



# Generator Outage Study

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Philippine Electricity Market Corporation –  
Market Assessment Group  
and approved by the  
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## EXECUTIVE SUMMARY

This Generator Outage Study, prepared by the Market Assessment Group of the Philippine Electricity Market Corporation (PEMC) for the Market Surveillance Committee, evaluates the reliability performance of power plants in the Philippines from July 2021 to June 2025. The study analyzes planned and unplanned outage trends, applies Reliability Performance Indices set by the Energy Regulatory Commission (ERC), and employs Kaplan-Meier Survival Curve Assessment (KMSCA) to assess operational survival following maintenance activities. It also examines the correlation between outage levels and market prices during peak-demand periods.

The findings reveal that while most generating units operated within allowable limits of the Reliability Performance Indices, a significant portion exceeded thresholds for both planned and unplanned outages. These exceedances were most frequent among mid-aged and newly commissioned Coal, Natural Gas, and Biofuel plants. Strict adherence to planned maintenance schedules emerged as a strong predictor of long-term reliability.

The Kaplan-Meier Survival Curve Assessment, based on recorded outage data from July 2021 to June 2025, shows distinct post-maintenance reliability patterns across plant technologies. Newly commissioned and mid-aged Coal, Hydro, and Natural Gas units generally experienced forced outages either immediately or within the first one to three months after completing planned maintenance. Older units particularly Geothermal and Hydro plants likewise exhibited early failures within similar time frames, though with greater variability in survival duration. However, when survival trends are examined across capacity, and unit count groupings, Geothermal, Hydro and Oil technologies consistently demonstrate longer operational survival probabilities relative to other plant types in several years maintaining higher survival ratios at key time benchmarks (e.g., 20, 50-day points), reflecting stronger resilience following planned outages. In contrast, Coal and Biofuel units regularly show earlier declines in survival curves, signifying shorter durations before encountering forced outages.

On the other hand, the correlation analysis found that outage levels displayed weak-to-moderate association with market prices in Luzon and Mindanao, but no meaningful relationship in Visayas. Based on these insights, the study recommends strengthening maintenance planning and execution, enhancing coordination under the Grid Operating and Maintenance Program (GOMP) among DOE, ERC, NGCP, and generation companies, reviewing ERC's penalty framework to ensure proportionality to operational risks and market impacts, institutionalizing survival analysis tools within regulatory and generator reliability programs, and integrating outage data with broader operational and economic indicators for comprehensive market assessments.

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## 1.0 INTRODUCTION

The reliable delivery of electricity remains one of the central objectives of the Philippine power sector, an aim reflected throughout the Electric Power Industry Reform Act of 2001 (EPIRA). Through this law, the industry was reorganized to encourage competition in generation and improve the overall efficiency of electricity supply. EPIRA also led to the establishment of the Wholesale Electricity Spot Market (WESM), where the interaction of supply and demand determines market prices under the supervision of the Department of Energy (DOE) and the Energy Regulatory Commission (ERC).

Despite ongoing reforms, the electricity system continues to face challenges that affect supply availability. Power plants must undergo periodic maintenance to retain operational performance, yet these activities combined with unexpected outages or events in the grid during a dispatch interval that is beyond the reasonable control of the System Operator, Market Operator, or any WESM Member, cannot be prevented despite reasonable diligence, and results in a reduction of power system capacity that materially affects spot market operations or threatens system security. To manage these conditions, the Philippine Grid Code (PGC) prescribes the development of the Grid Operating and Maintenance Program (GOMP), a coordinated schedule of operational and maintenance activities intended to guide the planning of outages over multiple timeframes. The National Grid Corporation of the Philippines (NGCP), acting as the System Operator, is responsible for preparing the GOMP in consultation with Grid Users, following the procedures and criteria set out in the PGC.

The DOE first established the formal requirements for outage and maintenance coordination through Department Circular No. DC2010-03-0003<sup>1</sup>, which obliges Generation Companies, the Transmission Service Provider (NGCP), Distribution Utilities, and the Market Operator to prepare and implement their respective maintenance plans. This directive highlights the importance of synchronized scheduling, proper coordination, and adequate fuel management to support grid reliability and continuous service to consumers. Under this framework, the GOMP serves as a consolidated reference for scheduling outages across the industry in line with EPIRA's objectives.

