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An index to measure SDG-aligned sustainable performance: A developing country perspective

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HIGHLIGHTS

- Developed a 0–1000 index for smallholder dairy farmer sustainability.
- Index integrates enablers, TBL outcomes, Cleaner Production principles.
- Validated with PLS-SEM using data from 324 Sri Lankan dairy farmers.
- Farmer capability is the strongest contributor, economic sustainability lags.
- Tool supports SDG reporting and scaling sustainability in agri-food chains.

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ABSTRACT

Existing sustainability assessment tools are often unsuitable for smallholder farmers in developing countries, where resource constraints and economic pressures outweigh environmental and social considerations. This study develops and validates an SDG-aligned index that operationalizes Cleaner Production (CP) at the farm level to measure the sustainable performance of smallholder dairy farmers in Sri Lanka. Drawing on triple bottom line (TBL) and sustainable supplier development (SSD) concepts, we test a conceptual model using survey data from 324 farmers. Partial least squares structural equation modelling (PLS-SEM) estimates construct weights that are translated into a transparent 0–1000 scoring system. The index comprises five dimensions—farmer capability (FC), farmer–processor relationship (FPR), and farmer economic (ES), social (SS), and environmental (EnvS) sustainability. Results show FC is the strongest contributor (236 points), while ES lags (170 points). By embedding CP principles—resource efficiency, waste minimization and circularity, and pollution prevention—the index enables processors to classify farmers, tailor interventions, and integrate verified outcomes into sustainability reporting. The framework contributes to SSD and CP practice, offers a replicable, low-burden measurement tool for agri-food supply chains, and outlines a tiered linkage to life-cycle assessment and carbon accounting for sector dashboards. The paper's primary contribution is methodological and practical: it operationalizes established TBL, SSD, and CP perspectives into an empirically weighted (0–1000) tool for smallholder supplier management and SDG reporting.

1. Introduction

Sustainability in agriculture in developing countries has emerged as a critical concern for at least two reasons. First, agriculture remains the backbone of rural livelihoods, yet most smallholder farmers—who dominate these regions—focus mainly on income generation, often neglecting broader sustainability dimensions (Sachitra and Chong, 2018; Siddiky, 2017). Second, with the United Nations' Sustainable Development Goals (SDGs) setting a global agenda, sustainability now encompasses economic viability, social inclusion, and environmental protection (United Nations, 2015; Pradhan et al., 2017; Zanin et al., 2020). For smallholder-based supply chains, this shift demands new

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approaches to measure and enhance sustainability performance (Chand et al., 2015).

Dairy farming has attracted growing scrutiny due to its environmental and social impacts. Concerns include greenhouse gas emissions, water pollution, nutrient losses, and biodiversity degradation (Clay et al., 2020; Salou et al., 2017), alongside social challenges such as low household well-being and limited educational opportunities for farming families (Razzaq et al., 2024). While farms in developed countries often adopt monitoring systems and cleaner production (CP) practices to mitigate these issues (Seuring and Müller, 2008; Lorenz et al., 2019), smallholder farmers in developing countries typically lack such mechanisms (Chand et al., 2015). This study applies the triple bottom line (TBL) framework (Elkington, 1994) to assess dairy farmers' sustainable performance and explicitly links it to CP principles—resource efficiency, waste minimization and circularity, and pollution prevention (Adesogan et al., 2013; Lebacq et al., 2013).

In this context, sustainable supplier development (SSD) offers a pathway for focal firms (e.g., food processors) to build farmer capability (FC), foster stronger farmer–processor relationships (FPR), and support the adoption of CP practices (Bai and Satir, 2022; Pedroso et al., 2021; Yawar and Seuring, 2018). When processors invest in farmer development, they not only secure milk quality and supply reliability but also enhance farmers' economic, social, and environmental performance (De Silva et al., 2023; Hidayati et al., 2023). The practical challenge is scale: with thousands of smallholder suppliers, how can processors efficiently measure, monitor, and benchmark progress toward sustainable, CP-aligned practices?

Established tools—Sustainability Assessment of Food and Agriculture Systems (SAFA), Response-Inducing Sustainability Evaluation (RISE), and Global Reporting Initiative (GRI)—are useful but often data-intensive and not tuned to smallholder decision realities (De Olde et al., 2016; Cammarata et al., 2021; Feil et al., 2023; Schindler et al., 2015; Munyaneza et al., 2019). Footprint methods (e.g., life cycle assessment (LCA), carbon accounting) provide valuable diagnostics but under-represent managerial enablers and farm level CP actions that are feasible and actionable in low resource settings. As a result, CP remains largely diagnostic rather than managerial in smallholder contexts: tools quantify impacts but rarely help processors classify farmers or design targeted CP interventions. There is therefore a need for easy-to-use, context-specific, empirically validated frameworks that integrate CP with the SDGs (Zhen and Routray, 2003; Hidayati et al., 2023).

Rather than proposing a new theory, this study's main contribution is methodological and practical: it integrates established TBL, SSD, and CP perspectives in a farm level index with empirically derived weights and a transparent 0–1000 translation. Specifically, study (i) use partial least squares structural equation modelling (PLS-SEM) with formative constructs to derive empirical weights and implement a 0–1000 scoring framework, (ii) integrate managerial enablers (FC, FPR) with TBL outcomes (ES, SS, EnvS) in a smallholder appropriate tool, and (iii) outline a low burden linkage to LCA/carbon accounting to support sector dashboards and credible reporting. These contributions are grounded in instrumental stakeholder theory and informed by shared value and corporate social responsibility (CSR), framing how processors can transparently integrate farmer outcomes into CSR reporting.

Accordingly, the research objectives (ROs) are to: RO1—develop and validate a CP embedded, SDG aligned index (0–1000) integrating FC and FPR with ES, SS, and EnvS for smallholder dairy; RO2—derive empirically grounded formative weights via PLS-SEM and translate them into a transparent management scoring system; and RO3—demonstrate actionability for processors/policymakers (farmer classification, tailored CP interventions, reporting) and outline a low-burden linkage to LCA for sector monitoring. These ROs directly address Gaps 1–3 identified in Section 2.5.

The remainder of the paper is organised as follows: Section 2 reviews the literature and synthesises gaps; Section 3 presents the methodology; Section 4 reports results; Section 5 discusses managerial and policy implications; Section 6 concludes with limitations and future research.

2. Literature review

2.1. Adaptation of the concept of 'supplier development' to agriculture

In operations management, manufacturers are known to gain competitive advantage by developing their suppliers, a practice termed supplier development (Wagner, 2010; Benton et al., 2020). Since the early 2000s, sustainability has increasingly been integrated into this concept, giving rise to SSD — initiatives by a buying firm to improve suppliers' economic, social, and environmental performance, thereby ensuring long term SC sustainability (Seuring and Müller, 2008; Bai and Satir, 2022; Pedroso et al., 2021).

