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*RESEARCH ARTICLE*

# DEVELOPING AND VALIDATING AN INCLUSIVE SUSTAINABILITY METRIC FOR INDEPENDENT SMALLHOLDER OIL PALM CULTIVATION IN MALAYSIA

**Abd Rahman Ahmad[a*], Noor Aslinda Abu Seman[b*], Umi Kartini Rashid[c], Muhammad Zakwan Abu@Hussin[d]**

*[a,b,c]Johor Business School, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*
*[d]Koperasi Keluarga Legasi Hussin Berhad, Felda Penngeli Timur, 81440 Bandar Tenggara, Johor, Malaysia*
**Corresponding Author Email :arahman@uthm.edu.my*

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**ABSTRACT**

The global initiative for sustainable palm oil has intensified; however, independent smallholders, who represent a substantial portion of the sector, continue to be marginalised due to the complexities and costs associated with sustainability assessments. Current certification metrics fail to adequately consider their operational contexts and constraints, resulting in significant deficiencies in inclusive sustainability governance. This research creates and verifies a detailed, multi-faceted sustainability metric specifically designed for independent smallholder oil palm farming in Malaysia, facilitating tiered performance assessment that extends beyond simple certification models. A cross-sectional survey involving 301 independent smallholders in Johor, Malaysia, was conducted. The metric, organised into environmental, social, and economic dimensions, was subjected to thorough psychometric validation, which included item-to-total correlation, Cronbach's alpha reliability testing, and Confirmatory Factor Analysis (CFA) to establish construct validity. Cluster analysis revealed the metric's ability to categorise smallholders based on sustainability performance. The validated metric included 32 indicators across three dimensions, exhibiting high internal consistency (Cronbach's $\alpha > .85$ for all dimensions) and excellent model fit (CFI = .951, TLI = .943, RMSEA = .042, 90% CI [.037, .047]). Cluster analysis revealed three distinct segments: High Performers (28%, n = 84), Moderate Practitioners (52%, n = 157), and Challenged Beginners (20%, n = 60). Significant differences were observed in farm size, certification status, and annual income ($p < .001$, $\eta^2 = .34$). This validated tool allows policymakers, certification bodies, and extension services to perform detailed sustainability assessments. The findings recommend moving from uniform certification to tiered support systems, which enable targeted interventions for more inclusive and equitable transitions to sustainable palm oil production.

**KEYWORDS**

Cluster Analysis, Metric Development, Oil Palm, Smallholder Farmers, Sustainability Assessment

## 1. INTRODUCTION

The global palm oil industry is at a pivotal moment, confronting substantial social and environmental issues while being essential to the world economy (Meijaard et al., 2020). As the most prevalent vegetable oil globally, palm oil is vital to the economies of nations such as Malaysia and Indonesia, creating jobs and enhancing export profits (Qaim et al., 2020). Nonetheless, its swift proliferation has been intricately linked to deforestation, loss of biodiversity, and societal discord (Dislich et al., 2017 ; Vijay et al., 2016). In this diverse context, independent smallholders, farmers who operate their land autonomously from giant businesses, have emerged as crucial although largely neglected participants in the industry (Azhar et al., 2021). In Malaysia, these smallholders cultivate around 30% of the total oil palm planted area, sustaining more than 250,000 farm households (MPOB, 2023). Ensuring the sector's long-term viability demands the widespread adoption of sustainable practices among both smallholders and larger industrial actors (Nambiappan et al., 2018).

The global response has been the establishment of other certification systems, such as the Roundtable on Sustainable Palm Oil (RSPO) and the Malaysian Sustainable Palm Oil (MSPO) standard, which is mandated. These frameworks have set fundamental requirements for major agricultural operations; nevertheless, growing data suggests they are less effective for small, independent farmers (Pacheco et al., 2020). Small-scale farmers face formidable obstacles stemming from rigorous audit mandates, considerable documentation costs, and complex compliance standards (Brandi et al., 2015; Euler et al., 2016). This is a significant issue since the instruments intended to protect the environment are adversely impacting those most vulnerable to market fluctuations and climatic variations (Tey and Brindal, 2021). In 2023, less than 15% of independent smallholders in Malaysia were certified by MSPO. This illustrates the disparity between policies and behaviours (MPOC, 2023). A growing

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contingent of academics supports the adoption of more sophisticated, context-dependent assessment methods instead of binary certification systems (Kadandale et al., 2019 ; Rietberg and Slingerland, 2022).

Contemporary research frequently concentrates on specific elements, such as environmental effect or economic feasibility (Aziz et al., 2021), neglecting the holistic concept of sustainability as defined by the United Nations Sustainable Development Goals (United Nations, 2015). This disjointed methodology overlooks the myriad trade-offs inherent in smallholder decision-making (Dixon et al., 2020). A farmer may excel in environmental conservation yet struggle with financial profitability. Audits that are successful or unsuccessful do not always reveal this information. Moreover, current metrics often exhibit insufficient empirical validation within Malaysian smallholder contexts, prompting questions over their measurement accuracy and practical applicability (Abu Seman et al., 2025).