These provisions were later expanded under DOE Department Circular No. DC2020-02-0004<sup>2</sup>, which set clearer procedures for consolidating, evaluating, and approving planned outage schedules for both generation and transmission facilities. This circular directs NGCP to compile industry submissions, secure DOE approval, and publish the updated GOMP to ensure public accessibility and transparency. It also restricts the implementation of planned outages during the summer or peak-demand months except for hydropower plants whose operations are closely tied to seasonal water availability recognizing the increased likelihood of supply shortages during this period. By reinforcing planning requirements and enhancing visibility of scheduled maintenance, this policy aims to improve system preparedness, strengthen coordination among market participants, and supports improved system readiness.

As part of its regulatory oversight, the ERC issued Resolution No.10, Series of 2020<sup>3</sup>, defining the allowable outage limits for each generation technology in WESM. This action was highly prompted by the unusually high outage levels recorded in March to May 2019, which necessitated a clearer benchmark for

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<sup>1</sup> Directing all Power Generation Companies, the Transmission Service Provider, and all Distribution Utilities to Ensure Adequate and Reliable Electric Power Supply in the Country

<sup>2</sup> Providing Guidelines on the Planned Outage Schedules of Power Plants and Transmission Facilities and the Public Posting of the Grid Operating and Maintenance Program

<sup>3</sup> A Resolution Adopting the Interim Reliability Performance Indices and Equivalent Outage Days per Year of Generating Units

evaluating the outage performance of generating units. The ERC has since required explanations from generators exceeding these thresholds, with possible sanctions depending on the outcome of the regulatory review.

Following the issuance of ERC Resolution No.10, Series of 2020, several significant developments highlighted the enforcement of outage regulations. On 10 June 2024, the ERC launched investigations of 29 power producers for potential breaches of outage allowances following widespread red and yellow alerts, with five generators initially identified as having exceeded limits. The ERC has consistently enforced Resolution No.10, Series of 2020, imposing PHP 60 million in penalties on 14 firms in 2023, underscoring its continued efforts to assess the justifiability of generator outages<sup>4</sup>.

Given these developments, this study aims to provide a detailed assessment of outage behavior in the Philippines' power system. The study evaluates the maintenance and operating schedules within the GOMP, examines outage trends across different plant types and regions. Through these analyses, the study seeks to identify opportunities to strengthen outage planning practices, support system reliability, and enhance the overall performance of the electricity supply chain.

## 2.0 OBJECTIVES OF THE STUDY

This study aims to evaluate the effectiveness of planned generator outages and identify potential areas for improvement by analyzing the behavior and performance of generators across different plant types. Specifically, it seeks to:

1. Assess the reliability and performance of generators during the July 2021 to June 2025 billing period.
2. Compare generator performance across plant types using Reliability Performance Indices set by the ERC.
3. Analyze the time to forced outages following planned maintenance activities using Kaplan-Meier survival curve analysis.
4. Determine the relationship between market prices and outage capacity during the summer season using data from July 2021 to June 2025.

## 3.0 SCOPE AND DELIMITATIONS

This study focuses on the analysis of planned and unplanned outages data from July 2021 to June 2025 for Biofuel, Coal, Geothermal, Hydro, Natural Gas, and Oil plants. Survival analysis is applied to units that underwent scheduled planned maintenance to evaluate operational reliability. Battery, Solar, and Wind plants were excluded from the study because only full outages were reported for these technologies, while partial deratings or outages were not considered. Generator performance and reliability are evaluated using Reliability Performance Indices, Kaplan-Meier Survival Analysis, and Pearson and Spearman Correlation Analyses, with comparisons made across plant types. Units without scheduled planned maintenance are also excluded from the survival analysis.

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<sup>4</sup> ERC investigating 29 power producers for breaching outage threshold. Source: [ERC investigating 29 power producers for breaching outage threshold – Matuwid na Singil sa Kuryente](#)

#### 4.0 REVIEW OF THE RELATED LITERATURES

Power outages have a significant impact on economic development, as productive sectors are highly dependent on a reliable electricity.<sup>5</sup> Consequently, power outages result in high societal costs and pose threats to power grid reliability.<sup>6</sup> Forced outages can be minimized through proper maintenance practices that extend plant life and enhance reliability.

