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# Determining The Dynamics of The Petroleum Buffer Reserve of Indonesia

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**ABSTRACT** - This study develops an integrated system dynamics and probabilistic Monte Carlo simulation framework to evaluate Indonesia's Petroleum Buffer Reserve (PBR) strategy in alignment with Perpres 96/2024 and the nation's broader energy security agenda. Monte Carlo simulation results reveal that only the scenario characterized by full import availability is capable of achieving the mandated 10.17-million-barrel reserve target, while all other scenarios consistently fail to accumulate sufficient stock under uncertainty. The probabilistic analysis further shows that this scenario yields a probability exceeding 98% of meeting or surpassing the target, in contrast to the near-zero success rates observed under restricted import conditions. Days-of-cover optimization highlights an additional strategic vulnerability: the current PBR target corresponds to only about 12 days of crude import protection. Building on the system's dynamic behavior, this study recommends a minimum reserve target of 30 days as an immediately achievable benchmark. A 60-day reserve is identified as a feasible medium-term objective, provided that replenishment rates and storage capacity are enhanced. Achieving a 90-day reserve, consistent with international strategic stockpiling standards, would require substantial investment and diversification of supply sources. These findings underscore Indonesia's structural dependence on imported crude oil and emphasize the need for assertive replenishment policies to strengthen national energy resilience

**Keywords**: system dynamics; petroleum buffer reserve; energy security; monte carlo simulation; import dependence.



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## INTRODUCTION

The global energy landscape is increasingly volatile, driven by supply chain disruptions, geopolitical shocks, and uncertainties in demand. For resource-importing countries like Indonesia, the establishment of a robust petroleum buffer reserve is no longer optional but a strategic imperative. Indonesia has responded through its Petroleum Buffer Reserve (PBR) policy, mandating the accumulation of a petroleum buffer of 10.17 million barrels by 2035, with implementation subject to the country's financial capacity and national budget constraints. Within this framework, the Ministry of Energy and Mineral Resources has announced that the buffer will be located near existing refinery complexes, enhancing logistical efficiency and strategic resilience in accordance with Decree of the President of the Republic of Indonesia Number 96 of 2024 (Perpres 96 2024).

Despite this policy commitment, significant gaps remain in the academic and operational literature (Ainuddin & Suryadilaga 2021; Ariyon et al., 2025; Rakhmanto et al., 2025). First, most prior studies emphasize deterministic reserve accumulation projections without adequately modelling import variability or supply-chain risk (Prima et al., 2025). Second, few analyses integrate system dynamics modelling with probabilistic simulation to assess the likelihood of achieving national targets under uncertainty (Sy 2023). Third, there is minimal discussion of how different import volume trajectories ranging from conservative to aggressive affect the time needed to build the buffer and the required annual import flows. In short, while the requirement to build a petroleum buffer is well documented, the feasibility, pace, and risk-adjusted performance of alternative reserve accumulation strategies remain underexplored (Mardiana 2023).

This research addresses these gaps by developing a combined methodological framework that couples system dynamics modelling (Azizsafaei et al., 2022; Davahli et al., 2020; Fanta & Pretorius 2023; Guzzo et al., 2022; Lane & Rouwette 2023; Purwosaputra et al., 2022) with Monte Carlo simulation (Betancourt 2019; Buchholz et al., 2021; Fielding 2023; Nemeth & Fearnhead 2021; van Ravenzwaaij et al., 2018) to assess four distinct scenarios of buffer accumulation. These scenarios differ primarily in their annual import volumes ranging from a modest import strategy (slow build-up) to a progressive high-import approach (rapid build-up) (Guo et al., 2023; Mavragani et al., 2018; Patel & Patel 2019; Snyder 2019). The novelty of the study lies in: 1). Explicitly modelling the range of import volumes as scenario parameters; 2). Quantifying probabilistically the time required to meet the 10.17 million-barrel target under each scenario, and 3). Contextualizing results within the Indonesian policy environment of locating the buffer near refineries. By doing so, the study provides not only projection figures but also probability distributions of success, enabling policymakers to evaluate reserve strategies in terms of both magnitude and risk.

The primary research question is:

- RQ 1: Which buffer accumulation scenario is most likely to achieve the 10.17-million-barrel target by 2035, considering differing import volumes and supply uncertainties? Subsidiary questions include:
- RQ 2: How large must annual imports be to reach the target?
- RQ 3: What is the probabilistic risk of failure under each scenario?
- RQ 4: What operational implications do different import strategies have for national energy security?

The implications of this research are broad. Policymakers in the Indonesian government, energy regulators, refinery operators, and strategic planners can benefit from better understanding of how import strategies influence buffer build-up timelines and risk exposure. The framework is also useful for international bodies supporting energy security in import-dependent nations, as it provides a replicable methodology and evidence -based results.

Nevertheless, the study carries several limitations. The analysis focuses on crude-oil import volumes and does not explicitly model downstream refinery output, alternative fuels, or global oil price shocks beyond a simplified import-volume variability. Moreover, the system dynamics model is calibrated using publicly available data and expert assumptions, which may limit precision at the site-specific level near refineries. While the Monte Carlo simulation models input variability, it does not incorporate extreme tail events (black swans) in full detail. Future research should extend the model to include multi-fuel buffers, detailed refinery throughput constraints, and integrated economic modelling of import cost burdens.

In sum, this study contributes to the literature by bridging deterministic reserve modelling, import-flow analysis, and probabilistic simulation in a policy-relevant context. It offers decision-makers practical insights into the trade-offs between import volume, buffer build-up rate, and risk of failure—all framed within Indonesia's evolving energy security policy of building the buffer near existing refineries. Beyond its methodological contribution, this study is also motivated by Indonesia's increasingly vulnerable energy position. As a net importer of crude oil, Indonesia faces structural exposure to geopolitical disruptions, supply chain bottlenecks, and fluctuations in international crude prices(Vlăduţ et al., 2024). The absence of a sufficiently sized petroleum buffer reserve magnifies these risks, leaving the national energy system highly sensitive to short-term shocks. Building a reserve near refinery sites, as proposed by the government, promises shorter logistical distances, reduced transportation risk, and improved emergency response times. However, the success of this initiative depends on a clear understanding of how rapidly the reserve must be accumulated, how much oil must be imported annually, and how uncertainty could either accelerate or delay achievement of the target. Such considerations highlight the importance of quantitative approaches like system dynamics and Monte Carlo simulation in guiding national strategy(Suo et al., 2021). Furthermore, existing literature often focuses on long-term energy planning but rarely integrates explicit scenario differentiation based on import intensity(Rokicki et al., 2023). In contrast, this study demonstrates that import volume is not merely an operational variable but a strategic lever that determines whether national reserve goals can be achieved at all(Sokhanvar & Bouri, 2023). Scenarios with low import volumes may appear fiscally attractive, yet they systematically fail to reach the mandated target—even under favourable assumptions. Conversely, higher-import scenarios impose larger short-term costs but dramatically increase the probability of achieving the CPE target on schedule. This insight highlights a critical policy trade-off: the balance between financial constraints and the strategic benefits of rapid buffer accumulation. By quantifying this trade-off, the study provides policymakers with a more nuanced basis for decision-making than traditional deterministic projections(Sadiyah et al., 2021).

