Agroprimatech
Vol.10 No.1 April 2026 *e-ISSN : 2599-3232*



The Impact of Oil Losses on Operational Efficiency and Profitability of Palm Oil Mills: A Systematic Literature Review

Seno Aji

Management Study Program, Adi Wangsa University, Jambi

Email: senostipap@gmail.com

ABSTRACT

Oil losses in palm oil mills (POMs) are commonly treated as a process quality issue, yet their value directly contributes to revenue per ton of fresh fruit bunches (FFB), to costs, and to equipment reliability. The objectives of this systematic literature review are to assess the evidence on (i) the relationship between oil losses and operational efficiency, (ii) how the economic value of losses is calculated and their comparability, and (iii) the strength of the evidence that losses determine profitability. Research Methods A guided open web search using PRISMA 2020 (15 queries, approximately 150 top records) yielded 17 sources that were opened and extracted; quality was assessed using four qualitative items and a narrative synthesis was conducted. The rupiah losses from the three Indonesian case studies were not comparable due to different bases, periods, and CPO prices; only one stated all assumptions. When normalized per ton of FFB, two studies with full assumptions provide comparable values within an order of magnitude (IDR 8,400/ton FFB for excess at the press station; US$ 1.78–1.89/ton FFB for fiber and broken shells above threshold). Efficiency studies (OEE and data envelope analysis) indicate low to moderate mill efficiency, but neither measures concurrent oil losses. Revenue is highly sensitive to OER, while evidence of net profit and recovery economics is thin. Recovered oil quality (free fatty acids) reduces net recovery but is rarely considered. Conclusions: The loss → revenue pathway is robust, loss → efficiency is inferential, and loss → net profit is under-measured. This review proposes a conceptual framework, a uniform reporting basis (tons of FFB), and an integrated field study agenda.

Keywords: oil loss; palm oil mill; operational efficiency; profitability; OEE; systematic literature review

INTRODUCTION

The primary performance indicator for mills has been oil extraction rate (OER), the ratio of crude palm oil (CPO) to processed FFB. Walat and Ng [1] point out its weakness: OER does not indicate where problems lie, leading plantations and mills to

blame each other for deficiencies they may not have control over. They propose the concept of “total oil” (OER plus oil losses) to hold mills accountable for all losses within the mill boundary, provided that each point of loss is measured and independently verified.

The economic value of OER has long been quantified at the macro level. Chang et al. [2] estimated that a 0.31 point decline in Malaysia’s national OER in 1999 cost approximately RM 255 million in lost CPO revenues, and that the 20% margin against the benchmark equated to approximately RM 1.15 billion in an annualized year at an average price of RM 1,449.5/ton. At the mill level, Simeh [3] found that the OER margin and kernel yield were the main revenue generators, increasing revenue per ton of FFB by 20% and 12%, respectively. On the efficiency side, a data envelope analysis (DEA) study of a survey of the Indonesian manufacturing industry showed that palm oil mills were generally inefficient [4–6].

The evidence on oil losses is scattered across three communities that rarely cite each other: (a) process engineering and quality control, which reports losses per station; (b) industrial engineering, which reports OEE, lean, and six sigma; and (c) managerial economics, which reports revenue, costs, and frontier efficiency. As a result, three questions remain unanswered within a single framework: how much are losses worth in dollars and are they comparable across studies; through what pathways do losses affect efficiency; and whether reducing them is financially feasible once recovery costs and oil quality are taken into account.

Research Questions RQ1. What is the evidence that oil loss is related to the operational efficiency of the mill (OEE, downtime, waste, technical efficiency)?, RQ2. How is the economic value of loss calculated, and how comparable are the results between studies?, RQ3. How strong is the evidence that oil loss determines profitability, and what assumptions inform the results? And Novelty. The contributions of this review are stated in limited terms: (i) normalization of loss values from case studies to a single basis (per ton of FFB) for comparability; (ii) pairing the previously separate literature on loss, efficiency, and oil quality into a single conceptual framework (Figure 4) with the strength of evidence per pathway; (iii) illustrative sensitivity analyses whose

assumptions are traceable to official sources and reference prices. This review does not produce pooled estimates because data do not permit this.