This also considers the duration of forced and planned outages in generation plants as an indicator of plant reliability. It should be noted that as the probability of forced outages increases, it gradually leads to a decline in generation system reliability.<sup>7</sup> Proper implementation and oversight of maintenance during planned and forced outages support effective outage management in the power system.<sup>8</sup>

Survival analysis has been widely applied in evaluating the reliability and operational performance of power generation units. In particular, the Kaplan-Meier survival curve is frequently used to estimate the probability that a generator will continue operating without experiencing a forced outage (FO) up to time  $t^9$ . In a study conducted in the Korean electricity market, the Kaplan-Meier method was employed to determine the duration before generators encounter an FO. Results indicate that approximately 50% of the generator population fails within about 260 days, as illustrated in Figure 1.

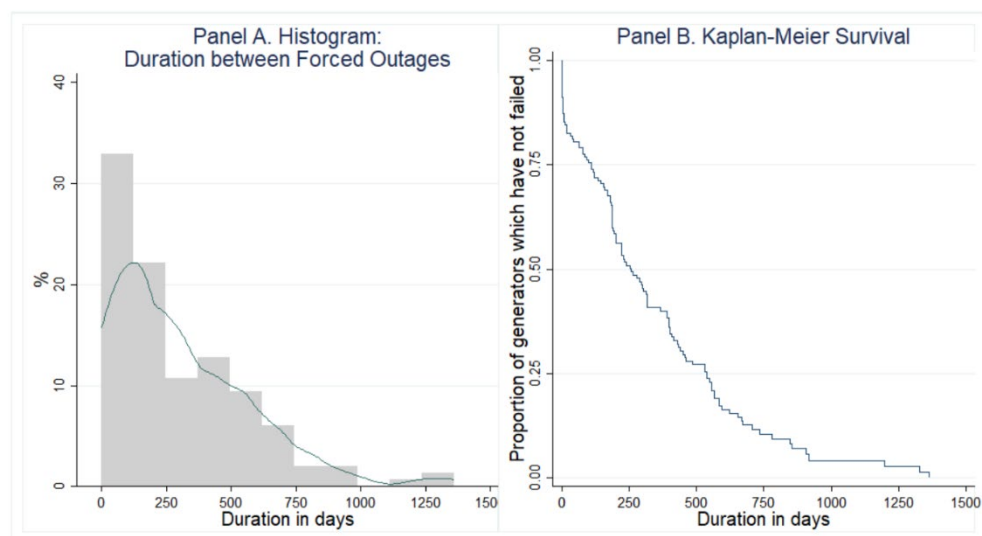


Figure 1. Duration Between Forced Outage and Kaplan-Meier Survival Curve<sup>10</sup>

<sup>5</sup> D. Owerko, F. Gama and A. Ribeiro, "Predicting Power Outages Using Graph Neural Networks," *2018 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, Anaheim, CA, USA, 2018, pp. 743-747, doi: 10.1109/GlobalSIP.2018.8646486.

<sup>6</sup> Abdullah M. Al-Shaalan, "Reliability Evaluation of Power Systems," submitted 14 September 2018, reviewed 1 March 2019, published 13 May 2019, IntechOpen, <https://doi.org/10.5772/intechopen.85571>

<sup>7</sup> Bahareh Bagheri and Nima Amjadi, "Stochastic Multiobjective Generation Maintenance Scheduling Using Augmented Normalized Normal Constraint Method and Stochastic Decision Maker," first published 21 September 2018, *International Transactions on Electrical Energy Systems*, <https://doi.org/10.1002/etep.2722>

<sup>8</sup> M. Lipár, "Operational Safety of Nuclear Power Plants," in *Comprehensive Nuclear Materials*, <https://doi.org/10.1533/9780857093776.3.773>

<sup>9</sup> Energies (2020). Preventive Maintenance and Forced Outages in Power Plants in Korea. Source: (PDF) Preventive Maintenance and Forced Outages in Power Plants in Korea

