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Research Paper

Leveraging Key Performance Indicators to Promote Environmental Stewardship in Commercial Agricultural Research

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Abstract: To ensure the sustainability of commercial agriculture in Sri Lanka within an increasingly competitive socio-economic environment, the sector must continuously respond to stakeholder expectations while safeguarding environmental integrity. Agricultural productivity largely depends on innovations in products and services that result from effective research and development (R&D). However, unintended environmental consequences may emerge during the implementation of R&D activities or from their resulting outputs, potentially undermining the long-term sustainability and societal value of research outcomes if such impacts are not adequately monitored and managed. In this context, Key Performance Indicators (KPIs) can serve as strategic tools for promoting environmental stewardship by incorporating environmental considerations into the evaluation of both the R&D process and its outputs. Accordingly, this study was conducted in two phases. Phase I involved a systematic literature review to identify environmentally relevant dimensions of research performance management. Phase II explored the potential relationships between KPIs and Key Performance Drivers (KPDs) through 32 in-depth personal interviews with stakeholders in the commercial agriculture research sector. This paper primarily draws on findings from Phase II, in which "Research for Society" emerged as a critical KPD and KPI dimension. Environmental stewardship was identified through stakeholder perspectives emphasizing environmental impact assessment, environmentally friendly research outputs, and the incorporation of environmental analysis into research evaluation. These 'code segments' collectively highlighted the potential of the "Research for Society" dimension as a suitable framework for integrating environmental considerations into research impact assessment. The study emphasizes the importance of leveraging KPIs not only to measure research productivity but also to promote environmentally responsible research within the broader social contexts of research practices in commercial agricultural R&D.

Keywords: Commercial agriculture, Environmental sustainability, Key Performance Indicators (KPIs), Performance management, Research and Development (R&D)

Introduction

Commercial agriculture (CA) remains one of the most important mechanisms for ensuring global food production and food security while supporting economic growth and rural livelihoods (Beddington, 2010). Food insecurity not only reduces access to nutritious food but also contributes to multiple forms of malnutrition, including undernutrition, overweight, and obesity (FAO, 2022). At the same time, global agricultural systems are increasingly challenged by climate change, environmental degradation, resource scarcity, biodiversity loss, and economic shocks, all of which threaten the sustainability of agricultural production systems and intensify food insecurity (Newsroom-FAO, 2022). These challenges have intensified the global demand for environmentally sustainable and socially responsible commercial agriculture practices, products, and services.

In Sri Lanka, the CA sector has continuously contributed to the stability of both macro- and micro-economic performance by strengthening food security, supporting rural livelihoods, generating employment opportunities, and sustaining numerous supply and value chains (DCS, 2019; DCS, 2020; Jayasinghe-Mudalige, 2010). Despite policy shifts and philosophical debates surrounding structural transformation, where the relative contribution of agriculture to national GDP tends to decline as economies industrialize and expand their service sectors, there is a broad consensus that the absolute contribution of agriculture must continue to increase through sustained improvements in productivity, profitability, innovation, resilience, and sustainability (Gollin, 2023; Barrett, Ortiz-Bobea, & Pham, 2023). Such progress largely depends on the development and adoption of advanced technologies, efficient production systems, and research-driven innovations capable of addressing emerging socio-economic and environmental challenges (Lampach, To-The, & Nguyen-Anh, 2021; Piesse & Thirtle, 2010; Boix-Fayos & De Vente, 2023).

Research and development (R&D) plays a critical role in shaping the future trajectory of commercial agriculture by generating innovations that enhance productivity, efficiency, and competitiveness (Anandajayasekeram, 2022). However, while agricultural R&D is primarily oriented toward improving productivity and commercial viability, environmental sustainability considerations are increasingly recognized as integral to the research–innovation continuum. Environmental concerns may arise at multiple stages of the research process and from resulting innovations (Pretty et al., 2018). First, environmental impacts can occur during the research process itself (Cluzel et al., 2020), for example, through experimental field trials, laboratory activities, prototype testing, and technology validation processes that may involve intensive use of land, water, energy, agrochemicals, or biological resources, potentially contributing to localized environmental stress if not properly managed (Greever et al., 2020). Second, environmental consequences may also emerge at the level of research outputs, where adopted technologies and innovations, although designed to improve efficiency, may unintentionally promote resource overuse, intensification of input-dependent farming systems, ecosystem disruption, pollution, loss of biodiversity, or unsustainable exploitation of land and water resources when scaled across commercial production systems (Biggi & Giuliani, 2021; Huo et al., 2022).