Another important aspect illuminated by this research is the temporal dimension of reserve formation. The 2035 deadline provides a finite window for accumulating the petroleum buffer, making the pace of import-driven reserve growth a central factor. The progressive scenario, characterized by larger annual imports, demonstrates significantly faster reserve build-up and a much higher resilience against year-to-year variations in supply. This suggests that Indonesia may need to adopt a more assertive import strategy during the early years of implementation to ensure that the momentum of reserve accumulation is sufficient to offset future uncertainties. Finally, the findings of this study may be valuable to a wide audience beyond government policymakers. Energy planners, refinery operators, national oil companies, emergency response agencies, financial analysts assessing energy risk, and academic researchers interested in system modelling may all benefit from the methodological and analytical insights presented here. The framework can also support regional bodies such as ASEAN, which are increasingly exploring collaborative energy security measures(Oliveira et al., 2023). By offering a transparent, replicable model for evaluating petroleum reserve strategies under uncertainty, the study encourages evidence-based decision-making at multiple institutional levels.

## METHODOLOGY

This study applies a combined system dynamic modelling and Monte Carlo simulation approach to evaluate the feasibility of achieving Indonesia's national Petroleum Buffer Reserve (PBR) target of 10.17 million barrels by 2035. The methodology consists of three main stages:

- System dynamics modelling,
- Import requirement analysis, and
- Monte Carlo–based probabilistic evaluation.

Additionally, the deterministic outputs allow researchers to understand the structural behavior of each policy pathway before introducing uncertainty. This step is crucial because it establishes the baseline performance of each scenario, ensuring that subsequent probabilistic analysis is grounded in a clear system-level understanding. Moreover, by visualizing the deterministic trends, policymakers gain early insight into whether a given scenario is fundamentally capable of meeting national objectives even before stochastic variability is considered. This deterministic foundation ensures that the subsequent Monte Carlo simulations are applied to scenarios that have been systematically validated in terms of their structural feasibility and policy relevance (Figure 1).

### System dynamics modelling

The first step involves building a system dynamics model (Abdel-Latif et al., 2023) that is used to simulate the annual accumulation of petroleum buffer reserves through stock–flow structures. Four policy scenarios—PBR_01, PBR_02, PBR_03, and PBR_04—are developed to represent different levels of reserve-building strategies. The model runs from 2025 to 2035, following the official time frame of the national Petroleum Buffer Reserve 9PBR) policy. This stage produces deterministic reserve trajectories that form the basis for evaluating how rapidly or slowly each scenario can reach the national target. Furthermore, the dynamic modelling should enable researchers better understand the environment affecting the PBR.

### Import requirement analysis

The second stage assesses the annual import volumes required to support each PBR scenario. Import flows were extracted directly from the system dynamics model outputs and plotted for comparison. This analysis helps determine the operational feasibility of each scenario, since higher reserve accumulation requires larger and more stable crude oil import flows.

### Monte carlo simulation

To incorporate uncertainty, a Monte Carlo simulation was conducted using 50,000 random iterations per scenario. Variability in annual imports was used to generate a distribution of possible 2035 reserve outcomes. Several statistical outputs were produced, including histograms, cumulative distribution functions (CDFs), and boxplots. This stage allows the study to estimate the probability that each scenario can achieve the national reserve target under uncertain future conditions.

### Scenario Comparison

The final step compares the deterministic projections, import requirements, and Monte Carlo results. This comparison identifies which scenarios perform well structurally and which remain feasible when uncertainty is considered. The combined insights support evidence-based recommendations for national PBR policy.

## RESULT AND DISCUSSION

Figure 2 presents the causal loop diagram (CLD) that captures the structural dynamics governing Indonesia's Petroleum Buffer Reserve (PBR) system. The diagram illustrates the feedback mechanisms linking demand, operational inventory, domestic and import supply rates, inventory adjustment behavior, and the activation and replenishment of the strategic buffer. The CLD provides a qualitative foundation for understanding the long-term behavior of the system and forms the basis for subsequent simulation experiments. First, the interaction between Demand, Operational Inventory, and the Inventory Gap constitutes a classical balancing process aimed at maintaining

