Digital Innovation in Palm Oil Governance: The Role of K-SMARD in Enhancing Strategic Decision-Making

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ABSTRACT

Index K, a key basis for profit-sharing between palm oil mills and smallholders, often fluctuates due to inconsistent data input, varying calculation methods, and lack of standardized digital systems. This study aims to develop and validate K-SMARD, a digital system designed to automate and standardize the calculation and reporting of Index K while supporting more reliable and transparent decision-making processes. The system was developed using a structured software engineering approach and evaluated using real operational data from palm oil mills. Statistical testing using the Paired Sample t-Test method on 177 pairs of K-Index data from 183 pairs of data and 6 pairs of data not included in the sample shows strong evidence that the K-SMARD application is able to produce calculations comparable to the Excel-based manual method that has been used by the Palm Oil Mill and verified by the Plantation Service (DISBUNNAK). The results indicate that K-SMARD produces highly consistent outputs compared to conventional spreadsheet-based calculations. Statistical validation using a paired sample t-test shows no significant difference between the two methods ($p > 0.05$), while regression analysis demonstrates a very strong linear relationship ($R^2 \approx 0.99$), indicating a high level of agreement. In addition, the system significantly reduces calculation errors and improves reporting efficiency. From a strategic perspective, the implementation of K-SMARD enhances data standardization, strengthens governance, and supports more informed managerial decision-making. The system also contributes to improving transparency and trust between mills and smallholders by providing more objective and accountable calculation results. This study recommends the broader adoption of K-SMARD as a standardized digital platform for Index K calculation at both regional and national levels. Future research should focus on system integration, mobile platform development, and the establishment of a unified national database to support the digital transformation of the palm oil industry.

Keywords: *K-SMARD, Strategic Decision-Making, Palm Oil Governance, Decision Support System, Index K, Digital Innovation, Data Standardization*

1. INTRODUCTION

The palm oil industry plays a critical role in the global agricultural and industrial economy, particularly in countries such as Indonesia and Malaysia, which dominate global production and supply chains (Goh et al., 2022; Loh et al., 2018; Pratama et al., 2024). Palm oil is widely used in various sectors, including food, energy, and manufacturing, making it one of the most strategically important commodities worldwide (Shigetomi et al., 2020). In Indonesia, the palm oil sector significantly contributes to national economic growth, export revenues, and employment, reinforcing its position as a key pillar in industrial and agricultural development(Azahari et al., n.d.; Judijanto, 2025a, 2025b; Purnomo et al., 2020).

Despite its economic importance, the governance of the palm oil industry faces complex challenges, particularly in ensuring transparency, consistency, and accountability in operational and financial processes (Intan et al., 2022; Pacheco et al., 2020). Previous studies highlight that weak institutional coordination, inconsistent data management, and fragmented regulatory implementation often lead to inefficiencies in palm oil governance systems (Hidayat et al., 2018; Judijanto, 2025c). In addition, the effectiveness of national policies, such as sustainability certification systems, depends heavily on the quality of data and reporting practices at the regional and operational levels (Astuti et al., 2022).

Index K is a critical operational metric in Indonesia's palm oil sector, serving as the basis for revenue distribution between mills and smallholders. Ideally, Index K should reflect actual operational efficiency derived from stable cost components such as production costs, yields, and processing efficiency. However, research shows that Index K values often fluctuate significantly due to factors beyond operational performance, including manual data processing, inconsistent calculation templates, and lack of standardized digital systems (Dahniar et al., 2026; Dahniar & Mikrianto, 2025). These inconsistencies undermine transparency and fairness in revenue sharing. Recent studies highlight the need for digitalization and standardization to improve accuracy, consistency, and trust in Index K reporting (Dahniar et al., 2026). Broader literature on agri-food supply chains underscores similar challenges with data management and transparency, emphasizing the transformative potential but also the barriers of digital innovation for sustainable governance (Gardner et al., 2019; Gumbi et al., 2023; Menon, 2021).