These dual pathways highlight that environmental externalities are not only a post-adoption issue but are also embedded within the research process itself. Consequently, modern agricultural R&D institutions are increasingly expected to embed environmental stewardship principles throughout the entire R&D cycle, ensuring that both research practices and resulting innovations are aligned with long-term environmental sustainability, societal well-being, and responsible innovation objectives. Environmental stewardship in research refers to the responsible integration of environmental concerns into research planning, implementation, evaluation, and impact assessment. In this context, institutional awareness, sensitiveness and flexibility on socio-environmental (SE) aspects, and the social responsibility of research have become essential components in promoting an environmentally sustainable and commercially viable agricultural R&D sector (Abeysiriwardana, Jayasinghe-Mudalige, & Seneviratne, 2022a).

Nevertheless, previous studies have revealed that many R&D institutions have not sufficiently incorporated environmental stewardship concerns into their decision-making and performance management systems (PMSs). In particular, SE dimensions are often not recognized as Key Performance Drivers (KPDs), which are understood in this study as underlying strategic factors that influence research performance and shape the design, implementation, and impact of research activities, whose effects should be systematically measured through Key Performance Indicators (KPIs) and communicated effectively to research management for strategic decision-making (Abeysiriwardana & Jayasinghe-Mudalige, 2021; Abeysiriwardana & Jayasinghe-Mudalige, 2022c).

KPIs have traditionally been used to assess research productivity, operational efficiency, scientific publications, commercialization outcomes, and financial performance (Lazzarotti et al., 2011). However, growing global concerns regarding climate change, biodiversity loss, resource 20depletion, and environmental degradation have prompted research institutions, funding agencies, and policymakers to reconsider how research performance is evaluated (Rodrigues et al., 2003). Increasing attention is being directed toward sustainability-oriented research assessment frameworks that incorporate environmental performance indicators, responsible research and innovation principles, and broader societal impacts alongside conventional output-based metrics (Issa et al., 2015; Stahl et al., 2021). Within this evolving paradigm, KPIs are increasingly recognized as strategic instruments for promoting environmental stewardship and guiding research activities toward sustainable development goals (SDGs).

In the Sri Lankan commercial agriculture sector, the need to integrate environmental stewardship into R&D through KPIs is particularly pronounced due to mounting environmental pressures associated with agrochemical-intensive cultivation practices, soil degradation, nutrient imbalances, water resource stress, and ecosystem fragmentation linked to plantation and export-oriented farming systems (Rathnachandra, 2023). These challenges underscore the importance of aligning agricultural R&D PMSs with environmental sustainability priorities to ensure that R&D activities contribute not only to economic and technological advancement but also to long-term ecological resilience and societal well-being.

Integrating environmental considerations into KPIs can help research institutions align innovation activities with sustainability goals, improve accountability, strengthen stakeholder trust, and ensure that research outputs contribute positively to society and the environment. In this context, “Research for Society” is conceptualized as a key KPD that reflects the extent to which research activities generate societal and environmental value beyond academic and commercial outputs, thereby providing a critical linkage between research performance and sustainability outcomes. Accordingly, it is argued that greater attention should be given to assessing the extent to which researchers and research administrators integrate environmental considerations into research design, implementation, and output generation, as well as whether the resulting innovations are justified in terms of their environmental implications.

Against this background, the objective of this paper is to identify and examine the KPIs currently used by R&D institutions operating in the commercial agriculture sector in Sri Lanka, and to assess their strengths and limitations in capturing environmental sustainability performance of R&D, alongside commercial and technological dimensions. Particular emphasis is placed on the KPD “Research for Society,” which is conceptualized as a strategic entry point for embedding environmental sustainability within research PMSs. The study aims to demonstrate how KPIs can be leveraged not only as instruments for evaluating R&D outputs but also as mechanisms for promoting environmentally sustainable, socially responsive, and sustainability-oriented agricultural innovation.

The remainder of this paper is organized as follows. Section 2 presents the research methodology adopted in the study, including the phases and stages used to develop an understanding of environmental stewardship within research performance measurement frameworks. Section 3 presents and discusses the findings of the study and highlights its contribution to scholarly literature and research management practices. Finally, Section 4 concludes the paper by summarizing the findings and highlighting the recommendations for policy, practice, and future research.

Materials and Methods

This study reports the findings of Phase II of a broader research project that examined the role of KPIs and KPDs in enhancing R&D performance management within Sri Lanka’s commercial agriculture R&D sector. While Phase I involved a systematic literature review that identified four key KPDs: Commercialization, Technology Transfer, Research Collaboration, and Research for Society (Abeysiriwardana & Jayasinghe-Mudalige, 2022), the present paper focuses exclusively on the empirical findings generated in Phase II. The KPD framework developed during Phase I served as the conceptual foundation for designing the interview protocol and interpreting the findings.

Phase II adopted a qualitative research design based on semi-structured, in-depth interviews, complemented by quantitative analyses of response frequencies and thematic occurrences. The unit of analysis comprised senior research leaders from commercial agriculture research institutions. The participants who, by virtue of their institutional roles and responsibilities, possessed expertise in the development, implementation, and use of KPIs, as well as substantial experience in R&D management, institutional performance evaluation, and strategic decision-making. These participants were considered information-rich cases, capable of providing valuable insights into the interpretation, operationalization, and integration of KPIs and KPDs within organizational PMSs.