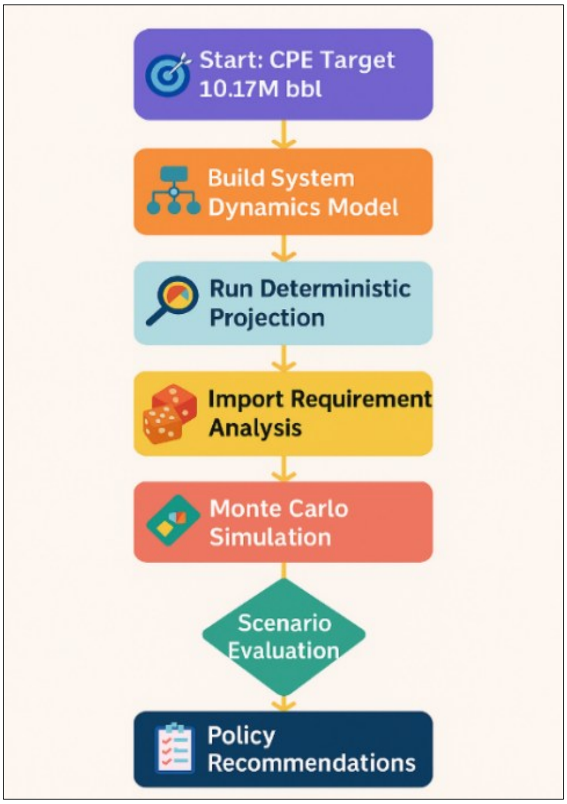


Figure 1. Work of flow

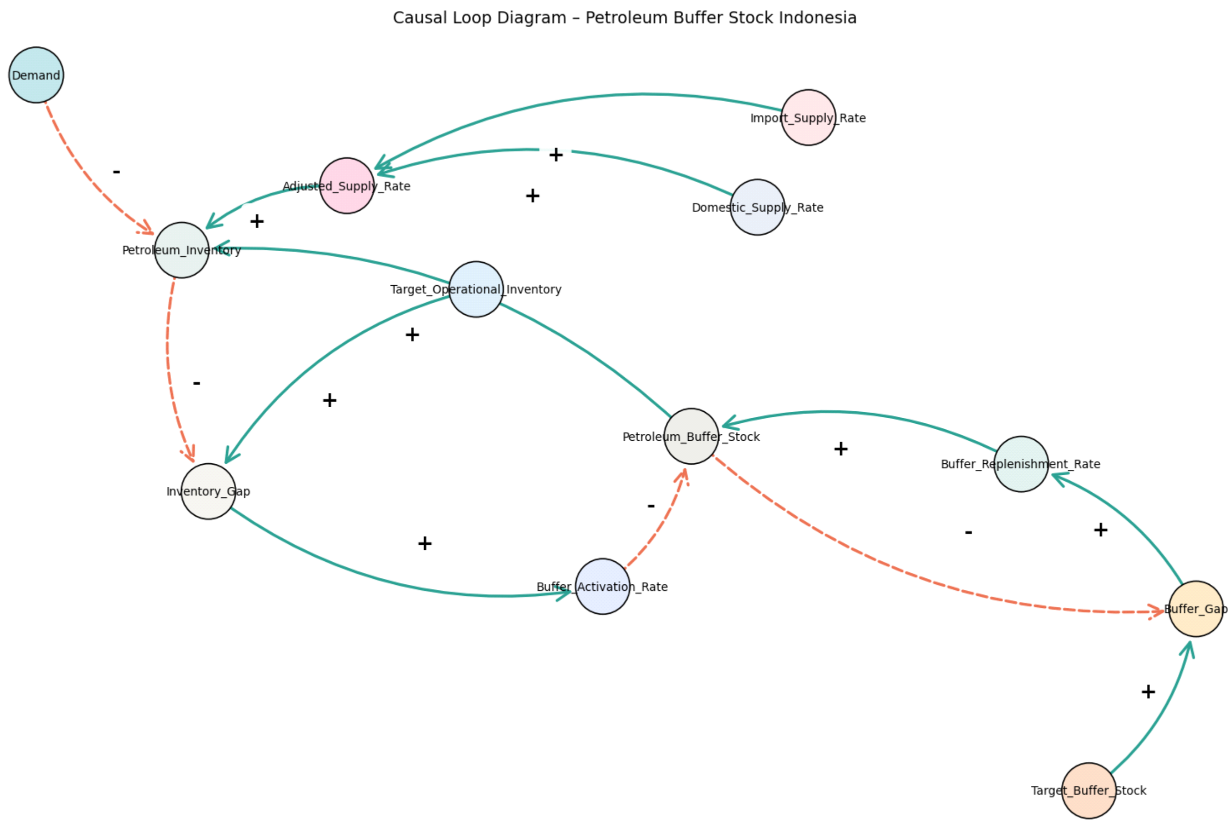


Figure 2.Causal loop diagrams (CLD) illustrating the feedback relationships among the variables of Indonesia's Petroleum Buffer Reserve system.

inventory near the operational target. An increase in demand reduces operational inventory, expanding the inventory gap and triggering higher adjusted supply rates. This expanded supply distributed between domestic production and imports feeds back positively to rebuild inventory. This balancing loop reflects the system's inherent desire to stabilize operational stock levels under normal market conditions.

Second, the model includes an emergency response structure in which the buffer activation Rate serves as a corrective mechanism when the operational inventory falls below its target. A larger inventory gap increases the buffer activation rate, resulting in immediate drawdown of the petroleum buffer stock and partial restoration of operational inventory. Although this feedback loop temporarily stabilizes inventory levels, it simultaneously depletes the strategic reserve, indicating a trade-off between short-term continuity of supply and long-term energy security.

Third, the replenishment of the petroleum buffer is governed by the Buffer Gap, which represents the distance between the actual strategic reserve and the national target (10.17 million barrels, as mandated in the Decree of the President of the Republic of Indonesia Number 96 of 2024. When the buffer gap widens, the system initiates replenishment flows aimed at gradually rebuilding the reserve. This loop behaves as a slow goal-seeking process due to physical and financial constraints associated with acquiring and storing crude oil. The long time constant in this loop reflects realistic policy lags and budgetary cycles, which are consistently reported in international strategic reserve planning literature.

Finally, the CLD highlights the system's dependence on Import Supply Rate as a major source of operational inventory replenishment. Import flows are influenced by adjusted supply requirements as well as external constraints that may reflect geopolitical, logistical, or market-driven limitations. The dominance of this pathway underscores Indonesia's structural vulnerability, as disruptions in import availability directly weaken both operational inventory stability and the ability to rebuild the strategic reserve. This dependency becomes particularly critical in scenarios where domestic production capacity is insufficient to offset fluctuations in external supply.

Overall, the CLD demonstrates that Indonesia's PBR system is driven by an interplay between fast-reacting balancing loops (operational inventory correction and emergency buffer activation) and slower, policy-driven replenishment loops. This combination of short-term and long-term feedbacks creates dynamic behavior that can only be fully understood through simulation. The CLD therefore provides a coherent conceptual map that explains why the strategic reserve may fail to reach the national target under certain conditions, especially when import availability is limited or when demand shocks persist.

The figure 3 illustrates the short-term dynamic response of the petroleum supply system following the initiation of the simulation. The operational inventory begins at approximately 20 million barrels and rapidly adjusts toward the target level of 30 million barrels. This rapid convergence reflects the action of the balancing inventory-control loop, where supply augmentation—through both domestic production and imports—offsets the initial inventory deficit. The speed of adjustment indicates that the system is capable of stabilizing operational inventory relatively quickly under normal supply conditions.

In contrast, the strategic petroleum buffer stock (SPBS) exhibits a much slower and smoother upward trajectory. Starting from an initial stock of roughly 5 million barrels, the SPBS gradually increases as the buffer-replenishment loop responds to the buffer gap. This long-term accumulation trend reflects the extended time delays and constraints associated with building a national reserve, consistent with strategic stockpiling practices observed internationally. The diverging time scales between the inventory and buffer loops highlight the system's dual structure: rapid stabilization of day-to-day operations and slow progression toward long-term energy security objectives.

The figure 4 provides insights into the behavior of the supply flows domestic production, import