<sup>10</sup> Ibid

In the said study conducted, survival analysis was applied on Korean power generators to assess the relationship between operational practices and FO occurrence. Findings revealed that higher preventive maintenance spending, longer planned maintenance outages, higher utilization rates, and greater reserve margins contribute to improved generator reliability and, consequently, lower probabilities of forced outage<sup>11</sup>. Similarly, hazard rate analysis applied to Mirant generating plants during the California electricity market crisis of 2000-2001 indicated that higher utilization typically leads to increased outage rates. Although predicted outage rates during the crisis were expected to exceed the historical average, the actual outage rates were significantly lower than anticipated based on pre-crisis behavior.<sup>12</sup>

A similar analysis was performed in the Philippines context by Ravago et al. (2021)<sup>13</sup> from the Ateneo de Manila University, utilizing both Kaplan-Meier survival curves and Cox proportional hazards regression. Their study concluded that longer maintenance durations, older powerplants higher reserve margins, and a larger share of the generator in total system capacity are associated with a reduced risk of outage participation in the market. Conversely, the only factor found to increase the likelihood of forced outage was the generator's technology or resource type.

Alongside survival-based methods, generator reliability is often evaluated using outage-based indices such as the Planned Outage Factor (POF) and Unplanned Outage Factor (UOF). These indices are widely utilized in power system reliability assessments to measure unit availability and operational risk.<sup>14</sup> The Planned Outage Factor is calculated as:

$$POF = \frac{\text{Planned Outage Hours}}{\text{Total Period Hours}}$$

Similarly, the Unplanned Outage Factor is defined as:

$$UOF = \frac{\text{Unplanned Outage Hours}}{\text{Total Period Hours}}$$

These measures serve as fundamental benchmarks for estimating generator availability and are commonly integrated into probabilistic reliability models and regulatory performance evaluations.

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<sup>11</sup> Ibid

<sup>12</sup> Harvey, Scott M., William W. Hogan, and Todd Schatzki. "A Hazard Rate Analysis of Mirant's Generating Plant Outages in California." KSG Faculty Research Working Paper Series RWP05-027, March 2005.

<sup>13</sup> Ravago, M. V., et al. (2021). Reliability and Forced Outages: Survival Analysis with Recurrent Events. Ateneo de Manila University.

<sup>14</sup> NERC | 2023 Appendix F. Performance Indexes and Equations

## 5.0 METHODOLOGY

This study primarily utilized generator outage data provided by NGCP, covering the period from July 2021 to June 2025 in Table 2 and 3. It may be noted that the outage data for Mindanao was only available starting February 2023. Analyses for this region are therefore limited to 2023 onward. The dataset included plant types such as Biofuel, Coal, Geothermal, Hydro, Natural Gas and Oil, involving the following variables in Table 1.

*Table 1. Description of Variables used in the Generator Outage Study (July 2021 – June 2025)*

Variable	Definition	Considerations
Time Duration to Forced Outage	Number of hours elapsed from the completion of the most recent planned outage to the occurrence of the first subsequent forced outage.	Only forced outages following a planned outage are considered.
Timely Conduct of Planned Outage	Binary variable coded as 1 if the planned outage, as scheduled in the GOP, was concluded on time or earlier; coded as 0 if delayed.	N/A
Forced Outage	Binary variable coded as 1 if a forced outage occurred following the resumption of the most recent planned outage; coded as 0 otherwise.	Outages related to the Outside Management Control and line-related outages are excluded.
Age	Age of the generating unit, expressed in years from the date of commissioning or WESM registration, whichever is earlier.	Plants aged 0-10 years are classified as NEW, 11-40 years as MID-AGED, and 41 years and above as OLD.
Plant Type	Type of energy source utilized by the generating unit.	N/A

*Table 2. Number of Generating Units by Plant Type*

Year	Number of Generating Units						Total
	Biofuel	Coal	Geothermal	Hydro	Natural Gas	Oil	
2021	30	47	45	72	15	105	314
2022	30	47	45	72	15	105	314
2023	36	65	50	127	15	138	431
2024	39	65	52	133	18	141	448
2025	39	68	52	133	18	141	451

*Note: The number of generating units shown in this table represent only the plant types included in the study – Biofuel, Coal, Geothermal, Hydro, Natural Gas, and Oil. Technologies such as Solar, Wind, and Battery were excluded.*