This study is conceptually grounded in Stakeholder Theory (Freeman, 1994), which emphasizes that organizational performance should reflect the expectations of multiple stakeholders, including society and the environment, rather than focusing solely on economic outputs. In addition, the Resource-Based View (RBV) and Dynamic Capabilities perspective (Teece, 2009) inform the analysis by positioning KPI-based PMSs as strategic organizational capabilities that enable R&D institutions to integrate, reconfigure, and deploy resources toward sustainable agricultural innovation.

Conceptual framework

The conceptual framework of this study is developed based on the assumption that effective agricultural R&D should balance productivity, commercialization, societal relevance, and environmental sustainability. From a Stakeholder Theory perspective, R&D institutions are expected to generate value not only for industry and government but also for rural communities and environmental systems.

Accordingly, the framework proposes that R&D performance is shaped by a set of strategic KPDs, which represent the broader dimensions through which R&D institutions create and deliver value. These KPDs are operationalized and monitored through KPIs, which provide measurable evidence of institutional performance. In this study, four KPD dimensions identified in previous research: Commercialization, Technology Transfer, Research Collaboration, and Research for Society, are considered central pathways through which R&D activities generate economic, societal, and environmental impacts.

Despite this expectation, existing literature suggests that KPI systems in many R&D institutions remain largely output-driven and insufficiently aligned with broader KPDs, particularly those related to societal and environmental outcomes. This creates a misalignment between R&D performance measurement systems/ PMSs and SDGs in commercial agriculture.

Consistent with the principles of Stakeholder Theory discussed earlier, the conceptual framework posits that institutional leadership and stakeholder engagement play a critical role in shaping the selection, implementation, and monitoring of KPIs. These KPIs serve as operational mechanisms for measuring progress toward KPDs, which represent the strategic dimensions of R&D performance. The achievement of these KPDs ultimately influences the extent to which R&D activities and outputs contribute to commercialization, societal well-being, and environmental stewardship. Within this framework, "Research for Society" is conceptualized as the principal KPD through which environmental considerations are integrated into R&D planning, implementation, evaluation, and impact assessment, thereby strengthening the alignment between R&D performance management and sustainable development objectives.

Accordingly, this study conceptualizes KPIs as operational tools and KPDs as strategic performance dimensions that collectively shape R&D impact pathways, particularly through leadership mediation and stakeholder engagement processes. The framework further assumes that stronger alignment between KPIs and KPDs enhances the capacity of R&D institutions to assess and manage both the societal and environmental implications of R&D processes and outputs. Against this background, the research problem statement is articulated as follows:

Despite the adoption of KPI-based PMSs in research institutions, existing frameworks remain largely output-oriented and insufficiently integrated with KPDs that capture societal and environmental sustainability impacts of R&D processes and outputs. This limits the ability of R&D institutes to effectively assess and align their research agendas with sustainable development objectives in the commercial agriculture sector.

Based on this problem statement, the following research question is formulated:

What KPI-based performance management strategies and KPDs are currently used in R&D institutions, and how can they be effectively leveraged to design and implement an R&D agenda that generates measurable productivity outcomes while ensuring positive societal and environmental impacts, thereby promoting sustainable commercial agricultural development?

Methodological Design and Data Collection

This study adopted a qualitative research design based on in-depth expert interviews to examine the role of KPIs and KPDs in R&D performance management within Sri Lanka's commercial agriculture R&D sector. The research adopted a sequential two-phase design comprising an initial thematic analysis of policy and strategic documents (Phase I), followed by a thematic analysis of interview data (Phase II). Phase II was implemented in two stages: an exploratory stage involving senior research leaders from 10 research institutions and a subsequent full institutional coverage stage encompassing all 32 research institutions in the study population. The primary sampling unit was the research institution, while the unit of analysis comprised senior research leaders responsible for R&D planning, monitoring, evaluation, and strategic decision-making.

The study context included 32 government and semi-government institutions engaged in agricultural R&D and innovation. These institutions represent the complete institutional landscape of Sri Lanka's commercial agricultural R&D sector and include commodity-based R&D institutes, multidisciplinary agricultural R&D organizations, and public-sector R&D entities. Their activities encompass both basic and applied research relevant to commercial agriculture, with considerable variation in staff strength, research scope, and institutional mandates.

In Stage 1, a purposive sub-sample of approximately 10 R&D institutions was selected to ensure diversity in institutional type, mandate, and research focus. This exploratory phase was used to examine existing KPI practices and to identify preliminary KPDs. Data collection and analysis followed the principle of theoretical saturation, whereby interviews were conducted until no new conceptual themes emerged. The findings from this stage informed refinement of the conceptual framework and the development of the final interview protocol used in Stage 2.