The sustainable livelihoods paradigm offers significant theoretical foundations, defining sustainability as the interplay of various capital assets influenced by vulnerability situations and institutional frameworks (Scoones, 2015). Nonetheless, its incorporation into measurable criteria is still insufficiently advanced for palm oil systems. The composite indicator methodology prioritises the assessment of variables from several viewpoints, utilising psychometric validation methods such confirmatory factor analysis (Greco et al., 2019 ; Schader et al., 2014). These methodologies have seldom been utilised in smallholder palm oil settings, where data limitations impede assessment (Lee et al., 2014).

A significant gap persists: a comprehensive, scientifically validated, multi-dimensional sustainability metric specifically designed for independent smallholders has yet to be established. This tool must evaluate performance from environmental, societal, and economic perspectives, providing diagnostic information to assist various policy support initiatives (Glasbergen, 2018 ; Schoneveld et al., 2019). Here, this study focusses on the development and validation of a comprehensive sustainability index for evaluating independent smallholder palm oil output in Malaysia.

## 2. Literature Review

### 2.1 The Sustainability Imperative in the Palm Oil Sector

The environmental impact of the palm oil industry, especially its link to tropical deforestation and peatland drainage in Southeast Asia, has subjected it to rigorous international examination (Gaveau et al., 2022). From 2000 to 2020, the increase of oil palm cultivation resulted in the loss of nearly 3.5 million hectares of forest in Indonesia and Malaysia, marking it as a key factor in land-use change in tropical regions (Austin et al., 2019). The resultant biodiversity decline, encompassing significant habitat risks to endangered species like orangutans, Sumatran tigers, and pygmy elephants, along with considerable greenhouse gas emissions from peatland conversion, has rendered sustainability the paramount concern for the sector's global reputation and enduring social license to operate (Santika et al., 2023 ; Meijaard et al., 2020). Recent estimates indicate that palm oil cultivation on peatlands contributes over 500 million tonnes of CO2 equivalent each year, highlighting the sector's climatic importance (Hooijer et al., 2010 ; Warren et al., 2017).

Simultaneously, the social aspect of sustainability has become increasingly significant, including land tenure rights, labour conditions, equitable salaries, and community well-being (Cramb and McCarthy, 2016). Research indicates ongoing issues such as disputes about customary land rights, exploitative labour practices predominantly impacting migrant workers, and insufficient benefit-sharing frameworks with local populations (Obidzinski et al., 2012; Pichler, 2015). The intricate interaction of ecological and social constraints has prompted global governance responses, chiefly via multi-stakeholder certification programs aimed at distinguishing sustainably produced palm oil in international markets (Schouten and Glasbergen, 2011). Nonetheless, the efficacy of these market-based processes in achieving meaningful sustainability results continues to be a topic of contention, as critics emphasise enduring discrepancies between certification criteria and actual impacts (Garrett et al., 2021; Carlson et al., 2018).

### 2.2 The Plight of the Independent Smallholder

In this governance context, independent smallholders pose a significant problem and a substantial opportunity for sustainable transitions. Farmers who manage their own land, generally under 50 hectares and without direct contractual relationships with large corporate estates, form a highly heterogeneous group distinguished by varied production practices, knowledge levels, and economic capabilities (Azhar et al., 2021 ; Euler et al., 2017). In Malaysia, independent smallholders oversee over 15% of the total oil palm land yet represent a far smaller fraction of certified production (MPOB, 2023). This cohort included both seasoned farmers with extensive experience and newcomers, demonstrating significant disparities in land tenure security, access to extension services, and incorporation into formal supply networks (Woittiez et al., 2017).

Although major corporate plantations have made considerable progress in implementing certification requirements, individual smallholders encounter distinct and cumulative obstacles. These encompass restricted access to capital for essential infrastructure enhancements, such as effluent treatment systems or the establishment of riparian buffers, inadequate technical expertise concerning integrated pest management and precision fertilisation, and intricate certification processes primarily tailored for corporate entities with specialised sustainability divisions (Rietberg and Slingerland, 2022 ; Brandi et al., 2015). Financial limitations are especially severe; research indicates that certification expenses might account for 10% to 15% of annual income for smallholders, an untenable strain for farmers functioning at minimal profitability (Hidayat et al., 2015).

Moreover, literacy and language obstacles hinder participation in documentation-intensive audit procedures, while restricted organisational capacity obstructs collaborative certification methods that could realise economies of scale (Jelsma et al., 2017). This has created an inclusivity gap, where a substantial portion of the supply chain faces exclusion from formal sustainability programs, hence fundamentally jeopardising sector-wide transformation goals (Tey and Brindal, 2021 ; Pacheco et al., 2020). This exclusion perpetuates environmental degradation and social disparities while exacerbating economic vulnerabilities for smallholders, who encounter possible market access constraints as major customers increasingly seek certified goods (Brandi et al., 2015). The implications for social justice are significant, since the exclusion of smallholders shifts the costs of sustainability compliance onto the economically disadvantaged, while enabling affluent corporate entities to seize premium market possibilities (Pichler, 2015).