From a theoretical standpoint, instrumental stakeholder theory posits that trust, and cooperation-based relationships create value for all parties (Jones et al., 2018; Bridoux and Stoelhorst, 2022). Applied to agri-food supply chains (AFSC), this implies that processor-led SSD initiatives—such as farmer training, financial support, and feedback—can enhance productivity, quality, and social, economic, and environmental outcomes, while also strengthening FPR (Yawar and Seuring, 2018; Hidayati et al., 2023). This mutual gain provides an incentive for processors to invest in farmer development as part of both their competitive and CP strategies. Related perspectives such as the concept of shared value suggest that social and environmental improvements among farmers can also contribute to business competitiveness (Menghwar and Daood, 2021). Similarly, CSR and sustainability reporting frameworks provide avenues for processors to disclose these farmer-level outcomes transparently (Heikkurinen and Bonnedahl, 2013; Daub, 2007). Together, these perspectives frame farmer development as both a CP oriented and strategically significant pathway for processors.

2.2. Measuring farmer performance – existing approaches

Numerous frameworks have been proposed to measure farm-level sustainability performance. Tools such as SAFA (Cammarata et al., 2021), RISE (De Olde et al., 2016), and GRI guidelines (Feil et al., 2023) provide structured assessments, often applied in developed-country contexts. However, these tools are often too complex, data-intensive, or resource-demanding for smallholders in developing countries (Schindler et al., 2015; Zhen and Routray, 2003). In developing contexts, some scholars have proposed sustainability indices tailored to smallholder systems (Chand et al., 2015; Munyaneza et al., 2019), but these remain fragmented, lack empirical validation, and often overlook the role of enablers such as FC or FPR. This is critical because lagging indicators (e.g., farm income, social well-being) only capture outcomes, whereas leading indicators (e.g., knowledge adoption, trust) are essential to drive continuous improvement in CP practices.

CP is central to reducing environmental impacts in livestock systems through strategies such as waste reduction, effluent management, feed optimization, and energy efficiency (Seuring and Müller, 2008; Adesogan et al., 2013; Lebacq et al., 2013). In the dairy sector, CP practices are commonly assessed through environmental foot printing methods such as LCA and carbon accounting (Lorenz et al., 2019; Salou et al., 2017). These approaches provide valuable insights into emission reduction potentials but remain diagnostic rather than managerial: they are data-intensive, technical, and often detached from the day-to-day decision-making of smallholder farmers in developing countries (Schindler et al., 2015; Munyaneza et al., 2019). A key gap is that existing CP research tends to quantify environmental outcomes without offering practical benchmarking frameworks for farmer classification, capability building, and tailored development programs. Recent transition work shows that producer perceptions and intertwined economic–social–environmental factors shape agricultural reconversion outcomes, underscoring the need for context-specific, actionable farm-level indicators in resource-constrained settings (Romo Bacco et al., 2024). Recent work across AFSCs—covering horticulture disruptions, digital supply ecosystems, and food-loss barriers—underscores the need for context-specific, actionable farmer-level metrics in developing-country settings (Sharma et al., 2022; Kashyap et al., 2023).

2.3. Alignment of the conceptual framework's enablers and farmer TBL outcomes to UN's SDGs

The UN's Agenda 2030; United Nations, 2015) and the 17 SDGs call for integrated strategies that balance economic, social, and environmental dimensions (Pradhan et al., 2017). For processors in AFSCs, farmer development initiatives can directly contribute to SDG1 (No Poverty), SDG2 (Zero Hunger), SDG3 (Good Health), SDG4 (Quality Education), SDG5 (Gender Equality), SDG8 (Decent Work), and SDG12 (Responsible Consumption and Production) (Zimon et al., 2020; Le, 2023). For example: farmer training → improves human capital, adoption of CP methods, occupational health (SDG3, SDG4, SDG12); financial support → lifts households above poverty line and empowers women (SDG1, SDG2, SDG5, SDG8); evaluation & feedback → encourages continuous improvement, reduces waste, and aligns with circular economy principles (SDG8, SDG12).

This study builds on prior work (De Silva et al., 2023) by developing an empirically validated measurement system that links processor-led farmer development to SDG progress through both enablers (FC, FPR) and TBL outcomes (economic, social, environmental).

2.4. Theoretical background of the study

The conceptual framework of this study is grounded in instrumental stakeholder theory, which posits that organizations achieve better performance when they build trust-based, cooperative relationships with stakeholders (Jones et al., 2018; Bridoux and Stoelhorst, 2022). Applied to AFSCs, this suggests that processors can improve both business outcomes and farmer sustainability by investing in supplier development initiatives (Yawar and Seuring, 2018; Hidayati et al., 2023). Complementary perspectives such as the shared value concept (Menghwar and Daood, 2021) and CSR (Heikkurinen and Bonnedahl, 2013) further reinforce that social and environmental improvements among farmers can enhance processor competitiveness while contributing to CP objectives.

As shown in Fig. 1, within this theoretical framing, FC (farmer's capability to improve productivity) and the FPR represents key enablers of sustainable outcomes. FC captures a farmer's ability to apply knowledge, adopt efficient practices, and meet quality requirements (De Silva et al., 2023; Chand et al., 2015; Korale-Gedara et al., 2023; Nath et al., 2010), while FPR reflects trust, fairness, and cooperation in interactions with processors (Lees et al., 2020; Moses et al., 2023). This is consistent with instrumental stakeholder theory and shared value perspectives, which link cooperative relationships and capability building to superior sustainability performance. Requirements for knowledge management systems in smallholder dairy (e.g., capturing practice data, structuring advisory feedback, supporting on farm decisions) further validate FC as a critical antecedent to CP adoption (Indriasari et al., 2024). Together, FC and FPR influence triple bottom line outcomes—economic (ES), social (SS), and environmental (EnvS)—by operationalising core CP principles. Accordingly, this study emphasis that processor-led development initiatives (e.g., training, timely quality feedback, advisory access, targeted finance) enhance FC and FPR, which in turn improve farmers' sustainable performance, aligning business competitiveness with CP, SDG targets, and CSR reporting (De Silva et al., 2023; Hummel and Szekely, 2022; Lebacq et al., 2013; Tsalis et al., 2020; Zanin et al., 2020).