Reliance on spreadsheet-based calculations and manual data entry remains a significant limitation in many palm oil mills, leading to increased risk of human error, inconsistent formula usage, and unreliable reported values. These challenges are not unique to palm oil but are echoed across broader agricultural and plantation management systems, where traditional data processing methods hinder accuracy, efficiency, and decision-making quality. As the industry moves toward digital transformation, integrated and automated systems are increasingly recognized as essential for improving operational reliability and sustainability (Al-hadi & Ismail, 2020; Basir et al., 2024; Nasution, 2022)

Recent developments in industrial digitalization emphasize the role of information systems in improving data accuracy, operational efficiency, and governance transparency. The integration of digital technologies into agricultural and industrial systems has been shown to enhance monitoring, reporting, and decision-making processes, particularly in complex supply chains such as palm oil. However, there remains a significant gap in the availability of specialized systems designed specifically for standardized Index K calculation and reporting (Amentae & Gebresenbet, 2021; Kamble et al., 2019; Lezoche et al., 2020; Wang, 2025).

To address this gap, this study develops K-SMARD, a digital system designed to automate and standardize the calculation of Index K in palm oil mills. Unlike conventional methods, K-SMARD integrates data processing, calculation algorithms, and reporting functions into a unified platform, enabling consistent and traceable computation results. The system is developed using a structured software engineering approach based on a waterfall model for information system development in the palm oil industry (Dahniar et al., 2026), in line with established software engineering practices for agricultural information systems that emphasize object-oriented modeling and clear architectural design (Nikkilä et al., 2010; Tekinerdogan, 2021). K-SMARD is validated using real operational Index K data from multiple palm oil mills and statistically compared against conventional Excel-based calculations, showing accurate and consistent results with no significant differences while improving efficiency and reporting reliability (Dahniar et al., 2026).

The novelty of this research lies in the integration of system development and statistical validation within the context of palm oil governance. While previous studies have focused on policy, sustainability, or supply chain management, limited research has addressed the technical aspects of standardized Index K calculation using a validated digital system. Therefore, this study contributes not only to the development of a practical digital solution but also to the scientific validation of its accuracy and reliability (Dahniar & Mikrianto, 2025) (Rina Sari & Irawan, 2025; Seminar et al., 2024; Yamin et al., 2020).

Furthermore, this study aims to evaluate the performance of K-SMARD by comparing its results with conventional calculation methods and analyzing its impact on data consistency, error reduction, and reporting efficiency, following common practices in digital system evaluations that benchmark new information systems against manual or spreadsheet-based approaches to demonstrate gains in accuracy and timeliness (Aron et al., 2024; Yamin et al., 2020; Yoraeni et al., 2025). The performance focus on data consistency and error reduction is aligned with broader information system research, where integrated and AI- or rules-based validation mechanisms have been shown to decrease undetected errors, reduce duplicate or inconsistent entries, and improve inter-departmental data coherence compared to traditional methods (Choudhury, 2025; Yamin et al., 2020; Yoraeni et al., 2025). The emphasis on reporting efficiency reflects evidence that web-based and integrated management systems can significantly cut processing time, automate report generation, and overcome delays and fragmentation found in manual reporting workflows (Abdul Raof et al., 2025; Kipilimba, 2024).

The findings are expected to support the broader adoption of digital systems in palm oil governance and contribute to improving transparency, accountability, and trust among stakeholders, consistent with studies showing that digitally connected supply chain systems, blockchain-based traceability models, and geospatial or ledger-based tools can enhance visibility, reduce opportunities for data manipulation, and strengthen stakeholder confidence in sustainability and compliance claims within the palm oil sector (Heryani et al., 2022).

2. RESEARCH METHODS

This study employs a quantitative approach combined with system development to evaluate the effectiveness of K-SMARD as a digital decision support system for Index K calculation in palm oil mills. The research design integrates software engineering processes with statistical validation to ensure both functional performance and analytical reliability.

The development of K-SMARD follows a structured software engineering approach, consisting of requirement analysis, system design, implementation, and testing. In the requirement analysis stage, the study identifies key components of Index K calculation, including production costs, crude palm oil (CPO) yield, kernel output, and marketing expenses. These components are then translated into standardized computational algorithms within the system. The design phase includes system architecture development, database modeling, process flow design, and user interface configuration to ensure usability and consistency. The system is then implemented as a digital platform capable of processing real operational data and generating automated reports (Pressman & Maxim, 2019).

To evaluate system performance, this study uses real operational data collected from palm oil mills. A total of 183 paired datasets of Index K calculations were obtained, consisting of results generated using conventional Excel-based methods and those produced by K-SMARD. After data screening, 177 valid data pairs were included in the statistical analysis, while 6 pairs were excluded due to inconsistencies in data completeness.