METHOD

Design

A systematic literature review guided by PRISMA 2020 and narrative synthesis. Due to heterogeneity in the baseline and the lack of a uniform effect size, no meta-analysis was performed. The protocol was not pre-registered.

Search sources and strategies

The search was conducted on the open web (general search engines and open journal and proceedings repositories), not on Scopus or Web of Science. Fifteen queries were used in two rounds, each filtering the top results (approximately 10 records per query). The first round (8 queries): financial loss per ton of FFB; rupiah oil losses; profit sensitivity to OER; OEE and oil losses; lean and six sigma with cost savings; techno-economic analysis of oil recovery; value stream mapping; and the impact of oil losses on profitability (Indonesian). The second round (7 queries): DEA of mill efficiency; technical efficiency and profitability of mills; economic analysis of empty fruit bunch oil recovery; fruit ripeness and losses; free fatty acids and price discounts; NIR loss monitoring; and cost-benefit analysis of oil recovery from sludge. The search was conducted in November 2026.

Selection criteria

Sources were included if they (i) concerned PKS or FFB processing, (ii) reported oil loss values, operational efficiency measures, loss-related oil quality, or related economic values, and (iii) were accessible and readable. Theses, vendor releases, and blogs were excluded from the synthesis; EFB studies for compost, briquettes, or bioethanol were excluded because they did not address oil loss.

Extraction and quality assessment

One reviewer (an AI assistant under the author's supervision) recorded bibliographic citations, basis of calculation, period, CPO price, and key figures from each source opened. The quality of evidence was assessed qualitatively on four points: (1) basis

of calculation stated, (2) price or price assumption stated, (3) internal consistency of figures, and (4) type of publication. Reading depth (full text, partial, or abstract only) is recorded in Appendix A.

Selection flow

Table 1. Study selection flow (adapted from PRISMA 2020; notes not duplicated)

Stage	Amount
Top records filtered from 15 queries	≈150
Pages opened for reading	18
Unreadable (binary file)	1
Sources extracted and inserted	17
Additional non-synthetic sources (official reference prices)	1

Reasons for exclusion at the title and excerpt stage were not recorded per note; this is an acknowledged limitation (Section 5.3).

RESULTS AND DISCUSSION

Each result is discussed directly below. Figures are taken from open sources; author counts are labeled.

Characteristics and quality of the corpus

Results

Seventeen sources were extracted: four case studies of losses or losses in plants [7–10], three OEE or lean studies [11–13], three OER economic studies [1–3], three DEA or frontier studies [4–6], one monitoring study [15], one oil quality study [14], one recovery study [16], and one investment study [17]. Ten sources were read in full text, two in part ([1] and [6]), and five from abstracts. Table 2 summarizes the quality assessment.

Table2. Qualitative quality assessment of primary sources

No.	Basis of calculation	Price	Consistency	Type	Reading depth
[1]	n/a	n/a	n/a	Technical bulletin	Page snippet
[2]	Yes (national)	Yes	Not yet rated	Journal	Abstract
[3]	Yes (per ton of fresh fruit bunches)	Not in the abstract	Not yet rated	Journal	Abstract
[4]	Yes (production value)	n/a	Yes	Journal	Full
[5]	Yes	n/a	Not yet rated	Journal	Abstract
[6]	Yes (panel)	n/a	Yes	Journal	Partly (≈52%)
[7]	Yes	Yes	Yes	Journal	Full
[8]	Part	Yes	No (three values)	Journal	Full
[9]	Part	Yes	No (unit, total)	Journal	Full
[10]	Yes	Yes	Partial (scenario label)	Journal	Full
[11]	n/a	n/a	Part (year)	Journal*	Full
[12]	n/a	n/a	Partial (component count)	Proceedings	Full
[13]	n/a	n/a	Partial (34 vs 31 activities)	Journal	Full

No.	Basis of calculation	Price	Consistency	Type	Reading depth
[14]	Yes	n/a	Partial (summary vs results)	Journal	Full
[15]	n/a	n/a	Not yet rated	Journal	Abstract
[16]	Yes (% recovery)	Not in the abstract	Not yet rated	Journal	Abstract
[17]	Yes	Yes (US$ 369/ton)	No (parameter)	Journal	Full

Note: n/a, not applicable. *Year and journal name [11] are not listed on the opened page.