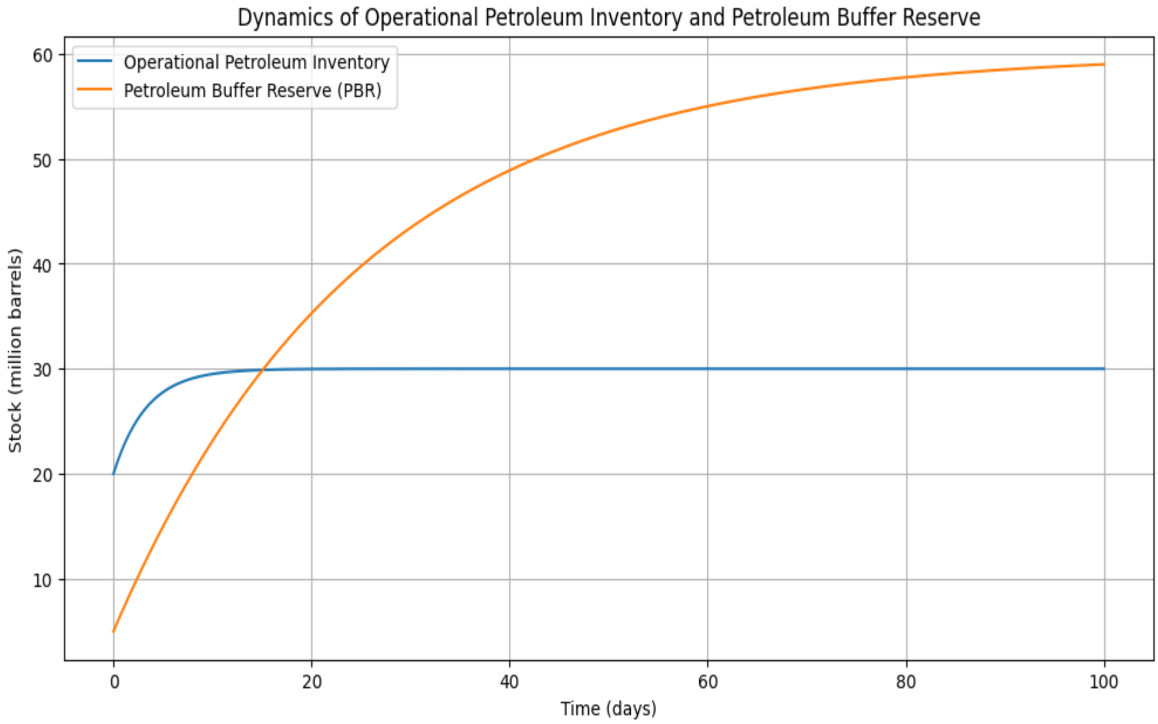


Figure 3. Dynamics of operational petroleum inventory and strategic buffer stock showing rapid stabilization of operational inventory around the policy target and gradual long-term accumulation of the strategic reserve.

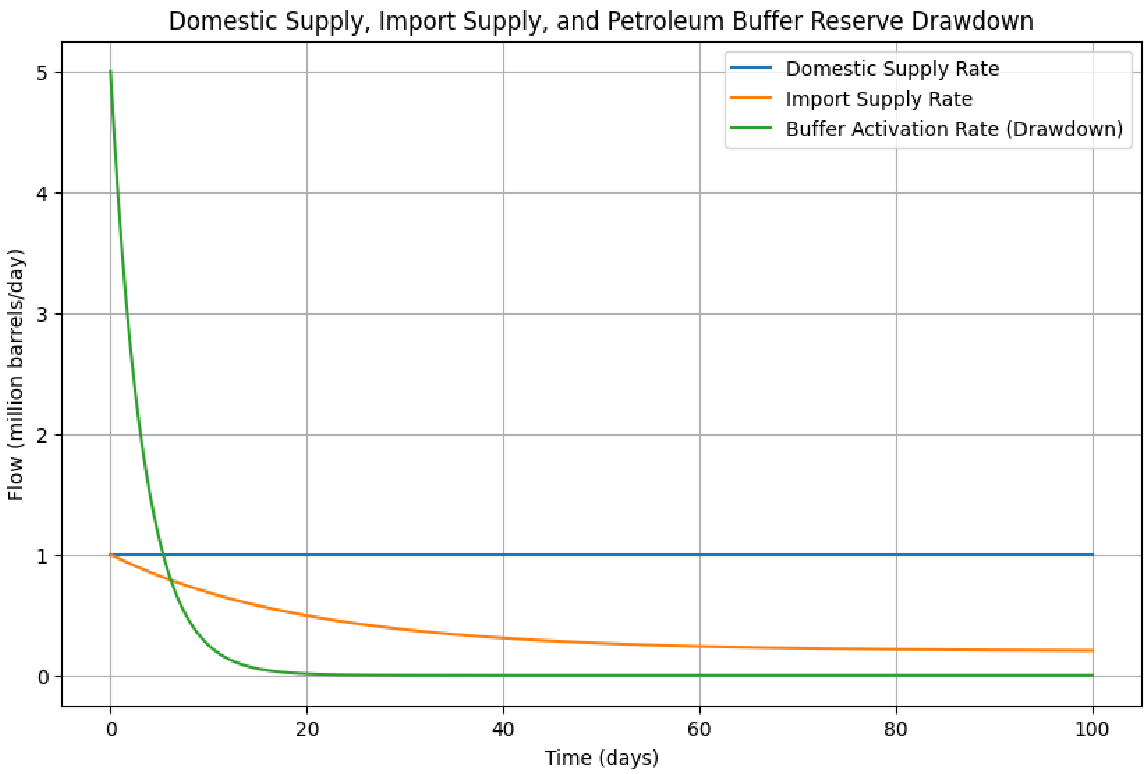


Figure 4. Domestic supply, import supply, and strategic buffer drawdown during the initial system adjustment phase highlighting the dominant role of imports in restoring operational inventory.

supply, and buffer drawdown during the initial adjustment period. Domestic supply remains nearly constant at its maximum capacity of 1.0 million barrels per day, indicating that domestic production alone is insufficient to meet total demand and inventory correction needs. Import supply initially spikes to meet the shortfall caused by a low initial inventory but subsequently declines toward a stable equilibrium as operational inventory converges to its target level.

The buffer activation (drawdown) rate displays a sharp initial peak, driven by the large inventory gap at the start of the simulation. This immediate draw on the strategic buffer reflects the emergency-support role of the SPBS in stabilizing the operational inventory. However, as the inventory recovers and the gap closes, buffer drawdown rapidly diminishes and approaches zero. The combined patterns of these flows emphasize the system's reliance on imports for operational stability and the limited but crucial short-term corrective contribution of the buffer stock.

The Figure 5 presents the same inventory and SPBS trajectories as Figure 1 but emphasizes the long-term behavior across the full 100-day period. The operational inventory remains tightly anchored at the policy-defined target of 30 million barrels, confirming the effectiveness of the inventory-balancing mechanism in sustaining stable supply for ongoing consumption needs. This stability also implies that uncertainties in external supply or fluctuations in demand would primarily impact the system through the buffer stock rather than through operational inventory levels.

The buffer reserve continues to rise throughout the simulation horizon, increasing from approximately 5 million barrels to nearly 58 million barrels. This monotonic growth reflects a scenario with favorable replenishment conditions in which the system is able to accumulate reserves well beyond the national target. The curvature of the buffer reserve growth line demonstrates diminishing marginal increases, which are characteristic of a first-order goal-seeking process with a large stock-adjustment delay. This reinforces the interpretation that while operational inventory responds rapidly, the strategic buffer follows a slower, asymptotic path toward its target level.

The Figure 6 evaluates the sensitivity of the PBR trajectory to variations in import availability, representing 100%, 50%, 30%, and 10% of baseline import capacity. The results demonstrate a strong dependence on import continuity. Under the 100% scenario, the SPBS eventually stabilizes slightly above the policy target of 10.17 million barrels, indicating that full import availability enables the strategic reserve to be built as planned.