### 2.3 Limitations of Current Sustainability Assessment Frameworks

The principal sustainability frameworks, including the Roundtable on Sustainable Palm Oil (RSPO) founded in 2004 and the obligatory Malaysian Sustainable Palm Oil (MSPO) standard enacted in 2019, have been instrumental in setting fundamental sustainability benchmarks (Schleifer, 2023). RSPO accreditation, albeit optional, garners market acknowledgement, especially in European markets, whereas MSPO embodies a governmental strategy for comprehensive sustainable governance in the sector (Schouten and Glasbergen, 2011). Nonetheless, their implementation among independent smallholders exposes numerous significant shortcomings that hinder both effectiveness and inclusion.

Primarily, these frameworks operate as binary pass or fail systems that insufficiently represent the gradual, non-linear dynamics of sustainable adoption (Rietberg and Slingerland, 2022). A farmer who adopts various beneficial practices but fails to meet one criterion is assigned the same non-certified status as one who employs no sustainable techniques, so negating acknowledgement for partial advancement (Dixon et al., 2020). This binary classification is disheartening and does not encourage gradual enhancement, which behavioural research indicates is essential for enduring practice change in resource-limited populations (Michie et al., 2011). Secondly, these frameworks impose relatively identical criteria across varied smallholder contexts without sufficient consideration for variances in agro-ecological conditions, market infrastructure, cultural norms, or household situations (Abu Seman et al., 2025). Riparian buffer criteria established for big estates may be unfeasible for smallholdings, as each hectare significantly impacts household subsistence (Jelsma et al., 2017; Schoneveld et al., 2019).

Thirdly, evaluation costs, including direct certification fees and indirect charges associated with time investment and documentation preparation, are excessively high for numerous smallholders (Hidayat et al., 2018). Research indicates that yearly certification maintenance expenses may surpass USD 2,000 per farmer, representing several months of revenue for average smallholders (Brandi et al., 2015). The technical intricacy of audit paperwork, which frequently necessitates comprehensive record-keeping systems that exceed the literacy or administrative capabilities of smallholders, poses tangible obstacles to participation (Jelsma et al., 2017). Existing frameworks have been criticised for insufficient validation in particular smallholder contexts; numerous standards were primarily formulated through expert consultation and corporate pilot testing, with minimal empirical evaluation of their reliability, validity, or cultural suitability for smallholder populations (Lee et al., 2014).

These constraints have created demands for a new generation of assessment instruments that are diagnostic rather than solely evaluative, developmentally orientated rather than punitive, and fundamentally designed with the operational realities and capacity limitations of smallholders at their core (Glasbergen, 2018 ; Schoneveld et al., 2019).

### 2.4 Towards Multi-Dimensional and Tiered Sustainability Metrics

An emerging scholarly consensus underscores that effective sustainability measurements should surpass isolated methodologies and adopt comprehensive, multi-faceted viewpoints that concurrently integrate environmental, social, and economic dimensions (Scoones, 2015 ; Morse and McNamara, 2013). This corresponds with the cohesive framework of the Sustainable Development Goals, which openly acknowledge interdependencies and possible trade-offs among sustainability components (Schader et al., 2014). An effective smallholder metric must evaluate environmental indicators, such as agrochemical management and biodiversity conservation, as well as social factors, including labour equity and community relations, in addition to economic dimensions, encompassing income sufficiency and financial resilience (Kadandale et al., 2019). Research indicates that smallholder decision-making inherently reconciles several aims, with environmental practices frequently limited by economic pressures and social obligations (Baudron et al., 2017).

Moreover, persuasive arguments advocate for tiered or graduated measures that classify performance into several categories, including emerging, developing, and advanced practitioners (Rietberg and Slingerland, 2022). These approaches recognise sustainability as an ongoing process of enhancement rather than a fixed endpoint, offering developmental frameworks with distinct progression trajectories (Potts et al., 2014). Tiered systems allow policymakers, extension services, and supply chain participants to distinguish between smallholders and offer customised technical assistance, financial incentives, or market connections instead of implementing uniform interventions for a diverse population (Schoneveld et al., 2019). This differentiation strategy has been effective in other agricultural sustainability contexts, such as coffee and cocoa certification systems, where tiered criteria promote wider involvement while upholding aspirational goals (Bacon et al., 2008).

Notwithstanding these theoretical advancements, empirical implementations of verified, multi-dimensional, tiered metrics particularly formulated for and evaluated with independent oil palm smallholders are conspicuously lacking in the literature. This study fills the gap by creating and thoroughly validating an instrument that is empirically based on primary data collection, multi-dimensional in nature, psychometrically sound, and able to produce detailed performance profiles to inform tailored support strategies for independent smallholders in Malaysia.