The corpus is small and skewed toward local case studies. Only three sources are based on sectoral or national data [2, 4, 6], while sources of per-station losses are almost exclusively single-plant studies. Consequently, any conclusions about Indonesia's loss rates should be read as a range of cases, not a population estimate. Consistency assessments also reveal systemic reporting quality issues: of the eleven sources for which consistency could be assessed, only three were free from demonstrable inconsistencies [4, 6, 7]. This is important because inconsistent figures are often requoted without verification.

Reported rupiah losses: real, but not comparable across studies

Three Indonesian case studies assessed losses in rupiah. At a 30 ton FFB/hour mill, Ranika et al. [8] found an average of 1.189% of the boiling water (standard 1%), 3.166% of the empty bunches (3%), 4.404% of the pressed pulp (5%), and 1.162% of the final sludge (1%), with a sigma level of 3.46 (DPMO 24,800.96) (Figure 1). The November 2022 empty bunch loss was assessed at IDR 61,416,002 from 4,241 kg of oil at IDR 14,448/kg. Putri et al. [7] reported losses at the press station of 4.05–4.12% against a standard of 4.0%; A 0.07% excess at 9,000 tons of FFB per month (30 tons/hour × 12 hours × 25 days) translates to 6.3 tons of oil or Rp 75.6 million per month at Rp 12,000/kg. Manalu et al. [9] estimated losses in sludge separator unit wastewater at 45–58 kg per month, approximately Rp 0.57–0.62 million per month.

Outside Indonesia, Chucheep et al. [10] in Thailand estimated losses of US$ 32,058–44,853 per month across four capacity scenarios and fiber and broken shell losses.

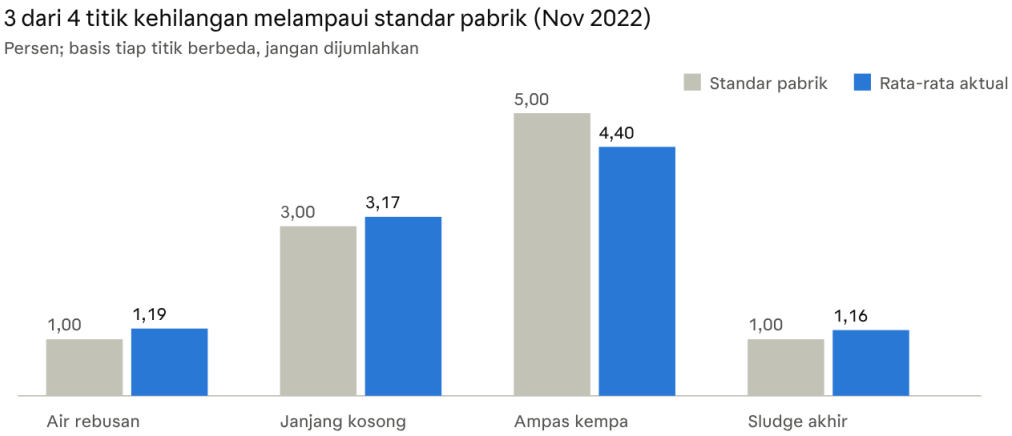


Figure 1. Average oil loss against factory standard, November 2022 (data from Ranika et al. [8]); the basis for each point is different so they are not summed.

By dividing monthly losses by capacity, two studies that state capacity can be compared: Putri et al. [7] found Rp 8,400 per ton of FFB (Rp 75,600,000 / 9,000 tons; excess over standard at press stations), and Chucheep et al. [10] found US$ 1.78–1.89 per ton of FFB (US$ 32,058 / 18,000 tons to US$ 44,853 / 23,760 tons; fiber above 4% threshold and broken shell above 10% threshold). The two figures are not converted to each other due to different exchange rates and prices, but both indicate that the excess over threshold is worth on the order of Rp 8,400 or US$ 1.8 per ton of FFB.