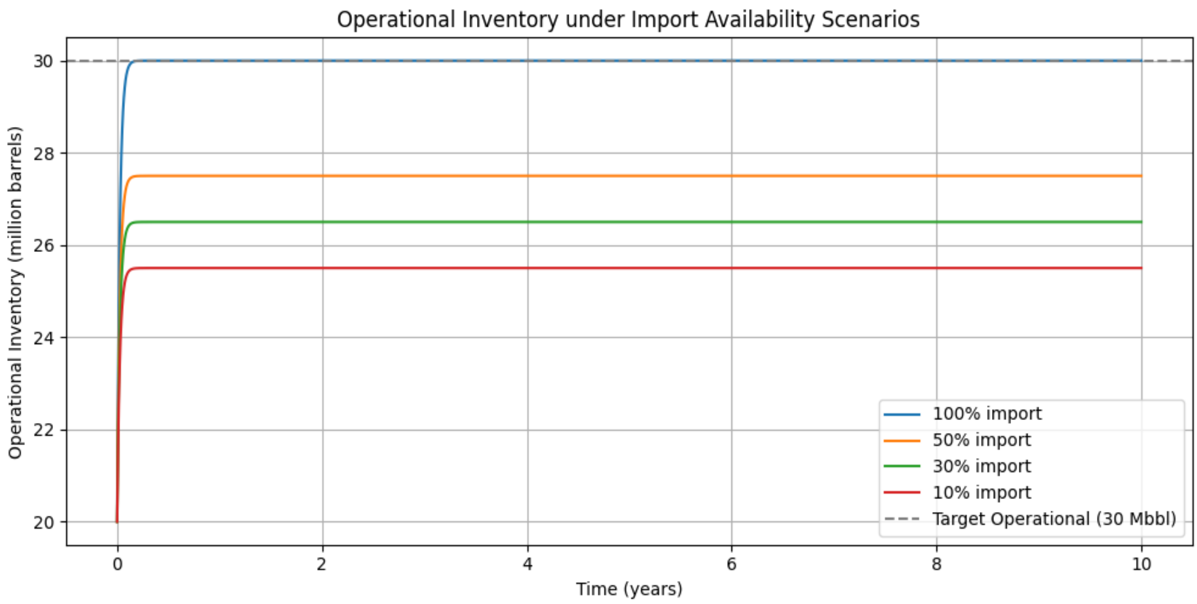


Figure 5. Long-term dynamics of operational inventory and PBR showing the contrasting time scales between rapid operational inventory control and slower goal-seeking behaviour of the petroleum buffer reserve.

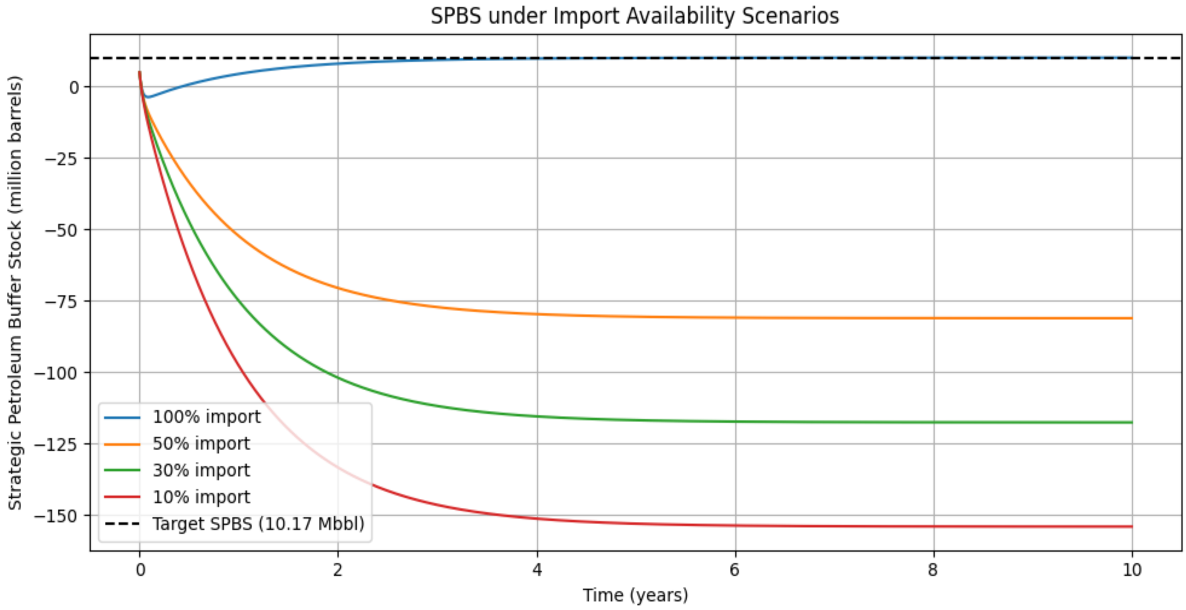


Figure 6. PBR under Import Availability Scenarios illustrating the strong dependence of reserve accumulation on import continuity.

However, even at 50% import availability, the SPBS fails to approach the national target and instead converges to a negative trajectory, indicating continuous buffer depletion.

More severe import constraints, 30% and 10% scenarios, produce increasingly pronounced declines in PBR levels. In the 10% case, the reserve descends rapidly and stabilizes far below zero, indicating complete depletion of the buffer and an inability to sustain emergency drawdowns. These trajectories reveal a structural vulnerability: the national strategic petroleum buffer cannot be accumulated or sustained independently under conditions of significant import disruption. This highlights the critical importance of diversifying supply sources, enhancing domestic production capacity, or revising replenishment policies to ensure the feasibility of meeting the *Perpres* 96/2024 target under realistic geopolitical conditions. The subsequent sections quantify these structural tendencies through deterministic and Monte Carlo simulations.

The fourth figure evaluates the sensitivity of the SPBS trajectory to variations in import availability, representing 100%, 50%, 30%, and 10% of baseline import capacity. The results demonstrate a strong dependence on import continuity. Under the 100% scenario, the SPBS eventually stabilizes slightly above the policy target of 10.17 million barrels, indicating that full import availability enables the strategic reserve to be built as planned. However, even at 50% import availability, the SPBS fails to approach the national target and instead converges to a declining trajectory, indicating continuous buffer depletion.

SPBS levels deteriorate markedly under a more severe import constraints, specifically the 30% and 10% scenario. When imports fall to 10%, the reserve is rapidly exhausted and settles well below zero, signalling total buffer depletion and the loss of capacity to support emergency withdrawals. This shows a structural weakness because the national strategic petroleum buffer is neither buildable nor sustainable when faced with major import disruptions. Therefore, to fulfil the Presidential Decree regulating the Energy Buffer Reserve (CPE) / 2024 target, policy measures that go beyond buffer management alone are required. They include supply diversification, strengthened domestic production, and adjustments to replenishment strategies that reflect realistic geopolitical risks.

From an optimization standpoint, this figure provides a basis for evaluating alternative coverage targets expressed in days of net import. With current imports of 0.848 million barrels per day, the regulatory target of 10.17 million barrels corresponds to only about 12 days of cover, which is insufficient under scenarios with sustained import reductions. To reach 30, 60, or 90 days of cover, Indonesia would require strategic stocks of approximately 25.4, 50.9, and 76.3 million barrels, respectively. The simulations imply that a 30-day coverage target is achievable under moderate import reliability, whereas 60-day or higher coverage would require both more aggressive replenishment policies and structural measures to secure supply. These quantitative benchmarks offer a transparent starting point for optimizing the petroleum buffer reserve in line with international energy security practices while accounting for Indonesia's fiscal and infrastructural constraints. The compact statistical summary presented in the Table 1 highlights clear performance differences among the four reserve-building scenarios evaluated in this study.