In Stage 2, the study was extended to all 32 R&D institutions, thereby providing full institutional coverage of the commercial agricultural research system in Sri Lanka. This phase constituted the main empirical component of the study and aimed to validate and further elaborate the insights generated in Stage 1 across the entire institutional context.

Within each institution, senior research leaders served as the unit of analysis. A purposive sampling strategy was employed to identify information-rich participants with direct knowledge and experience in R&D management and performance evaluation. To ensure adequate institutional insight, the highest-ranking research management positions within each institution were targeted, typically including Directors, Heads of Research, Programme Leaders, or equivalent senior officials. Where the designated position was vacant or unavailable, another senior officer with comparable responsibilities in R&D management and performance assessment was selected based on institutional nomination.

Across both stages, a total of 60 senior officials were initially invited to participate. Invitations were issued simultaneously to all eligible participants identified through the sampling frame. Interview appointments were scheduled based on respondents' confirmation and availability. This scheduling process was purely administrative and did not influence participant selection. Of the invited individuals, 32 agreed to participate and completed the interviews. These participants were drawn from 24 R&D institutions and captured a broad range of perspectives across the population of 32 R&D institutions considered in the study. Although representatives from eight institutions were unavailable, additional respondents from institutions with comparable mandates were included to enhance coverage of institutional perspectives relevant to commercial agricultural R&D. This approach aligns with established qualitative and survey methodological guidance emphasizing coverage of relevant variation and mitigation of non-response bias through inclusion of additional information-rich cases (Patton, 2015: Qualitative Research and Evaluation Methods; Groves et al., 2009: Survey Methodology; Dillman et al., 2014: Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method).

Data were collected through semi-structured, in-depth interviews conducted via an online video-conferencing platform. The interview guide consisted of 15 core questions covering the development, implementation, and use of KPIs and KPDs within institutional PMSs. While the guide ensured consistency across interviews, additional probing questions were used where necessary to explore emerging issues, clarify responses, and obtain deeper insights, consistent with a semi-structured interview design. Each interview lasted between 30 and 60 minutes of effective discussion time, excluding introductory remarks and administrative procedures.

To complement the qualitative analysis, descriptive quantitative analyses of response frequencies and thematic occurrences were conducted following the coding process. This enabled the identification of dominant themes and patterns related to the application of KPIs and KPDs in R&D performance management.

Data Analysis

The study employed thematic analysis as the primary qualitative data analysis method. Thematic analysis is widely recognized for its flexibility and robustness in identifying, analyzing, and interpreting patterns within qualitative datasets, enabling the generation of meaningful insights into complex organizational phenomena (Braun & Clarke, 2006; Clarke, Braun, & Hayfield, 2015).

This approach allows for both semantic (explicit) and latent (interpretative) coding, making it suitable for exploring institutional perspectives on KPI and KPD integration in R&D PMSs.

The analysis followed the six-phase framework proposed by Braun and Clarke (2006):

1. Familiarization with data through repeated reading of interview transcripts and notes
2. Generation of initial codes by systematically organizing meaningful data segments
3. Search for themes by clustering related codes into potential thematic categories
4. Review of themes to ensure internal coherence and relevance to the research questions
5. Definition and naming of themes to clearly capture the essence of each thematic category
6. Production of the final report through integration of selected themes into the research narrative

MAXQDA, a computer-assisted qualitative data analysis software, was used to support data organization, coding, relationship mapping, and visualization of findings. This facilitated systematic management of large volumes of qualitative data and enhanced the transparency and rigor of the analytical process. The final analysis involved organizing expert responses into a hierarchical structure of codes, categories, sub-themes, and themes, focusing specifically on perceptions of KPI utilization in research performance management and its implications for commercial agricultural development in Sri Lanka.

Results and Discussion

The systematic literature review deduced four highly important KPDs and KPIs, namely: (1) Commercialization; (2) Technology Transfer; (3) Research Collaboration; and (4) Research for Society. The thematic analysis of 32 interviews (based on full coding using MAXQDA-assisted qualitative analysis) exposed 5 themes, 12 sub-themes, 32 categories, and a code set containing 152 codes to describe and explain the performance measurement context in research institutes in response to the research questions. These thematic structures represent the full analytical hierarchy derived from the complete dataset and form the basis for interpreting KPI–KPD relationships in the study.

In general, the 32 leaders who represented top administrative leadership of research institutions unanimously agreed that research in this sector should contribute to the well-being of society and, more importantly, must integrate environmental sustainability considerations both in the R&D process and in the final research outputs generated for the commercial agriculture sector. This reflects a strong convergence of perspectives across institutions regarding the importance of sustainability-oriented research performance management.