The range from hundreds of thousands to tens of millions of rupiah per month stems primarily from differences in what is assessed (a single point of loss, partial points, or excess over the standard), not from differences in performance. The CPO prices used are also different (Rp 10,571–12,613/kg in [9], Rp 12,000/kg in [7], Rp 14,448/kg in [8]). Excess over the standard [7] and total loss at one point [8] answer different questions: the first “how much can be saved”, the second “how much is lost”. Interestingly, [10] uses the same logic as [7], namely only calculating excess over the threshold, and therefore the two are most comparable. This supports the reporting proposal: determine the threshold, calculate excess, divide by tons of FFB.

The quality of the calculations is noteworthy. Ranika et al. [8] contain inconsistent figures (abstract Rp 61,280,276, content Rp 61,416,002, product 4,241 × 14,448 = Rp

61,273,968), and Manalu et al. [9] contain unclear volume units and differing November totals between the table and the conclusion, leading both to be read as orders of magnitude. In [10], the label for scenario D in the table appears incorrect, and the oil price is stated as semi-crude while the text also refers to CPO. Only [7] states all assumptions and can be repeated without correction. Implications for managers: local study rupiah figures are useful for attracting attention, but should not be used as benchmarks across mills without a uniform basis.

Operational efficiency: low efficiency, but not measured together with losses

Wardani and Nugroho [11] reported OEE of sterilizers of 54.63%, threshers of 43.77%, and presses of 58.88% in one PKS in Jambi, with breakdowns being the largest loss. Saleh et al. [12] reported OEE of boiler stations of 27.03% against a world-class benchmark of 85%, with availability of 52.41%, performance of 55.93%, and quality of 95.05% (Figure 2). Armijal et al. [13] mapped 34 CPO production activities: 50% value-added, 8.82% non-value-added, and 41.18% necessary but non-value-added; proposed improvements reduced lead time from 22,141 seconds to 17,893 seconds (a 19.2% decrease) and increased process cycle efficiency from 55% to 68%. At the sector level, Stephanie et al. [4] used DEA on 137 PKS from the 2010 industrial survey: 26 plants (18.98%) were efficient and had an average score of 0.589; about 59% of plants were on decreasing returns to scale. Islamiya et al. [6] used stochastic frontier analysis on 457–654 firms per year (2010–2014): average technical efficiency was 0.789–0.853 and average total factor productivity growth was −5.19% (2010–2014). Anam and Suhartini [5] reported that allocative efficiency and fixed costs were low nationally in the 2015 data.

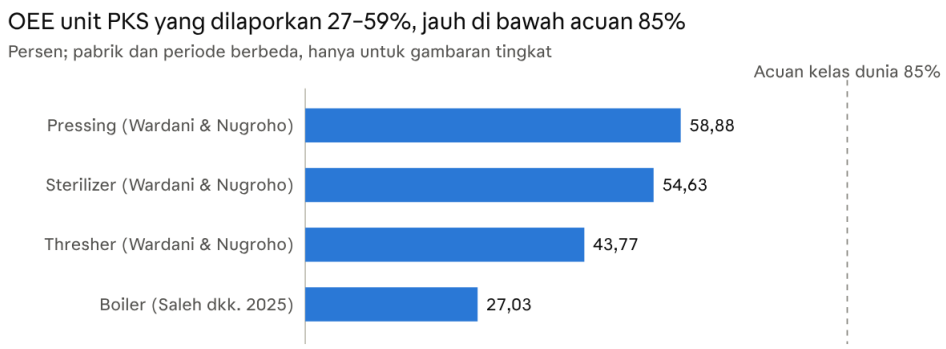


Figure 2. OEE of PKS units reported against the 85% benchmark (Wardani and Nugroho [11]; Saleh et al. [12]); different plants and periods, for level illustration only.

The most important finding is a gap: none of the OEE, lean, or DEA studies measure oil losses alongside efficiency. DEA studies [4,5] use CPO production or output as output, so oil losses are only reflected implicitly; OEE studies [11,12] measure machine availability, performance, and quality without correlating them with losses at the same station. Therefore, the loss → efficiency path (RQ1) can only be inferred.