*Table 3. Total Capacity by Plant Type*

Year	Total Capacity (MW)						Total
	Biofuel	Coal	Geothermal	Hydro	Natural Gas	Oil	
2021	380	9,770	1,502	2,585	3,285	2,114	19,636
2022	380	9,770	1,502	2,585	3,285	2,114	19,636
2023	417	12,171	1,637	3,698	3,285	2,623	23,831
2024	438	12,446	1,659	3,780	4,602	2,623	25,548
2025	433	12,508	1,661	3,806	4,574	2,603	25,585

*Note: The capacities shown in this table represent only the plant types included in the study – Biofuel, Coal, Geothermal, Hydro, Natural Gas, and Oil. Technologies such as Solar, Wind, and Battery were excluded.*

## RELIABILITY PERFORMANCE INDICES

The Reliability Performance Indices was applied in the available data to examine all units that exceeded the annual threshold set by the ERC. (see *Table 4*)

*Table 4. Allowable Planned and Unplanned Outage Days<sup>15</sup>*

	Pulverized Coal	Circulating Fluidized Bed	Combined Cycle	Gas Turbine	Diesel	Geo-thermal	Hydro-electric	Oil-Fired Thermal	Biomass
No. of Day Unavailable	44.7	32.3	20.2	29.2	19.0	19.7	29.9	58.6	39.7
No. of Days of Planned Outage	27.9	15.4	12.5	6.5	5.0	6.0	23.1	30.8	32.7
No. of Days on Unplanned Outages	16.8	16.9	7.7	22.7	14.0	13.7	6.8	27.8	7.0

The planned and unplanned outage factors were computed to assess the reliability performance of each generating unit.

## CORRELATION ANALYSIS

To examine the relationship between market prices and outage capacity during the summer season, Pearson and Spearman Rank Correlation analyses were conducted. The Pearson correlation was used to assess linear relationships between the variables<sup>16</sup>, while the Spearman rank correlation was applied to evaluate monotonic relationships, which do not require the data to be normally distributed.<sup>17</sup>

Correlation values range from -1 to +1, where values closer to  $\pm 1$  indicate a stronger relationship, and values near zero indicate a weak or no relationship. A positive correlation suggests that as one variable increases, the other tends to increase, whereas a negative correlation suggests the opposite. It is important to note that correlation measures association, not causation, and the observed relationships may be influenced by external factors.

<sup>15</sup> Energy Regulatory Commission. (2020). *Annex A – Rules for the Interim Reliability Performance Indices and Equivalent Outage Days Per Year of Generating Units* (Resolution No. 10, Series of 2020). Pasig City, Philippines: Energy Regulatory Commission.

<sup>16</sup> Hogg, R. V., McKean, J. W., & Craig, A. T. (2019). *Introduction to mathematical statistics* (8th ed.). Pearson.

<sup>17</sup> Diez, D. M., Barr, C. D., & Çetinkaya-Rundel, M. (2019). *OpenIntro statistics* (4th ed.). OpenIntro.

## 6.0 STATISTICAL ANALYSIS AND INTERPRETATION OF RESULTS

### A. USING THE RELIABILITY PERFORMANCE INDICES

In evaluating the reliability performance of generation facilities, it is essential to examine the Planned Outage Factor (POF) in relation to the allowable outage days prescribed by the ERC. Below showed the results in comparison to the threshold set to ensure whether the scheduled maintenance activities remain within regulatory limits while minimizing disruptions to system availability.

#### July to December 2021

As shown on Table 5 and Figure 2, from July to December 2021, 86.63% of units, accounting 67.54% of total capacity, were units that did not undergo planned outage. On the other hand, 7.96% of units (15.26% of total capacity) were within the planned outage threshold, while 5.41% (17.20% of total capacity) exceeded the threshold. The latter in terms of capacity comprises of 0.60% old units, 15.30% mid-aged units, and 1.31% new units, with most exceedances observed in mid-aged Natural Gas and Coal Plants.