Statistical validation is conducted using two main approaches. First, a paired sample t-test is applied to determine whether there is a significant difference between the results produced by K-SMARD and the conventional method. The test evaluates the null hypothesis that both methods yield equivalent results (Field, 2017). Second, linear regression analysis is performed to assess the strength and consistency of the relationship between the two calculation methods. Key parameters analyzed include the regression slope, coefficient of determination (R^2), Pearson correlation coefficient, and analysis of variance (ANOVA) (Montgomery et al., 2012). In addition, the Residual Sum of Squares (RSS) is used to measure the magnitude of error between the two methods.

Beyond statistical validation, the study also analyzes error distribution patterns to identify the main sources of discrepancies in manual calculations. This includes classification of errors such as data input inconsistencies, differences in data sources, and calculation or rounding errors. The effectiveness of K-SMARD in reducing these errors is then evaluated qualitatively and quantitatively.

Finally, the study assesses the implications of K-SMARD implementation from a strategic management perspective, particularly in terms of improving data standardization, enhancing governance, increasing reporting efficiency, and supporting managerial decision-making. In this context, K-SMARD is positioned as a decision support system that facilitates data-driven decision-making in organizational settings (Power, 2002).

3. RESULTS AND DISCUSSIONS

3.1 Statistical Validation of Index K Calculation: Excel vs. K-SMARD.

Statistical validation using a paired sample t-test on 177 matched observations indicates that K-SMARD produces Index K values comparable to the conventional Excel-based method used by palm oil mills and verified by regulatory authorities. Descriptively, both methods yield nearly identical average values, with only a negligible difference of less than 1%, suggesting minimal deviation between the two approaches. The t-test results show no statistically significant difference between the methods ($p > 0.05$), confirming that K-SMARD is able to replicate the established calculation framework with a high level of accuracy.

Further evidence is provided by linear regression analysis, which demonstrates a near-perfect linear relationship between the outputs of K-SMARD and Excel. The regression slope is approximately equal to one, indicating that both methods produce almost identical results across observations. The coefficient of determination ($R^2 \approx 0.99$) and the very strong Pearson correlation confirm a high level of consistency and agreement. In addition, the regression model is statistically significant, and the residual error is minimal, indicating that any differences between the two methods are random rather than systematic.

Taken together, these findings confirm that K-SMARD is both valid and reliable as an equivalent substitute for the conventional Excel-based calculation method. While maintaining numerical consistency, K-SMARD offers additional advantages, including reduced input errors, faster processing time, and built-in validation features. From a practical perspective, this implies that K-SMARD can be adopted without altering the substantive outcomes of Index K calculations while significantly improving efficiency and data integrity.

More broadly, the results support the role of K-SMARD as a digital decision support system that enhances transparency, strengthens governance, and facilitates data-driven decision-making in the palm oil industry. Its adoption also contributes to improving trust among stakeholders and supports the broader agenda of digital transformation in palm oil governance.

Linear regression analysis provides additional evidence reinforcing the equivalence between K-SMARD and the Excel-based method. The regression model shows a slope very close to unity, indicating an almost identical and perfectly linear relationship between the two calculation approaches. The coefficient of determination ($R^2 \approx 0.99$) and a near-perfect Pearson correlation further confirm a very high level of consistency and agreement. The regression model is statistically significant, and the residual error is minimal, suggesting that any differences observed are negligible and non-systematic.

When combined with the results of the paired sample t-test, these findings confirm that K-SMARD demonstrates strong validity and reliability as an equivalent substitute for the conventional Excel-based calculation method. The absence of a significant difference in the t-test verifies numerical equivalence, while the near-perfect linear relationship in the regression analysis indicates that any minor deviations are random rather than systematic.

From a practical perspective, this implies that K-SMARD can be implemented as a reliable calculation platform without altering the substantive outcomes currently used by palm oil mills and regulatory authorities. Moreover, K-

SMARD offers additional advantages, including reduced input errors, faster processing, and automated validation features, making it more effective than traditional spreadsheet-based approaches.

At a broader level, these findings provide both academic and practical justification for promoting the adoption of K-SMARD as a standardized digital platform. Its implementation supports the digital transformation of palm oil governance by enhancing transparency, improving data accountability, and strengthening trust among stakeholders, including mills, smallholders, and government institutions.