The inference makes mechanistic sense. Boilers available only about 52% of the time [12] limit steam to boiling, while boiling water and empty bunches, two points dependent on boiling, exceed standards in [8]. However, this is a hypothesis, not a source finding, and the reverse is also possible: downtime and uneven machine loading degrade process quality and thus increase losses, so OEE and losses can reinforce each other without either being the sole cause. The DEA pattern that most plants are on decreasing returns to scale [4], and that negative productivity growth is primarily due to technical change [6], suggests that the efficiency problem is structural, not simply a matter of single-station losses. The DEA data used are from 2010–2015, so they do not reflect current conditions.

There are three quality concerns. First, the OEE component in [12] when multiplied (0.5241 × 0.5593 × 0.9505) yields approximately 27.9%, not 27.03%; the difference is small but indicates that the figure cannot be used as a precise value. Second, the publication year and journal in [11] cannot be verified from the page opened, and the study period is stated differently in the abstract and body. Third, the result in [13] is a measure of process time, not oil loss; the 19.2% improvement in lead time should not be interpreted as an increase in OER.

Monitoring and quality: loss is not just about quantity

Yap and Abd Manaf [15] constructed near-infrared (NIR) spectrometer calibration curves for residual oil in press fiber, sludge, sterilizer condensate, and empty fruit bunches, allowing for faster monitoring of losses than laboratory methods (the abstract does not report accuracy statistics). Chucheep et al. [10] installed 16 sensors on four sets of digesters and presses (each 25 t/h) and showed that a manual checksheet system introduced delays and inaccuracies; the quoted 10% and 20% savings (US$ 3,206–8,971 per month) were assumed, with the 20% figure borrowed from an offshore wind turbine maintenance study, not measured at the mill. On the quality side, Tan et al. [14] showed that free fatty acids (FFA) at the mill increased from 0.48% at the ramp to 0.72% at the start of the conveyor and 1.22% at the end of the conveyor, with the conveyor being the point of greatest increase; Loose fruit had an average initial FFA of 3.3% which increased to 10.3% by day 6; and even 5% loose fruit oil in the mixture is not recommended as it worsens the oxidation index. Tan et al. also cited that every 20 loose fruits equals a loss of 0.37–0.92% OER (literature figures, not the study results themselves). Tang et al. [16] reported that ultrasonic pretreatment increased oil recovery from wastewater by 42.50% compared to no treatment and their cost-benefit analysis found the process feasible, with no figures in the abstract.

Two important implications. First, the value of salvaged oil is not the same as the value of sold oil: oil from loose fruit or from processes that have held the fruit for a long time carries a higher FFA [14], so discounts or blending can reduce the net value of recovery. Loss economic analyses that simply multiply mass by CPO price [7,8,10] therefore overestimate the recovery value at lower quality conditions. Studies in this corpus do not quantify this penalty, and the discounted FFA prices from contracts are not peer-reviewed. Second, rapid monitoring [15] and sensors [10] are prerequisites for control, but their economic benefits are assumed; the lack of post-installation measurements in [10] means the evidence for sensor benefits is weak. The results of [16] indicate that recovery from waste streams is technically feasible, but without accessible cost figures, its economic feasibility cannot be reassessed.

Additional value loss: illustrative sensitivity

With the capacity, working hours, and prices stated by Putri et al. [7], and 12 months of operation as the authors' assumptions, the mill processes 108,000 tons of FFB per

year. Each additional 0.1 percentage point of FFB lost translates to 108 tons of oil per year (1 kg per ton of FFB), worth approximately IDR 1.3 billion at IDR 12,000/kg and IDR 1.14–1.56 billion at the price range of IDR 10,571–14,448/kg used [8,9] (Figure 3a). This calculation is consistent with [7]: 0.07 points × 9,000 tons = 6.3 tons = IDR 75.6 million per month. As a comparison based on official reference prices, the average Malaysian CPO price is RM 4,179.50/ton in 2024 and RM 4,292.50/ton in 2025 [18]; At that price, 108 tonnes is worth approximately RM 0.45–0.46 million per year (Figure 3b). Indonesian domestic prices can vary due to export levies and taxes, so the Rp and RM figures are not converted.