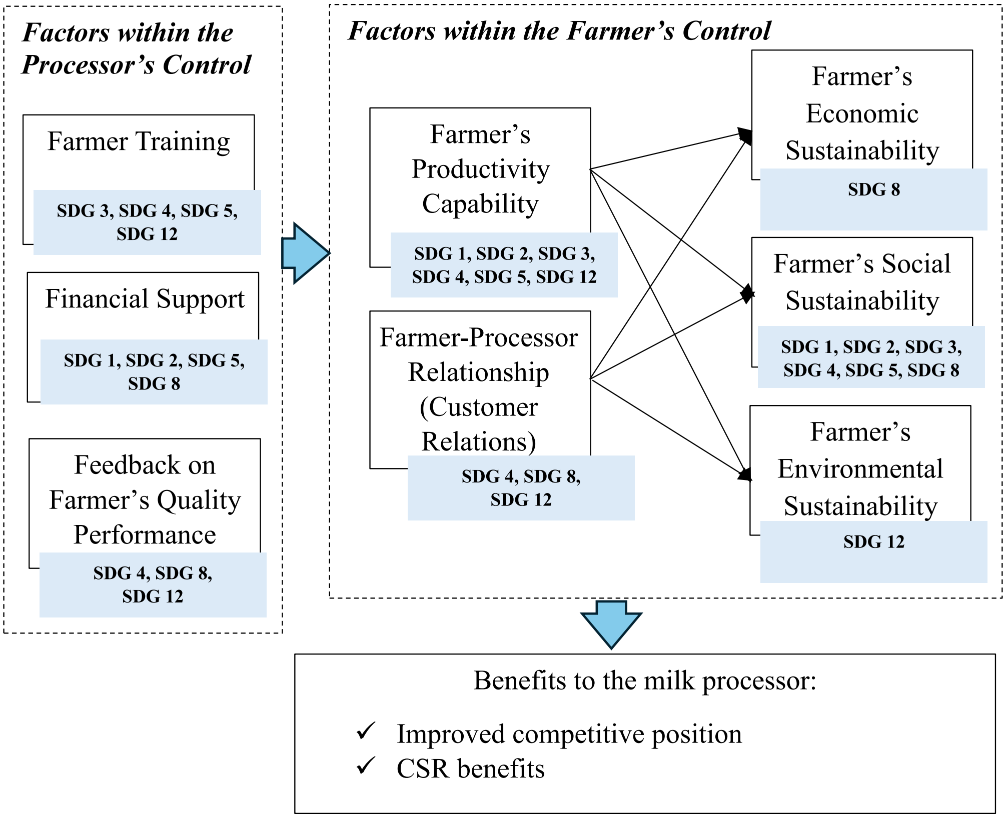


Fig. 1. The conceptual framework with alignment to SDGs.
Source: Author Composition

2.5. Identified research gaps

Building on the subsection level gaps identified above, the study synthesises three gaps.

Gap 1: While SSD is well established in manufacturing, its operationalisation in developing-country AFSCs—especially the explicit linkage to CP practices (resource efficiency, waste minimization/circularity, pollution prevention)—remains under-explored (Section 2.1).

Gap 2: There is no empirically validated, easy-to-use index that integrates enablers (FC, FPR) and outcomes (ES, SS, EnvS), bridges TBL and CP, and is tailored to smallholders in developing countries. This study addresses this gap by embedding CP principles—pollution prevention, waste minimization, and circularity—into an empirically validated index that enables processors to classify farmers, benchmark CP adoption, and design interventions aligned with CP and SDG targets (Section 2.2).

Gap 3: Although SDG alignment is common in CSR reporting, few studies offer a quantitative, replicable framework enabling processors to demonstrate and report farmer-level contributions to SDGs through CP aligned indicators (Section 2.3).

Recent tools and perspectives reinforce the need to link farm level CP metrics with LCA and sector monitoring, for example an online farm level LCA tool (Arulnathan et al., 2025) and current work on operationalising cleaner growth in agriculture (Barnes et al., 2024); moreover, clear CO_2 linked communication improves public understanding and reporting credibility (Fletcher et al., 2025).

3. Methodology

3.1. Development of the empirical model and parameter estimation

This study conceptualizes five constructs—FC, FPR, ES, SS, and EnvS—as the components of an index representing a farmer's overall sustainable performance. FC and FPR are treated as enablers, while ES, SS, and EnvS represent the TBL outcomes. Together, these five constructs reflect both the drivers and results of processor-led farmer development initiatives.

The empirical model was estimated by using PLS-SEM with SmartPLS 4 (Ringle et al., 2024). PLS-SEM was selected for two reasons: (i) all constructs were conceptualized as formative, where the meaning of a construct is determined by its indicators (Diamantopoulos et al., 2008), and (ii) the aim was to derive empirically grounded weights for a scoring system, rather than to test reflective measurement scales. The higher-order PLS-SEM model included three sub-models.

- Model 1: captured the contribution of enablers (FC, FPR).
- Model 2: captured the contribution of TBL outcomes (ES, SS, EnvS).
- Model 3: combined the contributions of the two higher-order constructs into the overall sustainable performance index (OVERL).

Equations for each sub-model are provided (Eq 1–Eq (3)), with all paths specified as formative–formative higher-order constructs (Crocetta et al., 2021). Each construct in each model is represented as a weighted linear combination of its indicators. As an example, the equations (Eq (1), Eq (2) and Eq (3)) pertaining to Model 1are as follows:

$$\text{FC to improve productivity} = w1{*}CAP1 + w2{*}CAP2 + w3{*}CAP3 + w4{*}CAP4 \quad \text{Eq 1}$$

$$\text{FPR} = w5{*}Satisfaction + w6{*}Trust \quad \text{Eq 2}$$

$$\text{The contribution of the sustainability enablers} = w7{*}Trust + w8{*}Satisfaction +$$

$$w9{*}CAP1 + w10{*}CAP2 + w11{*}CAP3 + w12{*}CAP4 \quad \text{Eq 3}$$

The way the equations have been specified ensures that when the indicator data is fitted into the SEM, the response (e.g., in Model 1, 'The contribution of the sustainability enablers') would be predicted by its predictors (in Model 1, 'FC to improve productivity' and 'FPR') perfectly (i.e. $R^2 = 1$). This is because all the indicators of the predictors become the indicators of the response, as required in the second-order model specification in PLS-SEM (Hair et al., 2022). The equations pertaining to Model 2 are like those of Model 1. In estimating the weights k6 and k7 (=w31 and w32, respectively) of Model 3, the indicators of the response 'Overall Sustainability of the Farmer' are used as predictors of the construct to meet the $R^2 = 1$ requirement (see Hair et al., 2022 for details). Bootstrapping confirmed that all 32 parameters were significant ($p < 0.05$), validating the statistical robustness of the index. Indicators within the Ends' construct (e.g., effluent disposal, solid waste reuse, air pollution reduction) explicitly reflect CP practices, while indicators under FC (e.g., applying training on sustainable farming, quality compliance) represent enablers of CP adoption. Thus, the empirical model not only measures farmer sustainability but also operationalizes CP practices in smallholder contexts. This study specifically used PLS-SEM to obtain empirically grounded formative weights while preserving construct interpretability and a transparent translation to the 0–1000 management score. Other non-AI techniques that can be used for this scoring and weighting are multi criteria decision analysis (e.g., Analytic Hierarchy Process (AHP)/Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), data envelopment analysis (DEA), or expert/rule-based weights).

To align the estimated weights with a scoring system in which 1000 points have been allocated as the maximum possible sustainable performance (the theoretical upper limit) a farmer can achieve, an arithmetic adjustment was made to calculate the maximum possible score that should be assigned to each construct (category) and its indicators (measurement items). For example, if 1000 points are allocated for the 'overall sustainability of the farmer', 'the contribution of the sustainability enablers' should secure 416 points while 'the contribution of TBL sustainability' should secure 584 points, because the weights k6 and k7 (=w31 and w32 respectively) were estimated to be 0.416 and 0.584 respectively (more details in Appendix A). The full item list and point allocations are provided in Appendix A (Table A1). A row-level worked example of the 0–1000 translation appears in Appendix B (Table B1).