However, to understand the commitment, readiness, potential, and flexibility of top administrators in guiding R&D toward environmental sustainability and broader societal responsibility in commercial agricultural R&D, a structured interpretation of the coded dataset was conducted. Although the full analysis identified five KPDs (Research Commercialization, Research Collaboration, Research for Society, Institutional Management, and Technology Integrated Systems), this paper deliberately focuses on the "Research for Society" dimension due to its direct relevance to environmental stewardship and sustainability-oriented R&D performance management.

Accordingly, while the other KPDs were identified in the broader thematic analysis, they are not elaborated in detail in this paper in order to maintain analytical focus and depth. Instead, "Research for Society" is treated as the primary analytical lens, allowing a more detailed examination of how environmental and societal considerations are reflected in institutional practices, perceptions, and research performance evaluation systems within the commercial agriculture sector.

Focused Thematic Analysis on Environmental KPIs within "Research for Society"

The code set considered in the specific analysis is presented in Table 1. "Environmental Aspects in KPIs" under the theme "Research for Society" was selected as the most appropriate sub-theme to obtain relevant categories such as "Business Environment Analysis" and "Corporate Social Responsibility" to discuss environmental and societal concerns when research produces outputs for the CA sector. Under these two categories, 8 key environmental-related codes were identified. In addition, the code "Integrated Systems" under the "Technology Integrated Systems" theme was also included to examine whether digital integration supports environmental KPI tracking across the R&D lifecycle (process and outputs).

Table 1. Codes used in the analysis of "Research for Society"

Theme	sub-themes	categories	Codes	No.
Research For Society				0
	Environmental Aspects in KPIs			0
		Business Environment analysis		0
			Outputs and Outcomes	5
			PESTEL Analysis	13
			Type of Research	4
			SWOT Analysis	9
		Cooperate Social Responsibility		0
			Environment aspects in KPI	25
			Environment impact	17
			Environmental friendly research outputs	12
			Research for people's benefit	14
Technology Integrated Systems				0
	Digitally Enabled KPI System			0
		Technology Adoption		0
			Integrated Systems	5

Code Mapping and Environmental Integration Analysis

Selected codes are shown on a map in the code visualization. The closer the two codes are placed together, the more they overlap in terms of their occurrence and semantic similarity within the dataset.

According to this analysis in Figure 1, environmental KPI-related codes primarily cluster within CSR and business environment analysis domains, rather than being strongly integrated into technology-driven or system-level R&D management structures. Notably, the code "Integrated Systems" shows limited connectivity with "Research for Society" and environmental KPI categories, indicating weak digital integration of environmental performance tracking within R&D management systems.

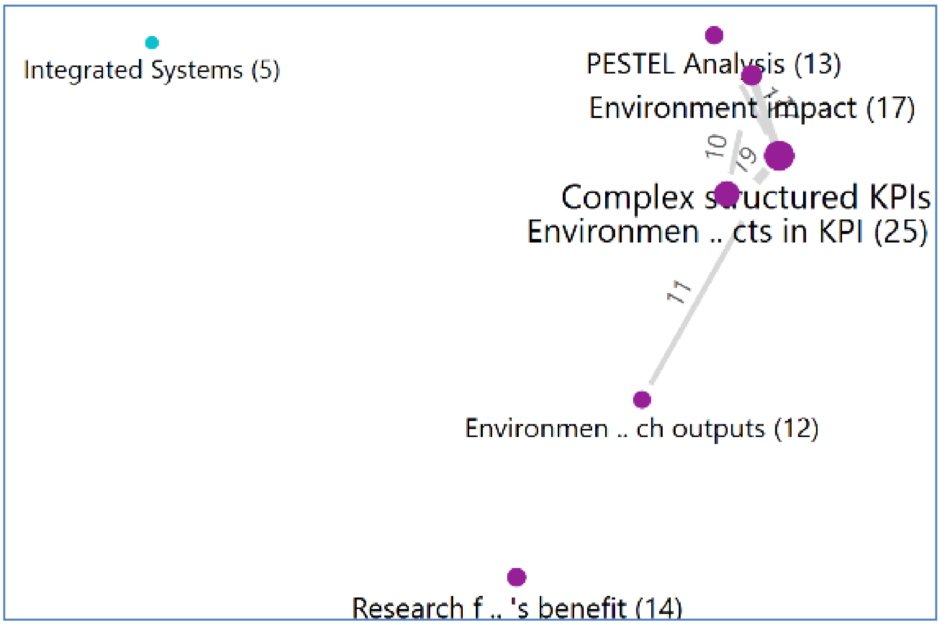

Figure 1. Relationships of research, environment, and KPI aspects in code map

Environmental KPI Weak Integration in Research Process and Output Pathways

To further refine the analysis, separate code maps were generated (Figures 2 and 3) to examine code co-occurrence within the same segments and documents.

Figure 2 illustrates code intersections within the same text segments, while Figure 3 shows co-occurrence within documents. Both analyses reveal a consistent pattern: environment-related KPI codes are discussed in isolation rather than being systematically embedded into R&D performance structures.