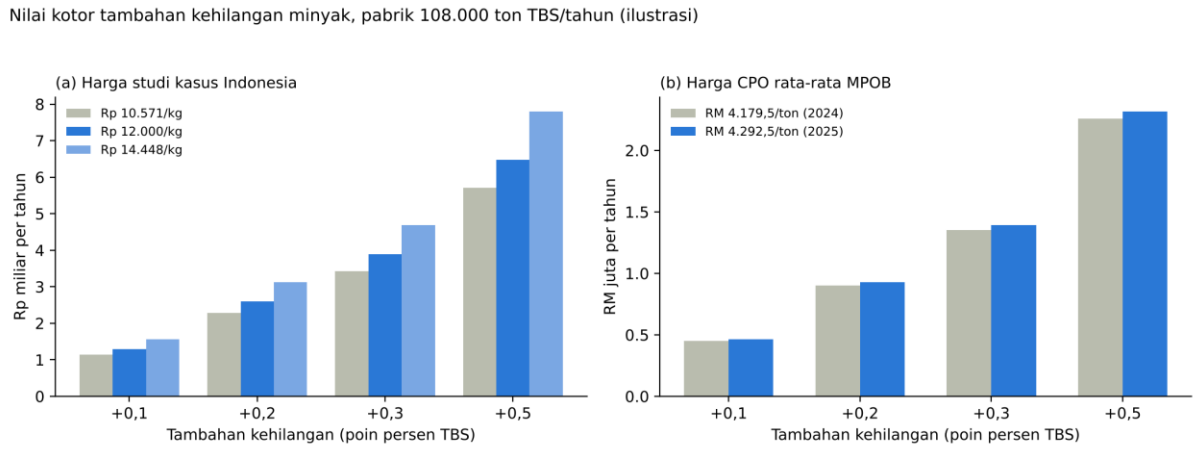


Figure 3. Gross value of additional oil losses for a 108,000 ton FFB/year mill (illustration): (a) prices from the Indonesian case study [7–9]; (b) average CPO price of MPOB 2024–2025 [18].

This value is gross, not profit; it excludes the costs of achieving loss reduction, taxes, and changes in the quality of recovered oil (Section 3.4). The linearity is also assumed; in practice, the marginal cost of reducing losses rises sharply to near zero. However, there is a strong economic argument: FFB has already been purchased and most processing costs have already been incurred, so salvaged oil adds to revenue at a variable cost much smaller than its price (the author's reasoning, not the source's findings). Therefore, the marginal margin of salvaged oil is much higher than the average margin per ton of FFB, and small, recurring losses are substantial. The price gap (approximately ±15% in Figure 3a) illustrates why comparing rupiah across periods without standardizing prices is misleading.

Profitability: evidence of strong revenue, evidence of profit and a slight economic recovery

Simeh [3] studied a single mill for 30 months: the difference between OER and core yield drove revenue per ton of FFB up by 20% and 12%, respectively, OER decreased by 0.27% per month and core yield by 0.22% per month, cost variation per ton was driven by maintenance and depreciation, and higher FFB receipts lowered the cost per ton. Chang et al. [2] showed at the national level that a 1.4 point OER difference against the 20% benchmark equates to approximately RM 1.15 billion per year. On the investment side, Nur Chairat et al. [17] evaluated five boiler scenarios at a mill in Indonesia: the refurbished option at 48, 51, and 58 tonnes of FFB/hour gave NPVs of US$ 6.7, 8.3, and 9.5 million, IRRs of 18%, 19%, and 21%, and paybacks of 4, 4, and 3 years, respectively, at a CPO price of US$ 369/ton; a 10% increase in revenue increases the best-case NPV to US$ 10.5 million.

The evidence points to two profitability pathways. The revenue pathway is clear: each OER point directly contributes to revenue per ton of FFB [2,3]. The cost pathway is more indirect: the cost per ton is determined by maintenance, depreciation, and capacity utilization [3], and results [17] show that higher processing capacity (58 versus 48 tons/hour) increases both NPV and IRR for the same boiler choice. This means that oil losses and downtime likely hit profits in a double-edged sword, but neither source measures the elasticity of net income to losses (RQ3).