3.2. Designing the data collection instrument and the data collection strategy

A structured Likert-type survey questionnaire was developed from literature and field-tested with local stakeholders for content validity. To demonstrate the link between the constructs, their indicators, CP practices, and the United Nations' SDGs, Table I presents a mapping of the measurement items. Each construct and its indicators can be directly linked to specific CP practices and SDG targets, ensuring that the index captures not only TBL outcomes but also measurable contributions to CP adoption in smallholder dairy systems. This provides conceptual clarity on how each indicator contributes to CP principles (e.g., resource efficiency, waste minimization and circularity, and pollution prevention). This study deliberately adopts a low burden non-AI approach suited to smallholder contexts: paper questionnaire to spreadsheet data capture for field collection; a spreadsheet calculator that applies the PLS-SEM weights and 0–1000 rescaling; and simple dashboards for routine feedback to farmers and managers. These choices prioritise repeatability and local implementation without advanced analytics. To mitigate common rater bias, the instrument used neutral wording, randomised item order within sections, and assured anonymity; trained enumerators clarified questions but did not prompt responses.

3.3. Sampling and data collection

The target population was small and medium-scale dairy farmers supplying milk to a large Sri Lankan processor implementing farmer development programs. A random sample of 400 farmers (200 per

Table 1
CP practices embedded in the farmer sustainability index and their SDG alignment.

Construct	Indicator	CP/Circular economy practice	Reference	Relevant SDGs
FC	CAP1: Applying knowledge from training to improve productivity & sustainability	Knowledge transfer → efficient use of resources & inputs	DeSilva et al. (2023); Chand et al. (2015); Indriasari et al. (2024); Korale-Gedara et al. (2023); Nath et al. (2010)	SDG4, SDG12
	CAP2: Maintaining service relationships (e.g., with extension providers)	Strengthened collaboration to adopt CP practices		SDG8, SDG12
	CAP3: Ability to supply milk year-round	Improved resource management; efficiency in production		SDG2, SDG8
	CAP4: Compliance with milk quality standards	CP & food safety practices		SDG3, SDG12
FPR	Satisfaction: Fair prices, reliable payments, open communication	Economic fairness & transparency → enabling CP adoption	Lees et al. (2020); Moses et al. (2023)	SDG1, SDG8
	Trust: Honesty, assistance, business values	Long-term relational capital → fostering sustainable practices		SDG8, SDG12
ES	ECNSUS1: Gross income from dairy farming	Financial viability supports investment in CP technologies	Lebacq et al. (2013); Munyaneza et al. (2019); Razzaq et al. (2024); Zanin et al. (2020)	SDG1, SDG8
	ECNSUS2: Farming income meets household needs	Poverty reduction, enabling sustainable livelihoods		SDG1, SDG2
	ECNSUS3: Farm profitability	Long-term viability for reinvestment in CP practices		SDG8, SDG12
SS	SOCSUS1: Quality of life from farming	Well-being supports social sustainability		SDG1, SDG3
	SOCSUS2: Access to quality education for children	Human capital development → knowledge for CP adoption		SDG4, SDG5
	SOCSUS3: Community recognition & social empowerment	Strengthened social capital; inclusive development		SDG5, SDG8
EnvS	ENVSUS1: Proper disposal of effluents	Pollution prevention (water, soil)		SDG6, SDG12
	ENVSUS2: Reuse of solid waste for agriculture	Circular economy practice → resource recovery		SDG12
	ENVSUS3: Actions to reduce air pollution	Cleaner production (GHG reduction, air quality management)		SDG12, SDG3

Source: Author Composition

district from two main milk producing districts in Sri Lanka: Kurunegala and Nuwara Eliya) was contacted, with 324 useable responses (65% response rate). Data was collected in person by trained research assistants to minimize missing data and ensure contextual understanding. Although the case is situated in Sri Lanka, the analytical generalization lies in the method: the validated scoring system can be adapted to other developing country AFSCs (e.g., coffee in Ethiopia, cocoa in Ghana, horticulture in Kenya), with construct weights recalibrated through local data. The study followed informed consent procedures, and anonymity was guaranteed. The potential non-response bias was assured by comparing early vs. late respondents on key items and found no meaningful differences. Reliability was ensured by pilot testing the questionnaire and by checking indicator collinearity within PLS-SEM (all VIF <3).

4. Results

4.1. Model estimation and scoring system

It is important to note that the weighted estimates shown in Fig. 2 are valid when the 1–5 Likert scale has been used to collect data. Appendix A shows the contributions of each element of the performance measurement system when the maximum possible 1000 points are allocated to the overall sustainability performance of the Farmer (OVERL), based on processor-led farmer development. The points were calculated by transforming the index OVERL (valid for a 1-5 scale) into a 0–1000 scale using the equation 'new weight = 250*old weight – 250'. Back translating this scoring system used to create the index OVERL, in a 0–1 scale, as a linear combination of its five constructs leads to the following relationship:

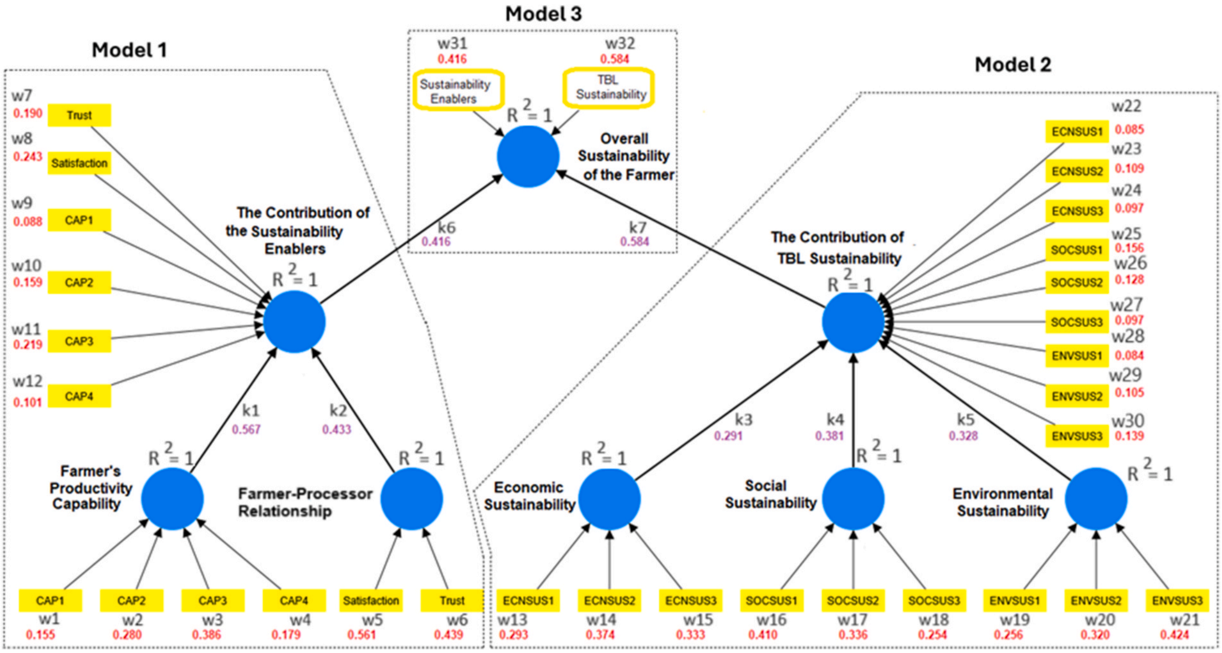
$$\mathrm{OVERL} = 0.236{*}FCTIP + 0.180{*}FPREL + 0.170{*}ECONS + 0.223{*}SOCLS + 0.190{*}ENVTS. \qquad \text{Eq 4}$$

Where: *FCTIP*–Farmer's Capability to Improve Productivity, *FPREL*–Farmer Processor Relationship, *ECONS*–Farmer's Economic Sustainability, *SOCLS*–Farmer's Social Sustainability, *ENVTS*–Farmer's Environmental Sustainability.