Scenario PBR_03 shows the strongest outcome, with a mean of 13.80 million barrels and a broad but consistently high P5–P95 range of 11.07–16.52 million barrels, resulting in a 98.5% probability of surpassing the national target of 10.17 million barrels. In contrast, Scenario PBR_04 demonstrates moderate performance, with a mean of 7.21 million barrels and a narrower range of 5.85–8.55 million barrels, but its probability of achieving the target remains extremely low at 0.03%. Scenarios PBR_02 and PBR_01 perform substantially worse, producing mean values of only 2.40 and 1.40 million barrels, respectively, both with narrow P5–P95 ranges that fall far below the required threshold and resulting in a 0% probability of target achievement. These results collectively reinforce that only the high-import, aggressive strategy represented by PBR_03 provides a feasible and statistically robust pathway for meeting Indonesia's strategic petroleum buffer reserve goals.

Table 1. Monte carlo statistical summary

| Scenario | Mean | P5–P95 Range | Probability ≥10.17 |
|---|---|---|---|
| PBR_03 | 13.80 | 11.07 – 16.52 | 98.5% |
| PBR_04 | 7.21 | 5.85 – 8.55 | 0.03% |
| PBR_02 | 2.40 | 2.02 – 2.78 | 0% |
| PBR_01 | 1.40 | 1.19 – 1.61 | 0% |

To quantify uncertainty associated with future reserve levels, Monte Carlo simulations were performed for the year 2035. The resulting probability distributions are shown in Figure 7. Scenario PBR_03 exhibits a wide yet centered distribution around approximately 14 million barrels, with a very high likelihood of surpassing the national target. Scenario PBR_04 shows a narrower distribution centered around 7–8 million barrels, offering only a small probability of reaching the target. Meanwhile, PBR_02 and PBR_01 present extremely narrow distributions at low values, indicating that these scenarios are statistically incapable of achieving national reserve objectives. The results highlight PBR_03 as the only policy option that maintains a reasonable probability of success. This reinforces the importance of adopting an assertive reserve-building policy to mitigate supply risks and enhance national energy resilience. The strong statistical performance of PBR_03 also suggests that delaying or scaling back import commitments could substantially weaken Indonesia's energy security posture. Moreover, the probabilistic evidence aligns closely with deterministic trends, providing a consistent and compelling basis for selecting PBR_03 as the preferred policy pathway.

To further evaluate scenario variability and distribution characteristics, Figure 8 presents a boxplot summary of the Monte Carlo simulation outputs. The boxplot for Scenario PBR_03 sits well above the national target and shows a tolerable level of dispersion, illustrating consistent performance despite underlying uncertainty. In contrast, the interquartile ranges for Scenarios PBR_04, PBR_02, and PBR_01 fall entirely below the target, with no overlap between their central tendencies and the required reserve threshold. his clear separation between PBR_03 and the other scenarios further demonstrates the robustness of the high-import strategy, even when subjected to stochastic variation.

The probabilistic outcomes reveal a consistent pattern: PBR_03 is the only scenario with a high probability approximately 98.5 percent of reaching or surpassing the national target as the Monte Carlo simulations with 50,000 iterations per scenario were conducted. The probabilistic outcomes reveal

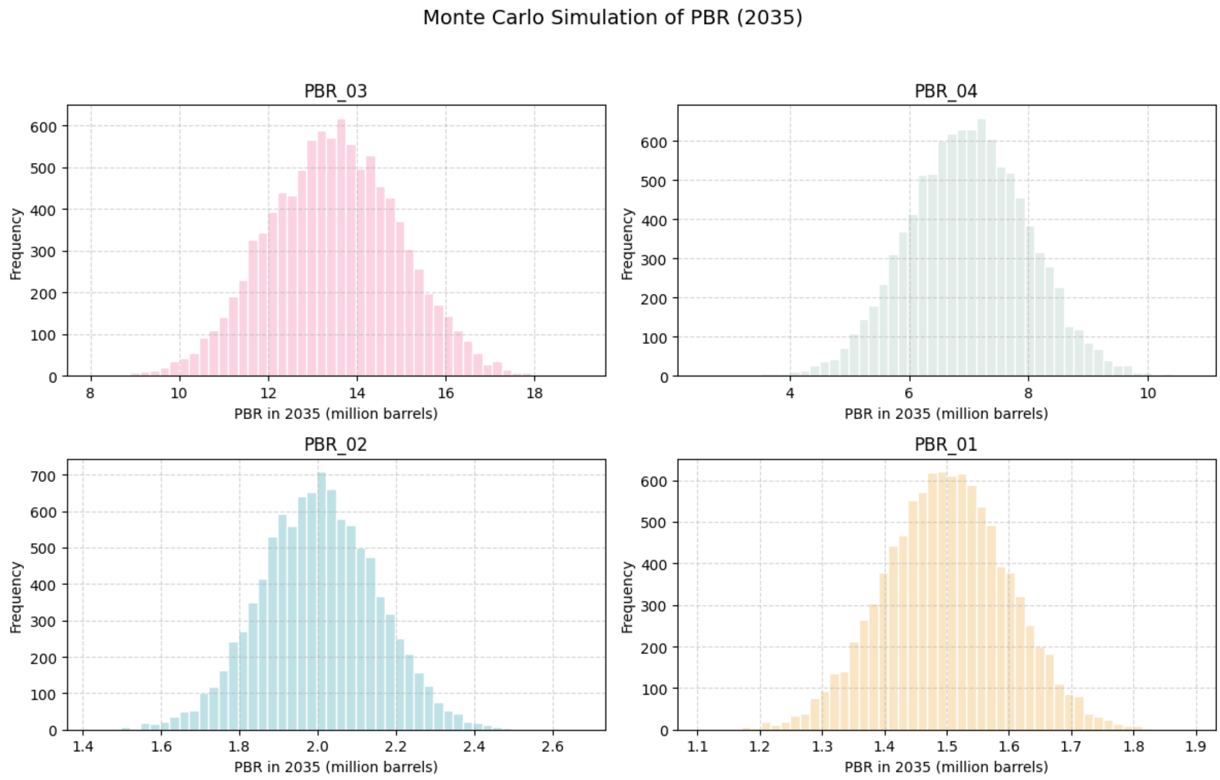


Figure 7.Monte carlo simulation of PBR levels in 2035 obtained from 50,000 Monte Carlo simulation iterations for each policy scenario.

a consistent pattern: PBR_03 is the only scenario with a high probability—approximately 98.5 percent—of reaching or surpassing the national target. The histogram distribution for PBR_03 is centered well above the threshold, while its cumulative distribution function (CDF) confirms that nearly all simulated outcomes exceed 10.17 million barrels. The Cumulative Distribution Function (CDF) presented in Figure 9 provides a comprehensive depiction of the probability that each PBR scenario will reach or exceed a given reserve level by the year 2035.