## 3. Methodology

### 3.1 Research Design

This research utilised a cross-sectional survey methodology to gather quantitative data from independent smallholder oil palm cultivators in Johor, Malaysia. The design was chosen for its efficacy in collecting data from a vast, geographically scattered population at a singular moment, facilitating the comprehensive statistical analysis necessary for measure formulation and validation (Creswell and Creswell, 2018). The study employed a systematic, multi-phase approach for scale construction as delineated by (DeVellis, 2017), which included: (a) domain identification and item generation, (b) instrument design, (c) data collecting, and (d) quantitative refinement and validation using psychometric analysis.

### 3.2 Participants and Sampling

The target population comprised independent smallholder oil palm farmers in Johor, a principal oil palm-producing area in Peninsular Malaysia. A multi-stage sampling method was employed. Initially, purposive sampling was employed to choose the state of Johor because of its substantial smallholder demographic. A random selection method was utilised to pick participants from the registry of independent smallholders supplied by the Malaysian Palm Oil Board (MPOB). A priori power analysis conducted with G*Power software revealed that a minimum sample size of 250 is necessary to identify small to medium effect sizes ($f^2 = 0.10$) with a power of 0.95 and an alpha of 0.05 for the intended multiple regression and factor analyses (Faul et al., 2009). To address probable non-response, 350 farmers were originally approached. The total sample had N = 301 respondents, resulting in a response rate of 86%. Sample Characteristics: The sample was primarily male (67.8%) with a mean age of 43.9 years, falling between the 46-60 age range. A majority had completed secondary education (44.5%) and possessed land ownership (81.7%). The predominant farm size was 2-5 hectares (41.2%), while the majority of farmers possessed over ten years of experience (59.5%). This profile accurately reflects the independent smallholder demographic in the region (MPOB, 2023).

### 3.3 Instrument and Measures

The data gathering tool was a structured questionnaire aimed at thoroughly assessing sustainability across environmental, social, and economic dimensions, in accordance with the study's main goal of creating a multi-dimensional sustainability index. The instrument was created based on an analysis of literature regarding agricultural sustainable practices and current palm oil certification standards (RSPO, 2023 ; MSPO, 2022). The questionnaire was pre-tested with 20 smallholders for clarity, and minor revisions were made based on their comments to guarantee its appropriateness. The survey comprised four sections:

- Section A: Demographic and Socio-Economic Profile: Documented essential variables like gender, age, education, land ownership, and farm size.
- Section B: Sustainable Agricultural Practices (6 items): Assessed the prevalence of sustainable practices, including the application of natural fertilisers, with a 5-point Likert scale.
- Section C: Government Support (5 items): Evaluated attitudes of governmental assistance with sustainability projects, employing a 5-point Likert scale.
- Section D: Farm Performance (3 sub-scales, 32 items): Assessed Environmental Performance (10 questions), Social Performance (10 items), and Economic Performance (12 items), employing a 5-point Likert scale for measurement.

This instrument was designed in order to offer comprehensive and exact measurement, emphasising both reliability and validity in assessing smallholder sustainability. The multi-faceted approach facilitates an in-depth examination, crucial for formulating a strong and all-encompassing sustainability indicator.

### 3.4 Data Collection Procedure

Ethical approval for the study was granted by the University Research Ethics Committee. Data were gathered during a three-month duration. Trained enumerators performed in-person interviews at the farmers' locations or an accessible nearby site. All participants provided informed consent after a thorough explanation of the study's objectives, confidentiality guarantees, and their right to withdraw. The typical time of the interview was 20 to 25 minutes.

### 3.5 Data Analysis Strategy

Data analysis was performed utilising IBM SPSS Statistics (Version 28) and IBM SPSS AMOS (Version 28) through a methodical, three-phase methodology. The initial phase concentrated on the refinement and validation of metrics. The internal consistency of each construct (B, C, D_env, D_soc, D_eco) was assessed using Cronbach's Alpha, with an acceptable threshold established at $\alpha \geq 0.70$ (Nunnally and Bernstein, 1994). Confirmatory Factor Analysis (CFA) was conducted on 32 items representing the three-dimensional Farm Performance scale (Environmental, Social, Economic) to evaluate the validity of the measurement model. The model fit was assessed using several indices: $\chi^2/df < 3$, CFI > 0.90, TLI > 0.90, and RMSEA < 0.08 (Hu and Bentler, 1999). Upon validating the measurement methodology, composite scores for each sustainability dimension and the Total Sustainability Score (TSS) were calculated by averaging the pertinent items. During the second phase, metric application involved descriptive and correlational analysis to calculate means, standard deviations, and inter-correlations of the composite scores. K-means cluster analysis was utilised to categorise farmers into performance-oriented groups, with the ideal number of clusters established by comparing 2, 3, and 4-cluster solutions. The validity of the cluster was assessed by ANOVA accompanied by Tukey post-hoc tests, while demographic profiles were analysed using cross-tabulation and chi-square tests.