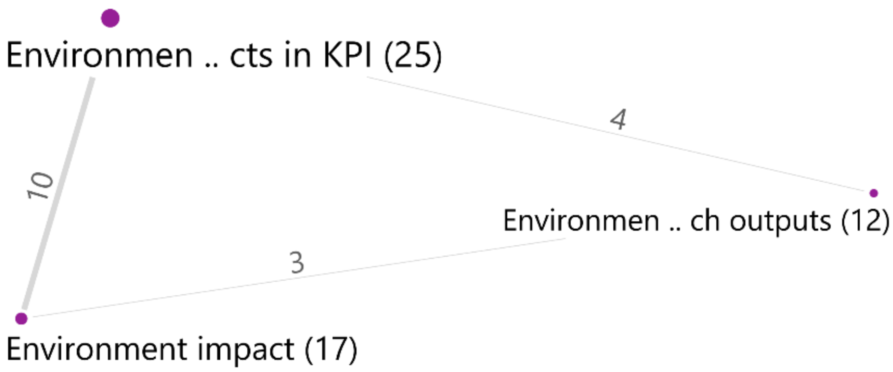

Figure 2. Code relationships in code map generated on code in the same segment

The code analysis shows that:

- “Environmentally friendly research outputs” (12 mentions)
- “Environmental impact” (17 mentions)
- “Environmental aspects in KPI” (25 mentions)

Do not strongly co-occur with each other or with “Research for Society” (14 mentions), indicating a fragmentation between environmental intent and KPI-based measurement systems.

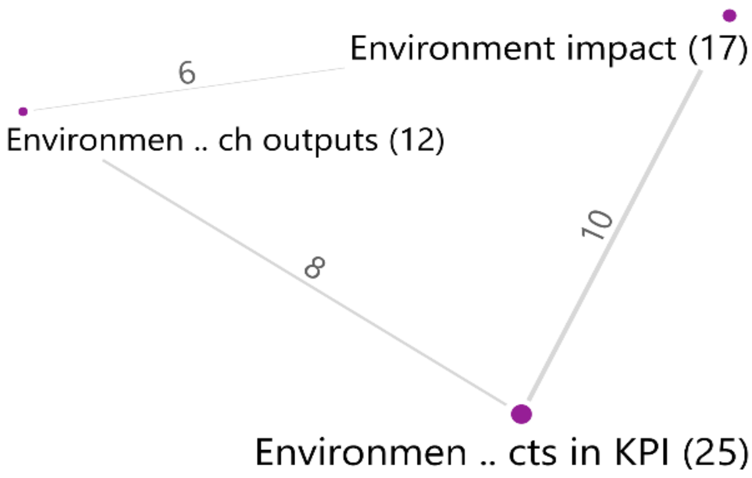

Figure 3. Code relationships in code map generated on code in same document

Importantly, this suggests that:

Environmental considerations are acknowledged at the conceptual level but are not consistently operationalized within KPI systems used to evaluate either research processes or R&D outputs.

Furthermore, environmental concerns during the R&D process (e.g., experimentation, trials, resource use) are not systematically linked to KPI structures, nor are downstream environmental effects of R&D outputs effectively tracked or measured. This interpretation is strongly supported by the interview evidence, which indicates a clear recognition among institutional leaders that conventional output-based indicators alone are insufficient for capturing research performance in a meaningful way. One respondent emphasized this limitation, stating: “papers patent or products, definitely no, it's much, much more than, it has to be a broader framework, grid, which is, doesn't have to be necessarily complex, but different facets of it.” This reflects the perceived need for a multidimensional KPI structure beyond traditional academic outputs.

In relation to environmental integration, participants consistently highlighted that sustainability considerations should be embedded within PMSs rather than treated as peripheral concerns. As one respondent noted: “We all have a role to play when it comes to environmental management and conservation, therefore, all our research priorities should be aligned with some kind of environmental concerns… everything, it should cover the Environmental Conservation aspects as well. And that also should be some KPI, should take it into account that as well.” This directly supports the interpretation that environmental stewardship is recognized as a necessary KPI dimension but is not yet structurally embedded.

Furthermore, respondents stressed the importance of aligning KPIs with national and societal needs rather than purely academic outputs. As stated by one participant: “I am not saying publications are not important, but that is restricted for some group of people only… KPI should not focus some product, publications or patents… it should address the country needs actually, national requirement is also very important.” This reinforces the argument that current KPI systems are perceived as misaligned with broader societal and environmental objectives.

Collectively, these empirical insights confirm that environmental considerations are conceptually acknowledged but remain weakly institutionalized within KPI frameworks, thereby supporting the observed fragmentation between environmental intent, "Research for Society", and PMSs.