All five components must be measured on a 0–1 scale for the 0–1 version of OVERL to be valid. As shown in Appendix A, Eq. (4) can be expanded to the 15 items (CAP1–ENVSUS3), allowing OVERL to be expressed as a weighted sum of item scores. Beyond providing a baseline, the 0–1000 index can be readministered periodically to build farmer level time series for monitoring continuous improvement and evaluating CP oriented interventions. Because construct weights are sample and context dependent, applications in other commodities or regions should re-estimate weights with PLS-SEM and then rescale to the 0–1000 metric.

Finally, the 0–1000 composite is a diagnostic entry point: practical decisions should be referencing construct and item level diagnostics (FC, FPR, ES, SS, EnvS; CAP1–ENVSUS3) rather than the aggregate alone. The composite should not be used as the sole trigger for incentives or sanctions; decisions should be based on construct sub scores and verified CP practices (e.g., ENVSUS1–3). In farmer development intervention decisions, set minimum FPR thresholds and remediation timelines; sub scores (not the composite alone) determine eligibility for benefits.

Beyond baseline use, the index can support panel tracking via a



Note: w1 to w32 are indicator weights, while k1 to k7 are regression weights.

Fig. 2. The specified SEM and the estimated parameters.
Source: Author Composition

quarterly light touch re measurement (key items only: ENVSUS1–3, CAP4, core FPR items) and an annual full cycle, enabling trend analysis for OVERL and construct sub scores and testing lagged effects from FC/FPR to EnvS/ES. A step-by-step worked example of the index calculation—from item scores to construct scores to the 0–1000 composite—is provided in Appendix B to facilitate replication.

4.2. *Farmer characteristics and descriptive statistics*

Of the 324 farmers who responded to the questionnaire, 227 (70%) were found to be smallholder farmers (less than 10 milk-yielding cows) and 97 (30%) were found to be medium-scale farmers (10-40 milk-yielding cows). Sufficient variability between farmers, in terms the herd size, farming method, cow breeds, and a wide range of farmer productivity characteristics implied sufficient variability within the sampling units for the findings to be useful.

Table 2 depicts the correlations between the five constructs of OVERL and their descriptive statistics. The correlations in Table 2 indicate that all the pairs of correlations of the five constructs are not overly strong (range: 0.449~0.684), suggesting that each of the five categories being examined has a certain level of discreteness (not too over lapping). In addition, the correlations suggests that all the five constructs are strongly related to OVERL (range: 0.730~0.887), suggesting that all five constructs are important in computing OVERL (this is more directly evident from Eq (4)).

Table 2
Construct correlations and descriptive statistics of the constructs.

Construct (Category)	The Five Constructs of the Index OVERL					OVERL
	FCTIP	FPREL	ECONS	SOCLS	ENVTS	
FCTIP	—					
FPREL	0.684	—				
ECONS	0.622	0.626	—			
SOCLS	0.485	0.570	0.569	—		
ENVTS	0.620	0.529	0.506	0.449	—	
OVERL	0.887	0.833	0.819	0.730	0.755	—
Mean	3.140	3.143	2.966	3.803	3.897	3.404
StDev	1.300	0.934	1.165	0.758	0.872	0.824
Minimum	1.000	1.000	1.000	1.590	1.000	1.397
Maximum	5.000	5.000	5.000	5.000	5.000	4.967

Note that the descriptive statistics of the constructs are reported based on the 1-5 scale being used in the survey questionnaire.
Source: Author Composition

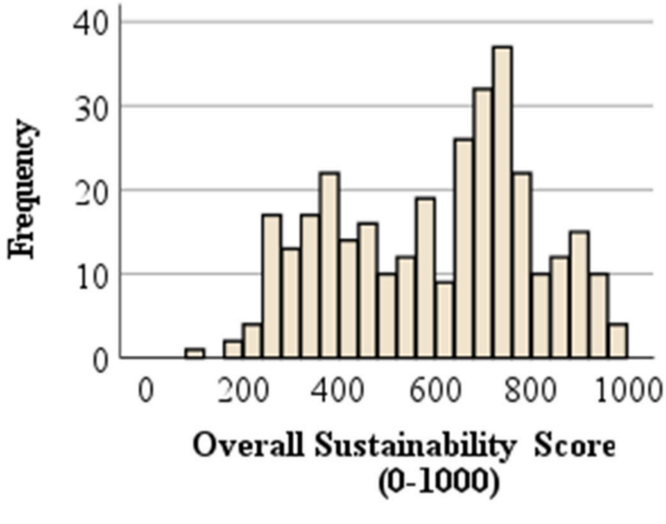
The estimated mean and the standard deviation (StDev) of OVERL (3.404 and 0.824 respectively), suggest that on average, farmers are performing moderately well, and there is sizable variation between the farmers. The implication is that farmers are at different stages of their continuous improvement journey towards sustainable performance.

4.3. *Distribution of farmer sustainability scores*

Fig. 3 shows the distribution of overall sustainability scores of the farmers on the 0-1000 scale. If required, milk processors can use a stricter assessment rubric to limit even the high achiever scores to about 800 points, because continuous improvement is a never-ending journey, and a strong message must go to the farmers that there is room to improve. Based on quartiles: Farmers scoring $\leq$416 (Q1) are in early stages of CP adoption and sustainability; Farmers between 417 and 749 (Q2–Q3) are moderate performers, requiring targeted interventions; and farmers scoring $\geq$750 (Q3+) are advanced performers, some reaching >800, reflecting strong alignment with CP practices. This distribution provides processors with a practical mechanism to classify farmers into performance groups and design tailored development programs.

4.4. *Construct level results and implications*

The scoring breakdown shows that FC (236 points) contributed the most to OVERL. Training adoption, quality compliance, and maintaining service relationships are key enablers, aligning with CP principles of resource efficiency and continuous improvement (see Table 1). FC to improve productivity can be enhanced when they receive training, financial support to develop their businesses, and timely feedback on their quality performance (De Silva et al., 2023; Korale-Gedara et al., 2023). In turn, these practices not only improve milk hygiene by



Mean = 601 StDev = 206 Min = 99 Max = 992
Q1 = 416 Q2 (Median) = 649 Q3 = 750

Fig. 3. Overall farmer sustainability histogram.
Source: Author Composition

reducing contamination risks but also lead to higher payments (Korale-Gedara et al., 2023).