There are three limitations. First, [17] is a study of boilers, not oil recovery, so the impact of losses on profits can only be read analogously; the loan parameters, taxes, and scenario assumptions in [17] are inconsistent between the text and the tables, so the figures are used for illustrative purposes. Second, [3] is only for one plant and was published in 2002, and [2] is based on national averages. Third, this corpus does not contain any peer-reviewed NPV or payback analyses for PKS oil recovery investments (e.g., three-phase decanters or empty fruit bunch presses) with verifiable figures; claims of quick payback in vendor posts and blogs are not included. Consequently, the claim that reducing losses is “always worth it” is not supported by open evidence.

Synthesis: conceptual framework and strength of evidence per pathway

Figure 4 summarizes the tested relationships. The path loss → revenue per ton of FFB is supported by direct measurements [2,3]. The path loss → operational efficiency is

only inferential [11–13]. The path loss → recovered oil quality is supported by quality studies [14] but is not linked to economic value. The path to net profit has not been measured [3,17].

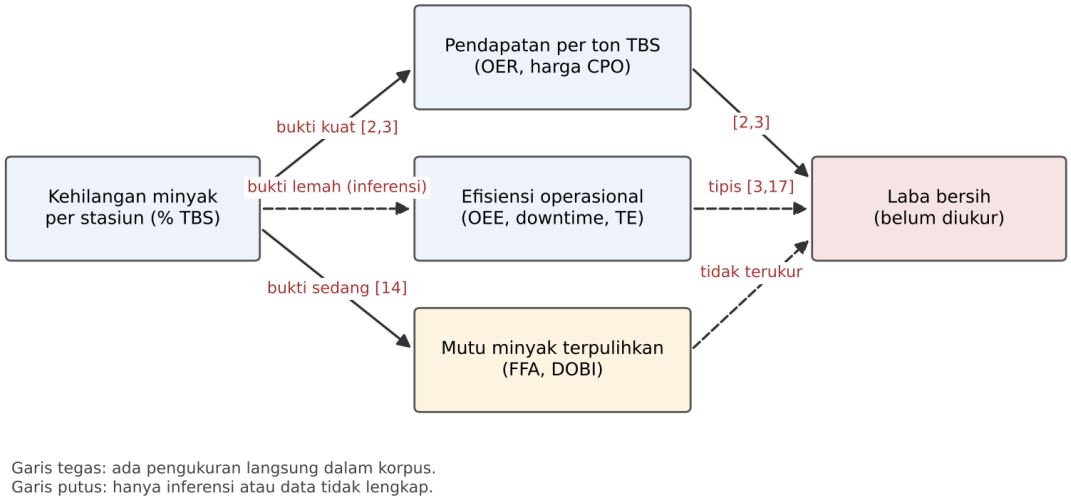


Figure 4. Conceptual framework and strength of evidence per pathway, compiled by the authors from the review corpus.

This framework is descriptive, not a causal model to be tested. Its value lies in showing where the evidence stops: three of the six relationships rely on inference or incomplete data. For RQ1, the evidence remains a mechanistic correlation; for RQ2, comparisons are only feasible after normalization per ton of FFB; for RQ3, the largest determinants of yield are CPO price, recovery costs, and oil quality, which are not present in any of the studies. The authors' proposed mechanism, that losses and downtime erode profits through both revenue and costs, is a hypothesis worth testing with mill-level panel data.

CONCLUSION

Open evidence suggests that oil losses in palm oil mills are substantial and consistently above standard levels, but their quantitative relationship to efficiency and profitability remains unproven. For RQ1, the OEE and DEA studies found below-standard or moderate efficiency, but did not measure oil losses, making the relationship a mechanistic inference. For RQ2, the rupiah losses from the case studies are not comparable due to different bases, periods, and CPO prices; normalization per ton of FFB allows for an order-of-magnitude comparison of the two studies with full

assumptions. For RQ3, revenue is highly sensitive to OER, and the authors' illustration suggests approximately 108 tons of oil per year (approximately IDR 1.3 billion) for every 0.1 percentage point of FFB at a 30 ton/hour mill, but evidence of net profit and economic recovery is not yet available. A valuable next step would be an integrated field study that measures losses, OEE, oil quality, and costs simultaneously.

BIBLIOGRAPHY

Walat O, Ng SB. Palm oil mill OER and total oil losses. Palm Oil Engineering Bulletin. 2013;(108):11–16.