## 4. Results

### 4.1 Demographic and Socio-Economic Profile of Respondents

The research commences with a delineation of the 301 independent smallholders who engaged in the project. Table 1 delineates the principal demographic and socio-economic attributes of the sample. The profile indicates a primarily male demographic (67.8%), predominantly middle-aged (43.9% aged 46-60 years), with considerable farming expertise (59.5% possess over 11 years of experience).

**Table 1:** Demographic and Socio-Economic Characteristics of Respondents (N=301) *

| Characteristic | Category | Frequency (n) | Percentage (%) |
|---|---|---|---|
| **Gender** | Male | 204 | 67.8 |
| | Female | 97 | 32.2 |
| **Age** | 18-30 years | 20 | 6.6 |
| | 31-45 years | 107 | 35.5 |
| | 46-60 years | 132 | 43.9 |
| | > 60 years | 42 | 14.0 |
| **Education** | No Formal Education | 15 | 5.0 |
| | Primary School | 57 | 18.9 |
| | Secondary School | 134 | 44.5 |
| | Certificate / Diploma | 67 | 22.3 |
| | Degree or Higher | 28 | 9.3 |
| **Land Ownership** | Yes | 246 | 81.7 |
| | No | 40 | 13.3 |
| | In Process | 15 | 5.0 |
| **Farm Size** | < 2 hectares | 93 | 30.9 |
| | 2-5 hectares | 124 | 41.2 |
| | 6-10 hectares | 54 | 17.9 |
| | 11-20 hectares | 23 | 7.6 |
| | 21-40 hectares | 7 | 2.3 |
| **Farming Experience** | < 5 years | 46 | 15.3 |
| | 5-10 years | 76 | 25.2 |
| | 11-20 years | 104 | 34.6 |
| | > 20 years | 75 | 24.9 |
| **Management Type** | Self-managed | 91 | 30.2 |
| | Family help | 95 | 31.6 |
| | Hired workers | 80 | 26.6 |
| | Under a scheme | 35 | 11.6 |
| **Certification (MSPO/RSPO)** | Yes | 45 | 15.0 |
| | No | 236 | 78.4 |
| | In Process | 20 | 6.6 |
| **Monthly Income** | < RM1,000 | 72 | 23.9 |
| | RM1,000-RM2,999 | 112 | 37.2 |
| | RM3,000-RM4,999 | 76 | 25.2 |
| | ≥ RM5,000 | 41 | 13.6 |

**Table 1 (cont):** Demographic and Socio-Economic Characteristics of Respondents (N=301) *

A significant proportion possesses a secondary school education (44.5%) and holds ownership of their land (81.7%). The majority of farms are small-scale, with 41.2% classified within the 2–5-hectare range. Significantly, hardly 15.0% of the participants possessed any sustainability certification (MSPO/RSPO), highlighting the inclusion gap that this study seeks to rectify. For the majority of smallholders (37.2%), the gross monthly income from oil palm ranged from RM1,000 to RM2,999.

### 4.2 Refinement and Validation of the Sustainability Metric

The preliminary collection of items for the sustainability measure was obtained from Sections B, C, and D of the questionnaire. The initial investigation included assessing item-to-total correlations and Cronbach's Alpha to enhance the scales. Items exhibiting low item-to-total correlations (< 0.30) were deemed for elimination to improve the internal consistency of the measures. The ultimate meter consisted of three fundamental dimensions: Environmental Management, Socio-Economic Resilience, and Farm Productivity and Economic Viability. Table 2 displays the final items, their descriptive statistics, and the reliability coefficients for each dimension. All retained scales exhibited strong internal consistency, with Cronbach's Alpha values significantly exceeding the 0.70 threshold, signifying exceptional dependability.

**Table 2:** Final Sustainability Metric Dimensions, Items, and Reliability Statistics

| Dimension and Items | Mean | SD | Item-Total Correlation | Cronbach's α |
|---|---|---|---|---|
| **1. Environmental Management** | **3.58** | **0.71** | | **0.91** |
| No open burning (B2) | 3.74 | 1.12 | 0.72 | |
| Use of natural pest control (B3) | 3.15 | 1.24 | 0.68 | |
| Planting of cover crops (B4) | 3.51 | 1.19 | 0.75 | |
| Reuse of farm waste (B6) | 3.38 | 1.16 | 0.71 | |
| Maintains biodiversity (D_env1) | 3.57 | 1.13 | 0.69 | |
| Pesticide use at safe levels (D_env5) | 3.61 | 1.11 | 0.76 | |
| Water quality is clean (D_env7) | 3.57 | 1.13 | 0.70 | |
| Waste management reduces pollution (D_env10) | 3.61 | 1.11 | 0.74 | |
| **2. Socio-Economic Resilience** | **3.49** | **0.68** | | **0.89** |
| Income sufficient for family (D_soc1) | 3.69 | 1.12 | 0.65 | |
| Balanced working hours (D_soc2) | 3.63 | 1.13 | 0.61 | |
| No underage workers (D_soc7) | 3.78 | 1.10 | 0.58 | |