SS (223 points) ranked highest among TBL outcomes. Indicators such as quality of life, education, and community recognition suggest that farmers perceive social gains as strongly reinforcing CP adoption. For example, households that benefit socially are more likely to maintain hygienic practices and adopt waste minimization methods. A milk processing company that actively collaborates with farmers to promote their SS can justifiably consider farmer-level improvements as part of its own sustainability achievements. This interpretation is consistent with the theoretical perspectives introduced earlier, where instrumental stakeholder theory emphasizes mutual value creation, the shared value concept links social and environmental improvements to business competitiveness, and CSR/sustainability reporting frameworks highlight the importance of transparent disclosure (Jones et al., 2018; Menghwar and Daood, 2021; Heikkurinen and Bonnedahl, 2013; Daub, 2007). Such justification, however, depends on processors being transparent about how farmer outcomes improved because of their development initiatives.

EnvS (190 points) contributed less than FC and SS in the overall index, yet it remains an important dimension as it reflects the uptake of CP practices such as effluent management (ENVSUS1), solid waste reuse (ENVSUS2), and air pollution control (ENVSUS3). Farmers who perform better in these areas not only reduce negative externalities but also generate co-benefits such as improved milk hygiene and higher payments (Adesogan et al., 2013; Lebacq et al., 2013; Qu et al., 2025). This suggests that even though EnvS is not the largest driver of sustainability performance, progress in these CP practices can meaningfully enhance overall farmer scores.

ES (170 points) scored the lowest. Empirically, it had the lowest mean ($M = 2.966$) and relatively high dispersion ($SD = 1.165$) compared with SS ($M = 3.803$, $SD = 0.758$) and EnvS ($M = 3.897$, $SD = 0.872$) (Table 2). Although ES correlates strongly with the overall index (OVERL, $r = 0.819$), its formative weight in Eq. (4) is smaller (0.170) than FC (0.236) and SS (0.223), indicating that—once all constructs are considered jointly—capability and social outcomes contribute more to the composite than the economic dimension. This helps explain why SS exceeds ES despite the centrality of financial stability for smallholders (Yawar and Seuring, 2018): social gains (e.g., education, recognition, empowerment) can sustain CP behaviours and resilience without immediately translating into higher income (Pradhan et al., 2017). Additionally, structural barriers—limited access to affordable credit, price volatility, and small scale—constrain short-run returns and reinvestment in CP technologies such as effluent systems or improved feed practices (Mor et al., 2018; Habib et al., 2024). Practically, CP adoption can be reinforced through social incentives, but easing systemic financial frictions via processor initiatives and supportive policies is essential to lift ES and, in turn, EnvS. In practice, bundling CP linked premiums with pickup repaid working capital lines and transparent payment SLAs directly targets the liquidity and volatility frictions underlying the low ES score, while reinforcing day to day CP adoption.

Evidence from Sri Lanka and comparable smallholder dairy contexts indicates that credit constraints, input/feeding costs, and market/payment conditions commonly limit near term economic gains and investments in environmental practices. A sector review for Sri Lanka highlights finance and input constraints as persistent bottlenecks (Vyas et al., 2020). It is also note that the impracticality of linking beneficiaries to formal credit in the current Sri Lankan context, underscoring liquidity barriers. More broadly, smallholders in developing countries face demand and supply side credit constraints that depress productive investment (Balana et al., 2022). Together, these findings triangulate our ES result and the mechanism proposed.

Overall, the pattern FC (236) > SS (223) > EnvS (190) > ES (170) indicates that capability and social enablers are the strongest current levers for CP adoption, while targeted support is needed to lift environmental and economic outcomes. This pattern is consistent with prior smallholder studies where capability and social factors precede environmental gains (e.g., Lebacq et al., 2013; Munyaneza et al., 2019), suggesting a staged pathway: enablers→ CP practices → EnvS/SS outcomes. To avoid 'scorecard' behaviour, reporting sub scores with percentile bands, require minimum thresholds on key constructs and verified CP practices (ENVSUS1–3) for incentives, and interpret the underlying indicators when targeting actions.

4.5. *Linking results to CP and SDGs*

Building on these results, the study maps constructs and indicators to specific CP practices and SDG targets to show where processors and policymakers can intervene most effectively. The findings demonstrate that CP adoption at farm level is both enabled by relational and capability factors and reflected in measurable sustainability outcomes. For instance: CAP1 (applying training) → resource efficiency → SDG4, SDG12, ENVSUS2 (solid waste reuse) → circular economy → SDG12, and SOCSUS2 (children's education) → long-term human capital for CP → SDG4, SDG5. Thus, the validated index not only benchmarks farmer sustainability but also allows processors to transparently report (CSR reporting) how their farmer development initiatives contribute to specific SDG targets via CP practices.

5. Discussion

This study developed and validated a performance measurement index that integrates enabling factors and TBL outcomes to evaluate the sustainable performance of smallholder dairy farmers. The findings provide insights into how FC, FPR, and ES, SS, and EnvS interact to shape sustainable outcomes. The discussion below interprets these results in relation to CP, SDG and CSR reporting highlighting theoretical, practical, and policy implications.

5.1. *CP implications*

While TBL captures outcomes, CP adds a preventive, efficiency-oriented management lens that targets the root causes of impacts. The index operationalizes this shift from diagnostic assessment to proactive management by linking enablers—FC and FPR—to concrete CP actions at farm level (e.g., hygienic handling and quality compliance, effluent management, solid waste reuse), which then manifest in the measured outcomes (ES, SS, EnvS). In this way, TBL tells what improved while CP tells what to change and how, and index operationalizes that by linking FC/FPR to concrete practices and then to TBL outcomes.

The results demonstrate that although EnvS (190 points) contributed less than FC and SS in the overall index, farmers who perform better in EnvS indicators—such as effluent disposal, solid waste reuse, and air pollution mitigation—still achieve comparatively higher overall sustainability scores. These indicators reflect core CP principles of pollution prevention, resource efficiency, circularity and waste minimization (Seuring and Müller, 2008; Adesogan et al., 2013). For example, ENVSUS2 (reuse of solid waste for agriculture) directly reflects circular economy practices, turning farm by-products into valuable inputs.

FC (236 points), the strongest contributor to the index, also enables CP adoption. Farmers who apply training (CAP1), comply with quality standards (CAP4), and maintain relationships with extension providers (CAP2) are better positioned to integrate CP methods into their daily practices (Adesogan et al., 2013; Yawar and Seuring, 2018; Korale-Gedara et al., 2023; Hidayati et al., 2023). This suggests that CP in smallholder contexts is not solely a technical challenge but also a function of knowledge transfer and relational support (Jones et al., 2018; Bridoux and Stoelhorst, 2022; Lees et al., 2020).

This study advances CP practice by operationalising CP at farm level through a scoring index. Unlike prior CP studies that rely more on environmental foot printing (e.g., LCA), this framework integrates CP practices with enabling social and relational factors, providing processors with a tool to benchmark farmers and design CP oriented interventions. This bridges the gap between CP principles and actionable supply chain management in developing country AFSCs.

Finally, to ensure environmental credibility without overburdening smallholders, the index can be linked to streamlined foot printing; details are provided in Section 5.2.