Table 5. Planned Outage Factor (July – December 2021)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Planned Outage Threshold	25	7.96%	2,996	15.26%	2.42% Old Units 7.33% Mid-aged Units 5.51% New Units
Exceeded Planned Outage Threshold	17	5.41%	3,378	17.20%	0.60% Old Units 15.30% Mid-aged Units 1.31% New Units

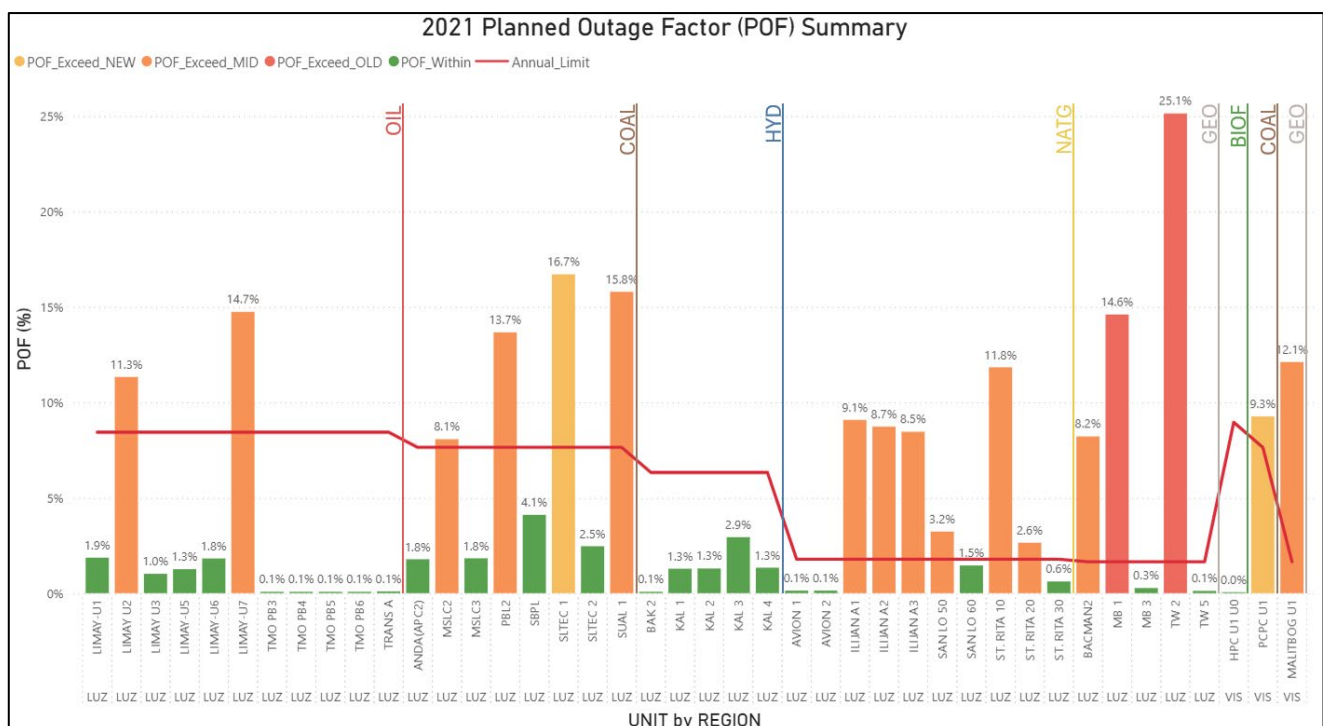


Figure 2. 2021 Planned Outage Factor Summary

For unplanned outages during same period, 42.99% of units representing 20.12% of capacity were units that did not undergo unplanned outage, 47.45% (65.69% of capacity) were within the unplanned outage threshold, and 9.56% (14.19% of capacity) exceeded it, comprising 0.97% old units, 6.07% mid-aged units, and 7.15% new units. Similarly, exceedances largely concentrated among mid-aged units, particularly Coal and Geothermal Plants, mostly in Visayas region where Geothermal units experienced multiple outages primarily due to undervoltage events, protection-initiated trips, emergency cut-outs, and equipment issues, with several shutdowns occurring during planned maintenance, while among new units, exceedances were primarily observed in Coal Plants, mostly in Luzon due to protection system actuations, mechanical component failures, abnormal operating conditions and emergency events. (see Table 6 and Figure 3)

Table 6. Unplanned Outage Factor (July – December 2021)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Unplanned Outage Threshold	140	44.59%	12,533	63.83%	8.22% Old Units 44.16% Mid-aged Units 11.45% New Units
Exceeded Unplanned Outage Threshold	30	9.56%	2,786	14.19%	0.97% Old Units 6.07% Mid-aged Units 7.15% New Units