The three-dimensional surface plot presented in figure 10 provides a comprehensive visual comparison of the Petroleum Buffer Reserve (PBR) growth trajectories across four policy scenarios over the period 2025–2035. By projecting the results onto a 3D surface, the figure captures both the magnitude and the temporal evolution of reserve accumulation, enabling a clear distinction between high-performing and low-performing strategies. The visualization highlights how the structural characteristics of each scenario translate into different reserve growth profiles over time. Moreover, the curvature and gradient of the surface clearly illustrate the sensitivity of reserve expansion to variations in import availability and domestic supply constraints. The figure also reveals the widening divergence between scenarios as the simulation progresses, underscoring the cumulative impact of policy choices on long-term stock outcomes. Overall, this visualization strengthens the analytical interpretation by linking quantitative dynamics with observable patterns in scenario behavior, thereby supporting more robust policy evaluation.

The summary table , as shown in the Table 2, presents a streamlined comparison of key statistical indicators for all four scenarios, with the probability column now explicitly referring to the likelihood of achieving 10.17 million barrels by 2035. Scenario PBR_03 continues to demonstrate exceptional performance, with a mean of 13.80 million barrels and a robust P5–P95 range, resulting in a high 98.5% probability of meeting the national strategic target. Scenario PBR_04, despite yielding moderate reserves, remains far below the required threshold with only 0.03% probability of success. Meanwhile, Scenarios PBR_02 and PBR_01 show extremely small but non-zero probabilities of reaching the target each less than 0.001% reflecting that success under these scenarios is statistically negligible but not strictly impossible. This scenario consistently demonstrates robust reserve accumulation across the entire planning horizon while maintaining a high probability of achieving the mandated stock level under uncertainty.

Collectively, these outcomes reinforce the conclusion that only PBR_03 provides a credible and resilient pathway for meeting Indonesia's Petroleum Buffer Reserve target by 2035(Figure 11). Moreover, PBR_03 exhibits superior adaptability to fluctuations in import availability and fiscal constraints, indicating a structurally sound policy design. As such, it emerges not merely as a technically feasible option, but as the most strategically viable framework for safeguarding Indonesia's long-term energy security.

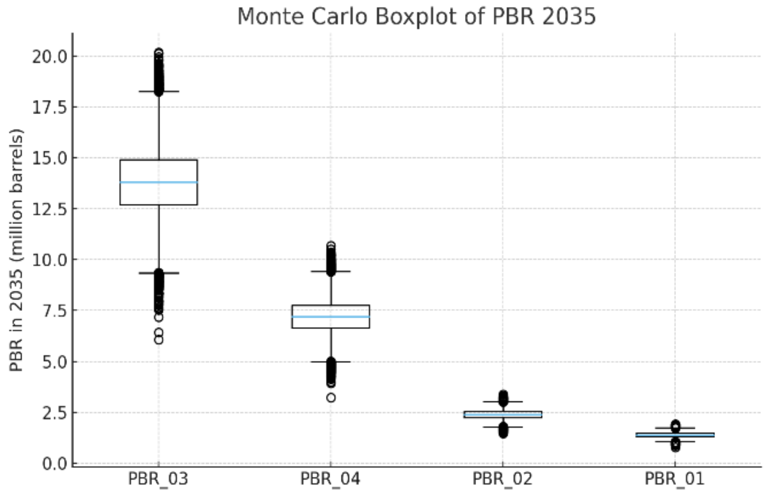


Figure 8. Boxplot summary illustrating median values, variability, and deviation from the national buffer reserve target.

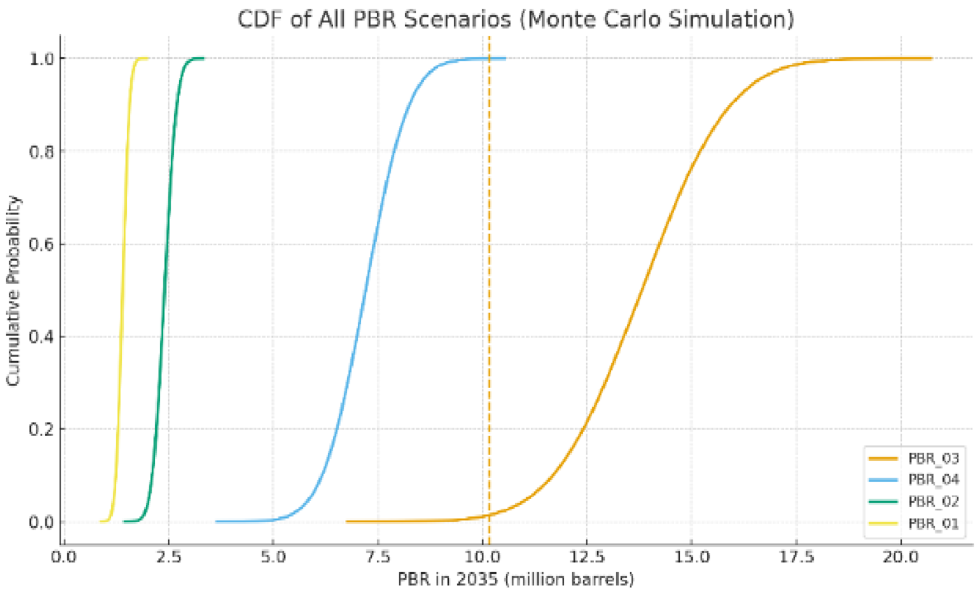


Figure 9. The Cumulative Distribution Function showing the probability of each scenario reaches the national PBR target of 10.17 million barrels by 2035.

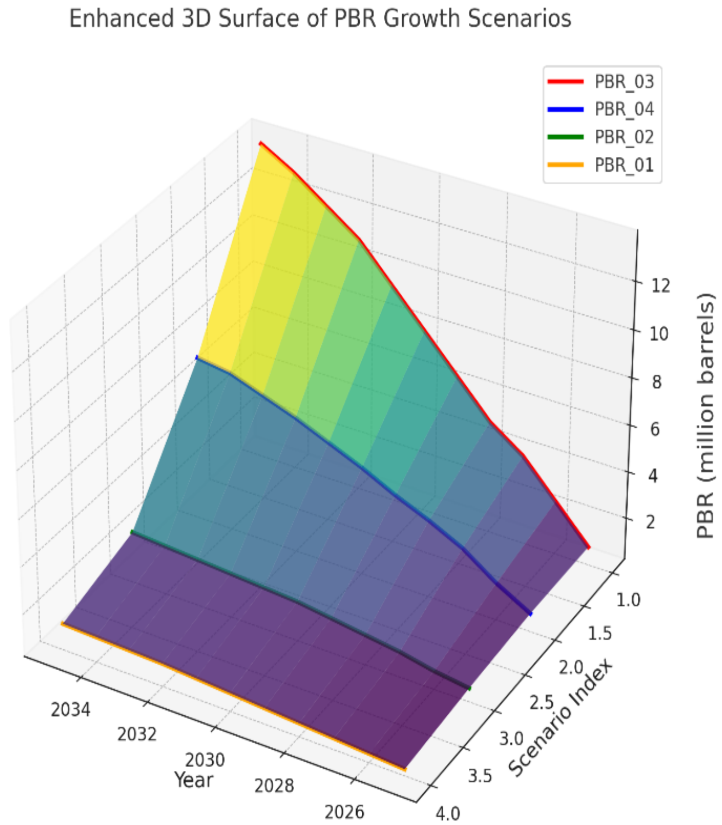


Figure 10. 3D surface plot of PBR growth trajectories across four scenarios from 2025 to 2035, highlighting temporal differences in reserve accumulation patterns.