**Table 2 (cont):** Final Sustainability Metric Dimensions, Items, and Reliability Statistics

| | | | | |
|---|---|---|---|---|
| Stable yield throughout year (D_soc8) | 3.65 | 1.12 | 0.67 | |
| Good community relations (D_soc10) | 3.69 | 1.11 | 0.63 | |
| Received government support (C1) | 2.80 | 1.25 | 0.55 | |
| Access to government advice (C3) | 3.21 | 1.19 | 0.59 | |
| **3. Farm Productivity and Economic Viability** | **3.52** | **0.65** | | **0.87** |
| High FFB yield (D_eco1) | 3.61 | 1.11 | 0.66 | |
| Profit after costs (D_eco2) | 3.65 | 1.11 | 0.70 | |
| No problem selling FFB (D_eco3) | 3.63 | 1.12 | 0.68 | |
| Controlled operating costs (D_eco4) | 3.57 | 1.12 | 0.64 | |
| Income helped family out of hardship (D_eco6) | 3.70 | 1.10 | 0.62 | |
| Sustainable practices beneficial (D_eco8) | 3.51 | 1.14 | 0.59 | |
| Have financial savings/assets (D_eco10) | 3.53 | 1.14 | 0.61 | |

*Note. N = 301. All items measured on a 1-5 scale. *

### 4.3 Confirmatory Factor Analysis (CFA) for Construct Validity

A Confirmatory Factor Analysis (CFA) was performed to evaluate the proposed three-factor structure of the sustainability indicator. The model demonstrated an excellent fit to the data: $\chi^2(249) = 485.32$, $p < .001$, $\chi^2/df = 1.95$, CFI = .951, TLI = .943, RMSEA = .042 (90% CI [.036, .048]). All standardized factor loadings were statistically significant ($p < .001$) and surpassed 0.55, suggesting substantial correlations between the items and their associated latent constructs. The results validate the strong construct validity of the three-dimensional sustainability metric.

### 4.4 Descriptive Statistics and Intercorrelations of Sustainability Dimensions

The results demonstrate distinct patterns across the three criteria of sustainability. Environmental Management achieved a mean of 3.58 and a standard deviation of 0.71. The mean of Socio Economic Resilience was 3.49, with a standard deviation of 0.68. The mean for Farm Productivity and Viability was 3.52, with a standard deviation of 0.65. The Total Sustainability Score had a mean of 3.53 and a standard deviation of 0.59. The correlations indicate robust associations among the dimensions. Environmental Management is positively correlated with Socio Economic Resilience at $r = .52$, $p < .001$. It is correlated with Farm Productivity and Viability at $r = .48$, $p < .001$. The association between socio-economic resilience and farm productivity and viability is the strongest, with $r = .68$ and $p < .001$. All three dimensions have robust connections with the Total Sustainability Score. The coefficients vary from .81 to .88, $p < .001$. These patterns validate that each dimension is closely aligned with the overarching sustainability construct within the dataset.

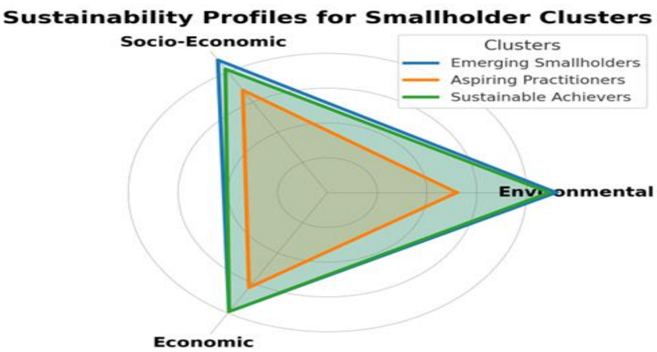
### 4.5 Application of the Metric: Smallholder Sustainability Clusters

A K-means cluster analysis was conducted with the standardised scores of the three sustainability characteristics to illustrate the metric's practical utility. A three-cluster method yielded the most conceptually coherent and statistically distinct categorisation of smallholders. The ultimate cluster centres are presented in Table 3, and the sustainability profiles are illustrated in Figure 1.