Disconnection between Environmental Stewardship and KPI Systems

The code map results (Figures 1–3) collectively indicate that:

- Environmental sustainability is treated as a peripheral consideration rather than a core KPI dimension
- Research-for-society discourse does not strongly translate into measurable environmental performance indicators
- "Integrated systems" (5 mentions) show minimal linkage with environmental KPI categories

This demonstrates a critical gap in institutional PMSs, where:

Environmental stewardship in R&D processes is not adequately translated into measurable KPIs, and the environmental impacts of R&D outputs are not systematically evaluated through KPI frameworks.

Proposed KPI–KPD Integration Framework for Environmental Sustainability

Based on these findings, a KPI–KPD integration framework is proposed (Figure 4) to address the observed fragmentation. The development of this framework is directly grounded in the empirical findings derived from the systematic literature review and the thematic analysis of 32 expert interviews conducted using MAXQDA-assisted coding procedures.

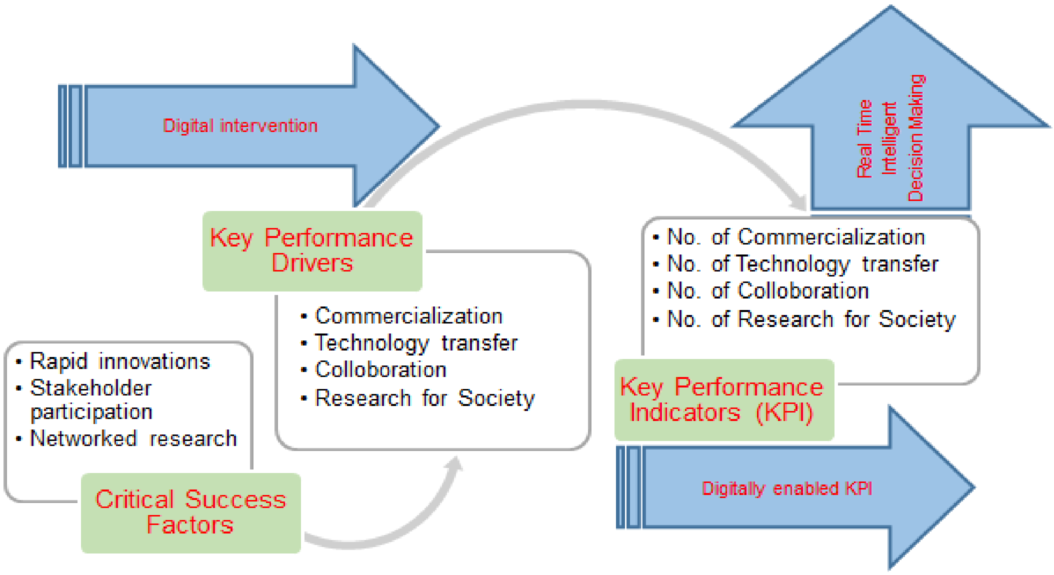

Figure 4. Proposed digital KPI-KPD framework

Among five themes, "Research for Society" emerged as the most dominant sustainability-relevant dimension, reflecting strong institutional consensus on the need to integrate societal and environmental considerations into R&D PMSs.

In particular, the findings revealed that senior research leaders consistently emphasized that R&D in the commercial agriculture sector should extend beyond productivity and commercialization goals to explicitly incorporate environmental sustainability and societal well-being. This convergence of views provides the primary empirical foundation for positioning "Research for Society" as the central KPD in the proposed framework.

Accordingly, this study focuses analytically on the "Research for Society" dimension, while the other KPDs are acknowledged as part of the broader performance ecosystem but are not elaborated in detail in this paper. This deliberate analytical focus enables a deeper interpretation of how environmental considerations are embedded within KPI-based R&D PMSs.

The empirical coding further demonstrates that environmental-related codes, such as environmental impact, environmentally friendly R&D outputs, and R&D for people's benefit, are primarily clustered within the "Research for Society" domain but show weak integration with system-level performance mechanisms, particularly technology-enabled monitoring systems. More broadly, the analysis indicates that all five KPDs: Research Commercialization, Research Collaboration, Research for Society, Institutional Management, and Technology-Integrated Systems, are not yet fully integrated within a unified digital performance monitoring architecture. This fragmentation directly informs the structure of Figure 4, which presents a futuristic integrated KPI–KPD framework linking all five KPDs within a centralized digital monitoring system, with environmental sustainability primarily embedded through the "Research for Society" pathway.

Accordingly, the proposed framework conceptualizes KPI–KPD integration as an adaptive governance and digital intelligence system in which institutional leadership, stakeholder engagement, and technology-enabled platforms collectively translate sustainability expectations into measurable and continuously evolving performance indicators. The framework represents a shift from isolated KPI tracking toward an integrated system-wide monitoring model that enables cross-KPD visibility, real-time tracking, and evidence-based decision-making in R&D performance management across institutions.

