between the ecological and institutional dimensions ($r = 0.429$). The technological dimension had the strongest correlation with the overall sustainability index ($r = 0.920$) and, at the same time, recorded the lowest index score (46.82). It therefore represents the principal leverage point for improving sustainability.

Based on these findings, efforts to strengthen the sustainability of smallholder coffee farming should prioritise technological improvement while integrating it with stronger cooperative institutions and broader access to finance. Future research should use longitudinal designs or structural equation modelling to examine the direction of relationships among dimensions. Expanding the study to additional locations would also help determine whether the findings can be generalised across Bandung Regency.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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