**Table 3:** Final Cluster Centres from K-Means Cluster Analysis (Standardized Z-Scores)

| Sustainability Dimension | Cluster 1: Emerging Smallholders (n=60, 19.9%) | Cluster 2: Aspiring Practitioners (n=157, 52.2%) | Cluster 3: Sustainable Achievers (n=84, 27.9%) | F-value | p-value |
|---|---|---|---|---|---|
| Environmental Management | -0.92 | -0.11 | 0.89 | 185.45 | < .001 |
| Socio-Economic Resilience | -0.88 | -0.08 | 0.82 | 192.67 | < .001 |
| Farm Productivity and Viability | -0.85 | -0.10 | 0.79 | 175.23 | < .001 |

A one-way ANOVA confirmed that the score disparities among the three clusters were statistically significant across all three dimensions ($p < .001$). Post-hoc Tukey HSD tests revealed that all pairwise comparisons among clusters were significant ($p < .001$).




*(Visual description: A radar chart featuring three axes that denote the three dimensions of sustainability. 'Sustainable Achievers' (Cluster 3) would exhibit a substantial, nearly equilateral triangle. 'Aspiring Practitioners' (Cluster 2) would exhibit a little triangle positioned near the centre. 'Emerging Smallholders' (Cluster 1) would be represented by a little triangle near the origin of the chart. )*

**Figure 1:** Radar Chart of Sustainability Profiles for the Three Smallholder Clusters

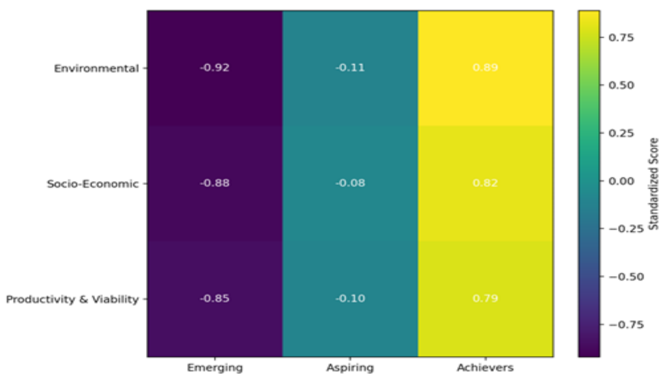



**Figure 2:** Heatmap of Standardized Sustainability Scores Across the Three Smallholder Clusters

Figure 2 illustrates a heatmap depicting the intercorrelations among the three dimensions of sustainability for each cluster. The visual pattern indicates that the clusters vary not just in performance levels but also in the structural links among the dimensions. Sustainable Achievers exhibit robust and harmonious relationships across all aspects, signifying a cohesive sustainability profile. Aspiring practitioners exhibit moderate internal consistency, indicating a limited correlation between practices and outcomes. Emerging smallholders demonstrate inconsistent and poor associations, indicating fragmented sustainability practices. These patterns validate that the clusters signify unique performance setups rather than mere variations in magnitude.

Cluster Profiling: The cluster profiles exhibit distinct variations in demographic and agricultural attributes. Cluster 1, Emerging Smallholders, oversees the smallest farms, averaging 2.1 hectares in size. This category exhibits the lowest educational attainment, with about 15.0 percent possessing a certificate or diploma. MSPO certification is uncommon, with a prevalence of 3.3 percent. The mean monthly income is RM1,850. Merely 15.0 percent utilise contracted labour.

Cluster 2, Aspiring Practitioners, exhibits moderate levels across all metrics. The mean agricultural land area is 4.3 hectares. Education at the certificate or diploma level constitutes 28.7 percent. The MSPO certification rate is 12.1 percent. The average monthly salary increases to RM2,650. Management support via employed personnel is indicated by 25.5 percent.

Cluster 3, Sustainable Achievers, exhibits the highest values in all attributes. The mean agricultural land area is 7.8 hectares. Educational attainment at the certificate or diploma level is 45.2 percent. The MSPO certification rate is 32.1 percent. The average monthly income attains RM4,100. Employment of hired labour is reported at 40.5 percent.

All group disparities are statistically significant. The F and chi-square values span from 18.23 to 45.32, with p-values $< .001$. These findings validate the unique characteristics of the three clusters.

## 5. Discussion

This research successfully developed and verified a thorough sustainability metric tailored for independent smallholder oil palm growers in Malaysia. The results offer strong empirical evidence for a multi-dimensional framework that transcends the binary pass-fail model of traditional certification systems. The findings affirm that sustainability in this setting is not a uniform condition but a complex journey, with smallholders situated at various points along a performance continuum.

### 5.1 Interpretation of Key Findings

The three-cluster method provides a refined and practical classification of smallholders. The Sustainable Achievers (Cluster 3), comprising 27.9% of the sample, illustrate that superior performance across all three dimensions is achievable. Their profile - distinguished by larger farm sizes, elevated educational attainment, and an increased probability of certification—corresponds with the Resource-Based View of the firm, which asserts that both tangible and intangible resources are essential for attaining a competitive advantage (Barney, 1991). These farmers presumably have the financial resources, expertise, and size to invest in sustainable technologies and accommodate the initial costs of adopting practices, hence allowing them to fulfil certification standards.