Within this integrated structure, "Research for Society" functions as the principal sustainability-sensitive KPD that ensures environmental and societal outcomes are explicitly captured within the overall KPI architecture, while all other KPDs are simultaneously monitored within the same system. The critical success factors identified for this futuristic model include rapid innovation supported by adaptive research cycles, stakeholder participation through multi-actor engagement platforms, environmental accountability embedded in both research design and output evaluation, and digital integration of KPI–KPD systems through interoperable platforms enabling real-time monitoring and AI-supported decision-making across all five KPDs.

Policy Implications

To operationalize the proposed model in R&D institutions, the following policy directions are recommended:

i. Increase community participation in R&D design and development to ensure environmental concerns are embedded at the R&D planning stage

ii. Institutionalize a collaborative evaluation strategy that integrates environmental KPIs into centralized performance assessment systems (Abeysiriwardana & Jayasinghe-Mudalige, 2022d)

iii. Facilitate a connected R&D culture supported by digital platforms and automated systems to ensure real-time environmental KPI tracking across R&D processes and outputs.

iv. Strengthen policy directives to formally adopt "Research for Society" as a KPD with explicit environmental sustainability performance indicators embedded within KPI frameworks

Limitations and Future R&D Directions

This study has several limitations that should be considered when interpreting the findings. Although the study achieved broad coverage of Sri Lanka's commercial agricultural R&D institutions, the analysis was based primarily on the perspectives of senior research leaders involved in R&D management and performance evaluation. As a result, the views of other stakeholders, including researchers, extension personnel, industry partners, and community beneficiaries, were not directly captured. Furthermore, the study employed a predominantly qualitative approach, complemented by descriptive quantitative analyses of coded responses, which limits the ability to statistically validate the relationships among KPIs, KPDs, and sustainability outcomes.

Future research should therefore extend the analysis to a broader range of stakeholders and employ quantitative approaches to validate and refine the relationships identified in this study. Comparative studies across different R&D systems and national contexts would also be valuable for assessing the wider applicability of the proposed framework. In particular, further research is needed to develop and validate environmental KPIs that can systematically measure environmental stewardship throughout the R&D process, thereby strengthening the integration of sustainability considerations into R&D PMSs.

Conclusion

The outcomes of this study indicate that the R&D institutions under investigation do not yet possess a sufficiently robust KPI-based PMS capable of effectively monitoring, integrating, and guiding environmental sustainability considerations in commercial agricultural R&D. In particular, existing KPI frameworks remain largely oriented toward traditional performance dimensions such as productivity, commercialization, and efficiency, while environmental sustainability aspects within both R&D processes and R&D outputs are not systematically captured or operationalized through measurable indicators.

At the institutional leadership level, respondents highlighted significant challenges in steering R&D activities toward the "Research for Society" KPD, particularly due to the absence of clearly defined and environmentally integrated KPIs that can guide decision-making across the research lifecycle. Although there is broad recognition of the importance of environmental sustainability, this recognition is not adequately translated into structured PMSs that can influence planning, implementation, and evaluation of R&D activities. These findings reflect a systemic gap between sustainability awareness and performance measurement operationalization within R&D governance structures.

These findings underscore the need for a strengthened KPI–KPD framework that explicitly embeds environmental sustainability as a core performance dimension, rather than a peripheral consideration. Such a framework should enable R&D institutions to systematically track environmental implications of both R&D processes (e.g., resource use, experimental practices, and field activities) and R&D outputs (e.g., adoption impacts, ecosystem effects, and scalability consequences). In this regard, the proposed integrated KPI–KPD model provides a conceptual foundation for linking environmental stewardship with institutional performance evaluation through digitally enabled monitoring mechanisms.

Accordingly, the study highlights the importance of developing a digitally enabled, integrated PMS that supports evidence-based decision-making through environmental KPIs aligned with institutional KPDs. In addition, targeted policy interventions are required to institutionalize environmental stewardship within R&D governance structures, enhance stakeholder engagement in R&D design and evaluation, and strengthen institutional capacity for sustainable innovation in commercial agriculture. Particular emphasis should be placed on operationalizing "Research for Society" as the key sustainability-sensitive KPD that bridges environmental objectives with PMSs.

Overall, the study contributes to the emerging discourse on sustainable R&D performance management by demonstrating that environmentally responsible agricultural innovation requires not only scientific advancement but also a reconfiguration of KPI systems to reflect environmental accountability across the entire R&D continuum. This includes integrating environmental considerations into both process-level and output-level performance assessments within a unified KPI–KPD governance framework.

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Data availability: All secondary data analyzed and cited in this article are available in the public domain. The primary datasets analyzed during the study are available in the Harvard Dataverse repository and not openly accessible due to ethical considerations, but may be provided upon an appropriate request to the corresponding author through the link provided at the data repository (Abeysiriwardana, Prabath, 2024, "KPIs of Research Leaders", https://doi.org/10.7910/DVN/BS00RO, Harvard Dataverse, V2).

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