Table 2. Sunmary table of all scenarios

| **Scenario** | **Import availability level** | **Mean PBR in 2035 (Million bbl)** | **Probability of achieving 10.17 Mbbl** | **Policy interpretation** |
|---|---|---|---|---|
| **PBR_01** | Very Low (≈10%) | 1.40 | 0% | Structurally infeasible; rapid buffer depletion and complete failure to meet national target |
| **PBR_02** | Low–Moderate (≈30%) | 2.40 | <0.001% | Insufficient accumulation; marginal improvement but strategically ineffective |
| **PBR_04** | Moderate (≈50%) | 7.21 | 0.03% | Partial buffer formation; fails to meet target under uncertainty |
| **PBR_03** | Full Import Availability (100%) | 13.80 | **98.5%** | **Only viable and resilient pathway; robust achievement of national PBR target** |

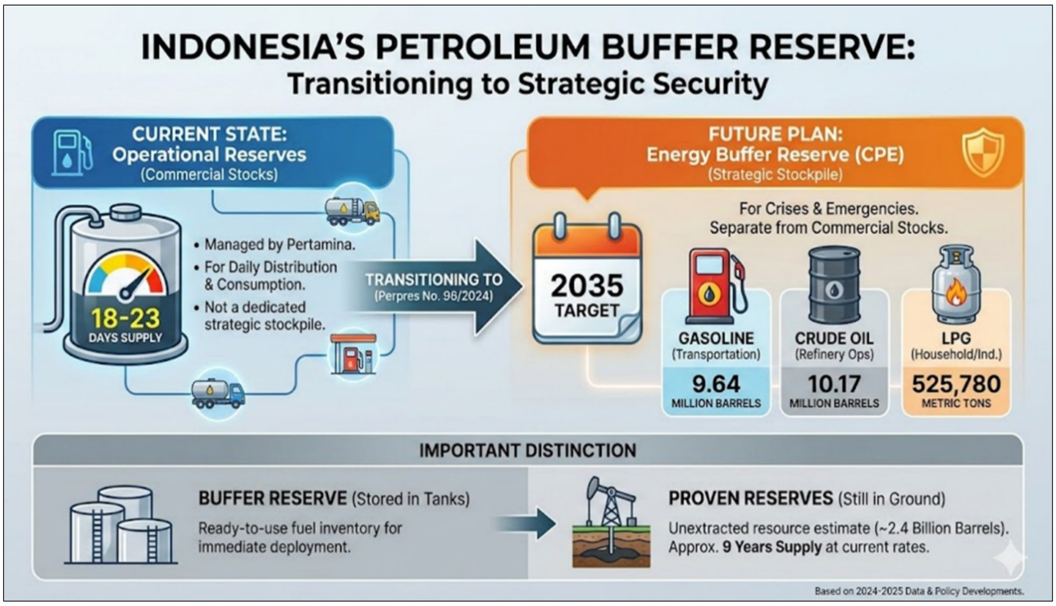


Figure 11. Indonesia PBR illustrating the long-term reserve accumulation path and its alignment with the national strategic target established in Perpres 96/2024.

## CONCLUSION

This study developed an integrated system dynamics and probabilistic simulation framework to evaluate Indonesia's Petroleum Buffer Reserve (PBR) strategy from 2025 to 2035. The framework combined causal-loop analysis, stock–flow simulation, and Monte Carlo methods to produce both deterministic and stochastic assessments of the national reserve system. The results demonstrate a clear distinction between the short-term stabilization of operational petroleum inventory and the long-term behavior of the strategic buffer. While operational inventory consistently converges rapidly toward its 30-million-barrel target, the strategic reserve behaves as a slow-moving accumulation process that is highly dependent on import availability, replenishment capacity, and structural delays.

The deterministic simulations revealed substantial performance differences among the four reserve-building scenarios (PBR_01–PBR_04). Scenario PBR_03—characterized by full import availability and faster replenishment—was the only pathway capable of exceeding the Perpres 96/2024 target of 10.17 million barrels. In contrast, Scenarios PBR_04, PBR_02, and PBR_01 consistently underperformed, demonstrating structural limitations in meeting long-term reserve goals. These results underscore the importance of temporary import escalation as a key instrument for achieving rapid reserve accumulation and safeguarding national energy security.

Probabilistic assessments using Monte Carlo simulation reinforced these findings by quantifying the likelihood of meeting the strategic target under uncertainty. Scenario PBR_03 exhibited a probability exceeding 98% of surpassing the national reserve requirement, whereas the other scenarios showed near-zero probabilities. The CDF curves and distributional patterns confirm that PBR_03 possesses both the resilience and structural capacity required to achieve robust energy security outcomes under realistic variations in demand, import availability, and replenishment rates.

The integration of days-of-cover optimization provides an additional policy-relevant insight. Based on Indonesia's daily crude import requirement of 0.848 million barrels, the current target of 10.17 million barrels corresponds to only about 12 days of coverage—substantially below international benchmarks. Achieving 30, 60, and 90 days of protection would require approximately 25.4, 50.9, and 76.3 million barrels, respectively. Simulation results indicate that a 30-day reserve is realistically attainable with existing replenishment structures, whereas achieving a 60-day buffer requires accelerated accumulation mechanisms and increased storage capacity. A 90-day reserve—aligned with IEA standards—would require substantial new investments, long-term procurement strategies, and diversification of supply sources.

These findings carry significant implications for Indonesia's ongoing initiative to develop petroleum buffer facilities near major refineries. The system dynamics results show that inventory-balancing mechanisms are effective in maintaining daily operational stability, but the strategic reserve is highly vulnerable to prolonged import disruptions. Without decisive short-term investment in incremental crude imports and the expansion of domestic storage infrastructure, Indonesia risks falling significantly short of its long-term energy protection goals and remaining exposed to global market volatility.

Several limitations must be acknowledged to guide future research. The current model prioritizes import-driven reserve development and does not fully incorporate factors such as technological advancements, geopolitical disruptions, refinery outages, fiscal constraints, or variability in domestic crude production. Future work could integrate optimization algorithms, game-theoretic geopolitical modeling, or real-option analyses to strengthen strategic planning. Nonetheless, the present study provides a transparent and rigorously validated foundation for national petroleum reserve policy, offering actionable guidance for designing a more resilient and future-proof energy security framework.

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## GLOSSARY OF TERMS AND SYMBOLS

| Terms & Symbols | Definition | Unit |
|---|---|---|
| PBR | Petroleum Buffer Reserve; Indonesia's strategic petroleum stock. | million barrels |
| Target 10.17 | National PBR target to be achieved by 2035. | million barrels |
| System Dynamics | Modeling approach using feedback loops and time delays to study dynamic systems. | — |
| Stock | Accumulated quantity in the system (e.g., petroleum reserves). | million barrels |

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