5.2. *Linking the CP index to LCA and carbon foot printing*

To enhance environmental credibility while keeping data demands feasible for smallholders, study outline a three-tier, low-burden linkage between the CP index and LCA/carbon accounting (Arulnathan et al., 2025; Kashyap et al., 2023; Sharma et al., 2022). Tier 1 (baseline) collects a minimal activity dataset alongside the index—herd size/-composition, annual milk yield, manure/effluent system, synthetic fertiliser/manure use, electricity and fuel for cooling/pumping, and typical milk collection distance—and applies standard/default factors (e.g., national grid factors for electricity; enteric/manure CH_4 and N_2O defaults; fuel/transport factors) to estimate a cradle to farm-gate carbon intensity (kg CO_2e/kg FPCM). Tier 2 (practice adjustments) translates verified CP practices into inventory changes using simple look-ups: ENVSUS1 (effluent management) → lower methane potential and nutrient losses; ENVSUS2 (solid-waste/manure reuse) → fertiliser credits for nutrient recovery; ENVSUS3 (air-quality actions) → reduced combustion/particulates and CO_2e. Tier 3 (calibration) conducts rotating deep dives on a small subsample annually (measured inputs/-flows) to calibrate Tier 2 coefficients and quantify uncertainty. Processors then aggregate farm level results using volume weighted averages and report construct sub scores alongside kg CO_2e/kg FPCM with uncertainty bands, enabling comparable, auditable dashboards without imposing full LCA burdens on every farm.

5.3. *Why SS scored higher than ES and how to balance incentives*

The results revealed that SS (223 points) ranked higher than ES (170 points). At first glance, this is surprising given the financial pressures smallholders face, but it reflects the interdependence of social and environmental improvements in CP adoption. Farmers reporting better quality of life, stronger community recognition, and improved educational access for their children are more likely to maintain hygienic handling and adopt waste-minimization practices, consistent with evidence that social capital and empowerment enable environmental change (Yawar and Seuring, 2018; Pradhan et al., 2017). In contexts where margins are thin, households may therefore prioritise community recognition and wellbeing as nearer term signals of progress, even before profitability improves. This aligns with the view that farmer development initiatives create shared value—social and environmental improvements among farmers can underpin processors' long-term competitiveness (Jones et al., 2018; Menghwar and Daood, 2021).

Given SS > ES, managers should pair social recognition (public awards, peer benchmarking/leaderboards, and timely performance feedback) with targeted financial instruments. Social mechanisms help sustain everyday CP behaviours (e.g., hygienic handling, waste minimization), while financial levers address liquidity constraints that limit investment in capital intensive CP options (e.g., effluent systems, manure storage, improved feed). Practical options include CP linked bonuses for verified ENVSUS1–3 practices and concessional credit/guarantees or time limited subsidies for CP technologies. To maintain credibility and avoid perverse incentives, pair recognition/bonuses with transparent quality testing, simple verification of ENVSUS1–3, and periodic re measurement of the 0–1000 index to monitor outcomes.

To overcome liquidity and price risk that depress near-term ES while sustaining CP behaviours, pair recognition/peer benchmarking with targeted finance levers. A practical mix—CP-linked bonuses for verified ENVSUS1–3, pickup-repaid working capital, input vouchers tied to CAP4/CP compliance, seasonal floor-price bands, prompt-payment SLAs/transparent testing, and optional micro-insurance—is detailed in Section 5.6.

5.4. *Longitudinal monitoring plan*

To assess change over time and intervention effects, remeasure the same farmer panel quarterly (light-touch) and annually (full), aligning quarters with production seasons. The quarterly pulse includes ENVSUS1–3, CAP4, and core FPR items; the annual cycle repeats all items. For analysis, use the panel to: (i) chart trajectories for OVERL and sub-scores; (ii) test lagged pathways (FC/FPR → EnvS/ES); and (iii) evaluate programs with staggered rollout using difference in differences or interrupted time series where feasible. Track uncertainty bands and exception signals (e.g., simple control charts) on dashboards. To versioning and invariance over time, keep the item set stable; if indicators must change, document a version and test measurement invariance across waves (MICOM/time-invariance) before comparing levels. Estimate again formative weights every 2–3 years (or when programs/contexts shift materially), then rescale to the 0–1000 metric. To data governance and retention, maintain a unique farmer ID for panel retention, store raw item responses (not just scores), and record verified CP checks (ENVSUS1–3). Use simple retention tactics (SMS reminders, aligning surveys to milk pickup) to minimize attrition.

5.5. *Implications for processors and corporate sustainability reporting*

For milk processors, the validated index is a practical benchmarking tool. By classifying farmers into quartiles, processors can target support: low performers (≤416 points) focus on foundational CP practices (e.g., effluent management), moderate performers receive capability and finance to scale adoption, and high performers (≥750 points) pilot circular-economy initiatives. The grouped instruments below (Finance, Governance/contracting, Extension & capability, Monitoring & data) specify how to operationalise these tiers. For clarity, the study group actionable instruments into four categories.

- ➢ Finance: CP-linked premiums; working-capital lines repaid at pickup; input vouchers/bundles; price-stabilisation bands; optional micro-insurance.

- ➢ Governance/contracting (FPR): prompt-payment SLAs; transparent quality testing with retest rights; simple grievance mechanism; independent spot checks; digital passbooks/e-payments.
- ➢ Extension & capability: targeted training; on-farm advisory; timely quality feedback; materials focused on ENVSUS1–3.
- ➢ Monitoring and data: periodic re-measurement (quarterly pulse + annual full); construct sub-scores; dashboards; two-key disbursement rule (practice verification + sub-score floors).

Beyond classification, the index enables processors to integrate farmer-level impacts into sustainability reporting. For example, improved effluent disposal (ENVSUS1) aligns with SDG 12, while gains in children's education (SOCSUS2) support SDG 4. In line with CSR frameworks and instrumental stakeholder theory, transparent disclosure that links processor initiatives to farmer-level CP outcomes and measurable SDG contributions strengthens report credibility. Processors can report construct sub-scores (including FPR) and show verification logs for ENVSUS1–3 alongside narrative CSR claims. Grouping improves readability while preserving the full set of actionable levers for practitioners.

5.6. *Policy implications and global relevance*

This section consolidates the political/policy, practical/managerial, and social implications of the index for scaling CP adoption in smallholder systems. Although tested in Sri Lanka, the methodology is analytically generalisable to other AFSCs. The five-construct architecture (FC, FPR, ES, SS, EnvS) is transferable, but indicators and weights must be recalibrated to commodity-specific CP practices using local data. For example, rice may emphasise water-use efficiency and methane mitigation; tea, soil conservation and energy efficiency; cocoa, shade management and soil restoration. Replication should follow: (i) co-design a commodity-specific indicator shortlist with local experts/extension; (ii) administer items on a 1–5 scale; (iii) screen indicators for relevance and multicollinearity (e.g., VIF <5); (iv) estimate PLS-SEM to obtain formative weights; (v) rescale to 0–1000 using the new weights; and (vi) set farmer-classification thresholds (e.g., quartiles or policy targets) from the new score distribution. See Appendix B for an illustrative row and the two-key rule.

Recalibrated versions of the index can underpin digital, sector-level dashboards that track CP adoption, reveal gaps, prioritise extension and incentives, and support SDG-aligned reporting and green growth. Dashboards should pair construct sub-scores with farm-gate carbon intensity (kg CO_2e/kg FPCM) and uncertainty bands to target support and transparently monitor progress. A one-page farm card (Tier-1 variables + ENVSUS1–3 verification) and a simple spreadsheet with default factors operationalise this linkage and standardise reporting.