Chang LC, Abdul Rahim AS, Zainon B. An economic perspective of oil extraction rate in the oil palm industry of Malaysia. Oil Palm Industry Economic Journal. 2003;3(1):25–31.

Simeh MA. Factors influencing fluctuations in net returns from the processing of oil palm fruit bunches. Oil Palm Industry Economic Journal. 2002;2(1):28–33.

Stephanie H, Tinaprilla N, Rifin A. Efficiency of palm oil mills in Indonesia. Indonesian Agribusiness Journal. 2018;6(1):27–36.

Anam MK, Suhartini S. Efficiency of palm oil companies in Indonesia: a DEA approach. Habitats. 2020;31(2):55–63. https://doi.org/10.21776/ub.habitat.2020.031.2.7

Islamiya HAT, Sari DW, Yasin MZ, Restikasari W, Shaari MS, Susandika MD. Technical efficiency and productivity growth of crude palm oil: variation across years, locations, and firm sizes in Indonesia. Economies. 2022;10(12):303. https://doi.org/10.3390/economies10120303

Putri FP, Ariani T, Hairiyah N, Nuryati, Amalia RR, Lestari E. Analysis of oil loss at press stations in palm oil mills using the Fault Tree Analysis (FTA) method. Journal of Agro-Industrial Technology. 2026;13(1):249–264.

Ranika AP, Meutia S, Irwansyah D. Analysis of oil loss control in crude palm oil (CPO) using the six sigma method. Industrial Engineering Journal. 2023;12(2):68–74. https://doi.org/10.53912/iej.v12i2.1137

Manalu IS, Sibuea SR, Novarika W. Potential economic losses due to oil loss in liquid waste in the sludge separator unit at PTPN IV Adolina Perbaungan Plantation. Main Engineering Bulletin. 2023;18(3):296–302.

Chucheep T, Mahathaninwong N, Limhengha S, Suvonvorn N. Development of sensor monitoring for loss reduction analysis in palm oil extraction process. South African Journal of Industrial Engineering. 2025;36(1):66–78. https://doi.org/10.7166/36-1-3122

Wardani EP, Nugroho WPS. Analysis of the calculation of Overall Equipment Effectiveness (OEE) values in three CPO processing processes and analysis of six big losses in the palm oil mill of PT Bukit Barisan Indah Prima (BBIP) Palm Group. Diponegoro University (Industrial Engineering Online Journal; year of publication not listed on the opened page).

Saleh N, Rohani JM, Burhani NRA, Yasir PM. System of predictive maintenance in palm oil mill. Proceedings of the 6th Asia Pacific Conference on Industrial Engineering and Operations Management, Bali, 5–7 August 2025:461–474. https://doi.org/10.46254/AP06.20250115

Armijal, Marta A, Patrisina R, Hasan A, Amrina E. Waste evaluation in crude palm oil (CPO) production using lean manufacturing approach. Journal of Industrial Engineering Systems. 2025;27(1):47–56.

Tan BA, Nair A, Zakaria MIS, Low JYS, Kua SF, Koo KL, et al. Free fatty acid formation points in palm oil processing and the impact on oil quality. Agriculture. 2023;13(5):957. https://doi.org/10.3390/agriculture13050957

Yep AKC, Abd Manaf FY. Application of NIR spectrometer for oil loss monitoring in palm oil mill. Journal of Oil Palm Research. 2014;26(1):84–95.

Tang YM, Tan KT, Wong LP. Valorization of palm oil mill effluent via enhanced oil recovery as an alternative feedstock for biodiesel production. Water Science and Technology. 2023;88(6):1404–1416. https://doi.org/10.2166/wst.2023.264

Nur Chairat AS, Abdullah L, Caswito A, Pangestu GA, Kefli MH, Md Fauadi MHF, et al. Evaluating financial viability of boilers in palm oil mills under processing capacity variability: a case study approach. Business, Management and Economics Engineering. 2026;24(1):1–16. https://doi.org/10.3846/bmee.2026.23679

Malaysian Palm Oil Board. Overview of the Malaysian oil palm industry 2025. Bangi: MPOB; 2026. https://bepi.mpob.gov.my/images/overview/Overview2025.pdf