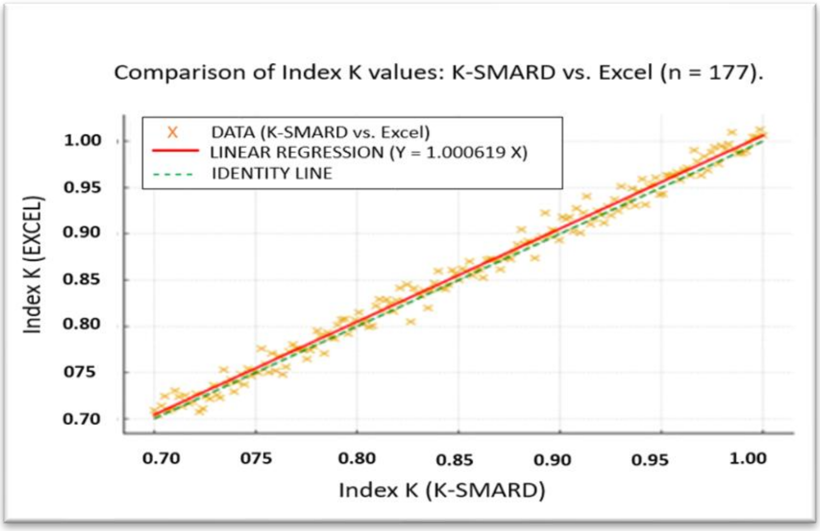

Figure 1 Visualization of the comparison of the K-Index results from K-SMARD vs. Excel with the regression line (red) and the identity line y=x (dotted green). These results show that the two methods are nearly identical, with a slope of ~1.006 and a correlation of $R^2 \approx 0.99$.

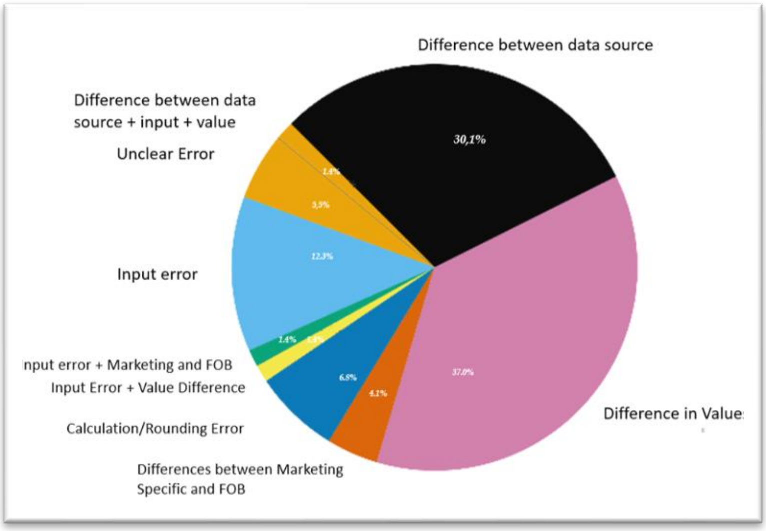

Figure 2 Shows the percentage distribution of 9 error categories

4. CONCLUSION

This study demonstrates that K-SMARD is a valid and reliable digital system for the calculation and reporting of Index K in palm oil mills. The statistical results confirm that there is no significant difference between the outputs generated by K-SMARD and the conventional Excel-based method, indicating that the system is capable of accurately replicating the established calculation framework. The strong linear relationship and minimal deviation further support the robustness and precision of the system. Beyond numerical equivalence, K-SMARD offers substantial operational advantages, including reduced calculation errors, faster processing time, and automated validation features. These improvements enhance efficiency and minimize the risks associated with manual data handling, which has traditionally been a major source of inconsistency in Index K calculations. From a strategic management perspective, the implementation of K-SMARD contributes to improved data standardization, strengthened governance, and more reliable decision-making processes. By providing consistent, transparent, and auditable outputs, the system supports better coordination between palm oil mills, smallholders, and regulatory institutions. This, in turn, helps to reduce potential conflicts and enhances trust among stakeholders. Importantly, the findings of this study provide both empirical and practical justification for adopting K-SMARD as a standardized digital platform for Index K calculation. Its implementation aligns with broader digital transformation initiatives in the palm oil industry, particularly in improving transparency, accountability, and data integration.

Therefore, this study recommends the wider adoption of K-SMARD at both regional and national levels as part of a standardized governance framework. Future research should focus on system integration across institutions, mobile platform development, and the establishment of a unified national database to further support data-driven decision-making and sustainable industry governance.

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