- ➢ Finance: CP-linked incentives—results-based bonuses for verified ENVSUS1–3 (effluent management, solid-waste/manure reuse, air-quality actions), paid through the milk cheque and shown on farmer dashboards; concessional finance & guarantees—credit-guarantee windows and interest buy-downs for CP investments (e.g., effluent systems, manure storage, low-emission feed), with simple eligibility tied to construct sub-scores (not the composite alone); input vouchers/co-funded bundles (hygiene kits, effluent materials); price-volatility stabilisers—seasonal floor-price bands or targeted top-ups; optional low-premium micro-insurance (animal health/weather) bundled via the milk cheque.
- ➢ Governance/contracting (FPR): prompt-payment SLAs; transparent quality testing with retest rights; simple grievance mechanisms with service-level targets; independent spot checks; digital transparency (e-payments with timestamps, accessible logs); joint farmer–processor committees for prices, disputes, and programme design; public-procurement preferences for processors showing rising CP sub-scores and verified ENVSUS1–3 compliance.
- ➢ Extension and capability: fund advisory visits focused on ENVSUS1–3; targeted training and quality feedback; minimum advisory service levels (e.g., ≥1 visit/quarter, training entitlements, hotline access).
- ➢ Monitoring and data: maintain sector dashboards pairing construct sub-scores with farm-gate CO_2e (kg CO_2e/kg FPCM) and uncertainty bands; require periodic re-measurement (quarterly pulse + annual full); apply a two-key rule for disbursements (verified ENVSUS1–3 + sub-score thresholds); document verification logs and publish aggregate results. Grouping the instruments into Finance, Governance/contracting, Extension & capability, and Monitoring & data improves practitioner uptake without losing specificity.

Applying the index in other commodities or countries also requires re-estimating formative weights with PLS-SEM, screening VIF/validity via bootstrapping, and testing measurement invariance—e.g., the Measurement Invariance of Composites (MICOM) procedure—before any cross-group comparisons. Anticipated challenges include indicator relevance (commodity-specific CP priorities), data quality/heterogeneity (seasonality, recall, market arrangements), weight validity, cross-group comparability, local benchmarks, FPR governance, and foot printing parameters. These can be mitigated by co-designing commodity-appropriate items for FC, FPR, ES, SS, and EnvS; improving data quality via stratified sampling and short recall windows; setting context-specific thresholds from the new score distribution; adapting FPR clauses to local contracting norms; and updating LCA factors using a tiered integration. Where feasible, public procurement standards can favour processors that demonstrate rising CP sub-scores and verified ENVSUS1–3 compliance across suppliers.

6. Conclusion

This study develops and validates a CP-embedded, SDG-aligned 0–1000 index that integrates managerial enablers—farmer capability (FC) and the farmer–processor relationship (FPR)—with triple-bottom-line outcomes (ES, SS, EnvS) for smallholder dairy systems. Using data from 324 farmers, FC emerges as the strongest contributor to overall sustainability, while ES lags.

The key added value is methodological and practical: a replicable, CP-embedded, empirically weighted index that managers and policymakers can apply immediately. Specifically, the study (i) derives formative weights via PLS-SEM and translates them into an actionable 0–1000 scoring framework, (ii) integrates managerial enablers (FC, FPR) with TBL outcomes (ES, SS, EnvS) in a smallholder-appropriate tool, and (iii) outlines a low-burden linkage to LCA/carbon accounting for sector dashboards and credible reporting. Conceptually, the work operationalizes established SSD and instrumental-stakeholder perspectives through explicit CP principles (pollution prevention, resource efficiency, and circularity), positioning the contribution as an implementable method rather than a new theory.

Relative to established farm-level frameworks (e.g., SAFA, RISE, GRI)—valuable but often diagnostic and data-intensive for smallholders—the index is designed for day-to-day management and reporting. Compared with footprint-centric approaches (e.g., LCA), it complements environmental accounting by foregrounding adoption-ready CP practices and the enabling conditions that make those practices stick in resource-constrained settings; a low-burden linkage to farm-gate CO_2e supports comparable dashboards and clearer communication of impacts.

Practically, the weight pattern (FC > SS > EnvS > ES) indicates that building capability and trust/fairness in the relationship are pivotal for accelerating CP adoption, while economic gains can lag without targeted financial instruments and clear governance. Managers can use the index to classify farmers, tailor support, and disclose verified CP outcomes (e.g., ENVSUS1–3) in corporate sustainability reports; policymakers can use it to prioritise extension, incentives, and monitoring at sector level.

What generalises versus what is context-specific is explicit. Generic, transferable elements are the five-construct architecture (FC, FPR, ES, SS, EnvS), the embedded CP principles (prevention, efficiency, circularity), and the PLS-SEM → 0–1000 translation. Context-specific elements include item wordings, thresholds, and empirically estimated weights, which should be recalibrated with local data. Transferability therefore requires indicator co-design and re-estimation of formative weights (with validity checks and, where relevant, measurement-invariance tests) before cross-group comparisons; once recalibrated, the same logic supports classification, targeting, and SDG reporting in other commodities/regions.

6.1. Limitations and future research

The cross-sectional, single-country design limits causal inference and may miss seasonal variation. Although trained enumerators, anonymity, and neutral wording were used to reduce bias, residual recall and selection biases are possible. Future applications should shorten recall windows, add simple validation spot-checks (e.g., quality-test logs, payment records), and triangulate with processor administrative data. To track change, we recommend a panel with a quarterly light-touch pulse (key items) and an annual full cycle to analyse trajectories of OVERL and sub-scores and to evaluate interventions with lagged effects (FC/FPR → EnvS/ES).

Indicators capture practices and outcomes but do not directly quantify environmental footprints (e.g., GHGs, nutrient losses, water). Integrating the index with streamlined LCA/carbon accounting can translate verified practices (e.g., effluent management, solid-waste reuse) into quantified impacts, strengthening corporate reporting and policy monitoring.

External validity would be enhanced by replication across countries and commodities, with locally co-designed indicators and re-estimated formative weights, followed by rescaling to the 0–1000 metric and context-specific classification thresholds. Before cross-group comparisons, test measurement invariance (e.g., MICOM in PLS-SEM). Multi-processor or multi-region samples would further strengthen generalisability.

Future work should examine how credit access, price volatility, and scale constraints affect CP investment, and test processor-led finance/policy levers to mitigate these frictions. Where data systems mature, lightweight analytics (e.g., anomaly flags, short-horizon forecasts) could complement the index for ongoing monitoring; these are beyond the scope of the present non-AI design.

Overall, the study moves beyond diagnostics to a repeatable management instrument that aligns farm-level action with sector reporting and the SDGs. By embedding CP principles within an empirically validated scoring system, the framework equips processors, policymakers, and development agencies to scale CP adoption across smallholder systems and link everyday practices to measurable sustainability outcomes.

CRediT authorship contribution statement

Leeza DeSilva: Conceptualization, formal analysis, investigation, writing the original draft. **Nihal Jayamaha:** Supervision, conceptualization, verification of the analysis, writing (reviewing and editing). **Elena Garnevska:** Supervision, conceptualization, writing (reviewing and editing).

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2026.147821.

Data availability

Data will be made available on request.

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