The predominant group, the Aspiring Practitioners (Cluster 2, 52.2%), constitutes the essential "middle majority." They operate at almost the sample average, suggesting a basic level of sustainable practice, however there is much potential for enhancement. This cluster has the possibility for comprehensive sector restructuring. Their middling scores indicate that they have assimilated fundamental extension guidance but may be deficient in resources or specialised help to maximise their operations (Rietberg and Slingerland, 2022). This discovery contests the effectiveness of uniform extension services and highlights the necessity for more tailored support systems.

The Emerging Smallholders (Cluster 1, 19.9%) underscore the ongoing inclusion gap. Their markedly worse scores in all dimensions, along with their characteristics of limited landholdings and minimal formal education, exemplify a cycle of vulnerability. These farmers encounter systemic obstacles that hinder their participation in formal sustainability projects, a conclusion aligned with research on the exclusion of the most impoverished and marginalised participants from global value chains (Tey and Brindal, 2021). For this group, the principal obstacle is not an absence of willingness but a deficiency in competence, a distinction frequently neglected in hierarchical sustainability governance

### 5.2 Theoretical and Practical Implications

This study theoretically extends the discussion from debating the sustainability of smallholders to examining the mechanisms of their sustainability and the specific dimensions involved. Through the validation of a three-dimensional metric, we offer a quantitative instrument that corresponds with the holistic, nexus-oriented framework advocated by the Sustainable Development Goals (United Nations, 2015). The favourable interrelationships among the categories indicate synergies; for example, enhancements in environmental management may enhance long-term economic sustainability, reinforcing the notion of "win-win" scenarios in sustainable intensification (Qaim et al., 2020).

The metric serves as a robust diagnostic and planning instrument for various stakeholders. The cluster typology can guide policymakers and government entities such as MPOB and RISDA in the development of tiered support programs. Emerging Smallholders may require direct subsidies and fundamental agronomic training, whereas Aspiring Practitioners could gain from access to microcredit for efficient technologies and group certification programs. For certification bodies (RSPO, MSPO), the metric offers a framework for establishing a progressive certification pathway that acknowledges and incentivises incremental advancements, rather than imposing a singular, elevated standard. For agribusinesses and mills aiming to procure sustainable palm oil, the clusters can assist in identifying smallholders prepared for certification and those needing basic capacity-building, hence facilitating more effective and responsible sourcing strategies.

### 5.3 Limitations and Future Research

This study includes several drawbacks that offer opportunities for future investigation. The cross-sectional design offers a temporal snapshot; a longitudinal study monitoring these clusters would yield critical insights into the paths of smallholders and the determinants facilitating transfers across performance tiers. Secondly, the data were obtained from a singular state, Johor; subsequent study should assess this metric in several geographic contexts throughout Malaysia and Indonesia to evaluate its generalisability. Third, although the metric is extensive, it predominantly depends on self-reporting by farmers. Subsequent research could enhance the evaluation by triangulating survey data with objective metrics, including soil analyses, yield documentation, and satellite images for environmental indicators. Moreover, subsequent study ought to investigate the causal mechanisms that underlie cluster membership. Qualitative studies could examine the influence of social networks, gender dynamics, information accessibility, and particular policy interventions on a smallholder's progression towards sustainability.

## 6. Conclusion

This research aims to fill a significant gap in sustainable palm oil governance by creating a comprehensive, empirically-validated metric specifically designed for independent smallholders in Malaysia. The findings indicate that sustainability in this context is a multi-dimensional construct, encapsulated by three interrelated pillars: Environmental Management, Socio-Economic Resilience, and Farm Productivity and Economic Viability. The development process, which included Confirmatory Factor Analysis, has produced a reliable and valid instrument demonstrating high internal consistency across all dimensions. This research's primary contribution is advancing beyond a binary classification of sustainability. Cluster analysis of the metric's outputs has identified a heterogeneous smallholder landscape with three distinct performance tiers: Sustainable Achievers, Aspiring Practitioners, and Emerging Smallholders. This typology offers significant detail, illustrating that smallholders are not a uniform group but occupy various stages of the sustainability journey, each possessing distinct characteristics, capacities, and constraints. The practical implications are significant. This metric equips policymakers, certification bodies, and extension services with an effective diagnostic tool to transition from uniform interventions to targeted, tiered support systems. The emphasis for Sustainable Achievers lies in sustaining excellence and accessing high-end markets. Support for the critical middle majority of Aspiring Practitioners should focus on facilitating the transition to full certification via technical and financial assistance. For Emerging Smallholders, the metric underscores the necessity of foundational capacity-building to mitigate fundamental vulnerabilities. This research offers a framework for transitioning from the measurement of sustainability to its active management via inclusive and differentiated pathways. The sustainability of the palm oil sector hinges on the acknowledgement and support of its diversity, ensuring that independent smallholders are not marginalised but rather empowered as key participants in the sector's transformation.

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