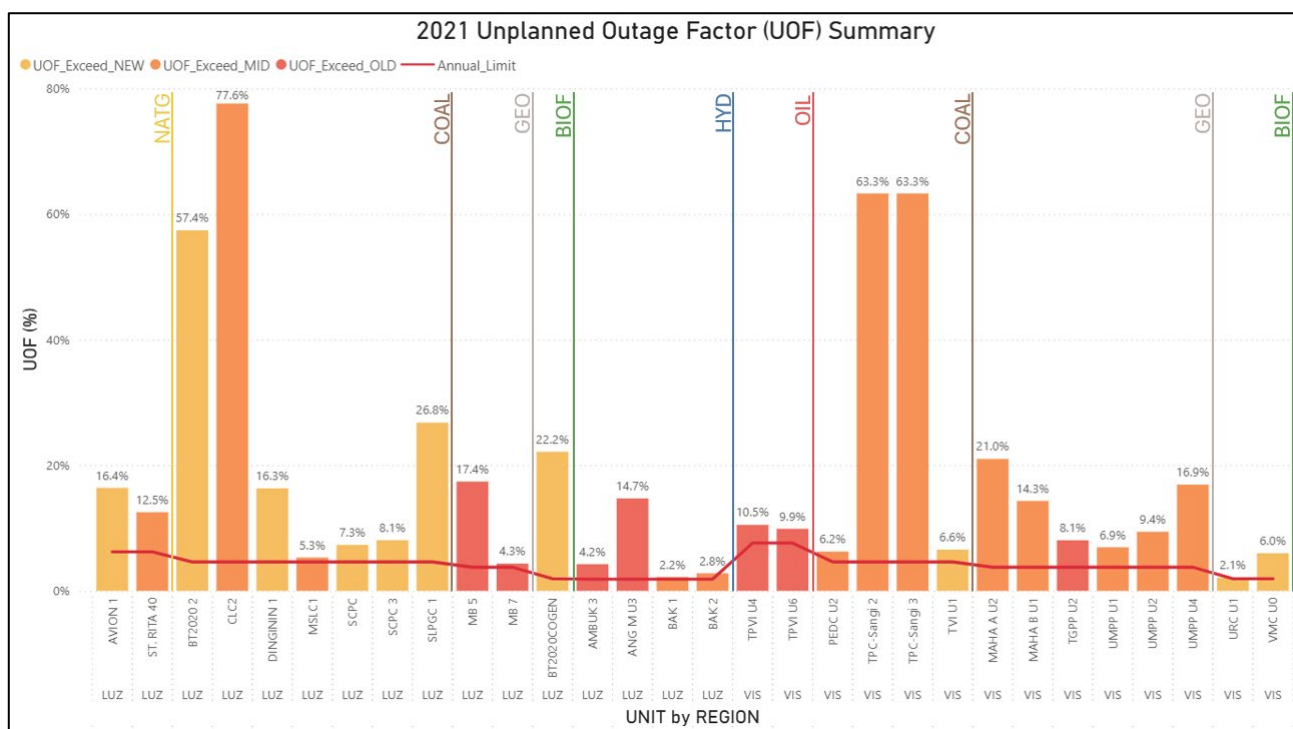


Figure 3. 2021 Unplanned Outage Factor Summary

**January to December 2022**

As shown on Table 7 and Figure 4, from January to December 2022, 58.28% of units, accounting 30.83% of total capacity, were units that did not undergo planned outage. Meanwhile, 27.39% of units (34.52% of total capacity) were within the planned outage threshold, and 14.33% (34.65% of total capacity) exceeded the threshold, comprising of 3.88% old units, 19.10% mid-aged units, and 11.67% new units, with most exceedances observed in mid-aged Coal, Hydro and Natural gas plants, while among the new units, exceedances were primarily observed in Coal Plants, mostly in Luzon.

Table 7. Planned Outage Factor (January – December 2022)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Planned Outage Threshold	86	27.39%	6,778	34.52%	4.19% Old Units 21.37% Mid-aged Units 8.96% New Units
Exceeded Planned Outage Threshold	45	14.33%	6,804	34.65%	3.88% Old Units 19.10% Mid-aged Units 11.67% New Units

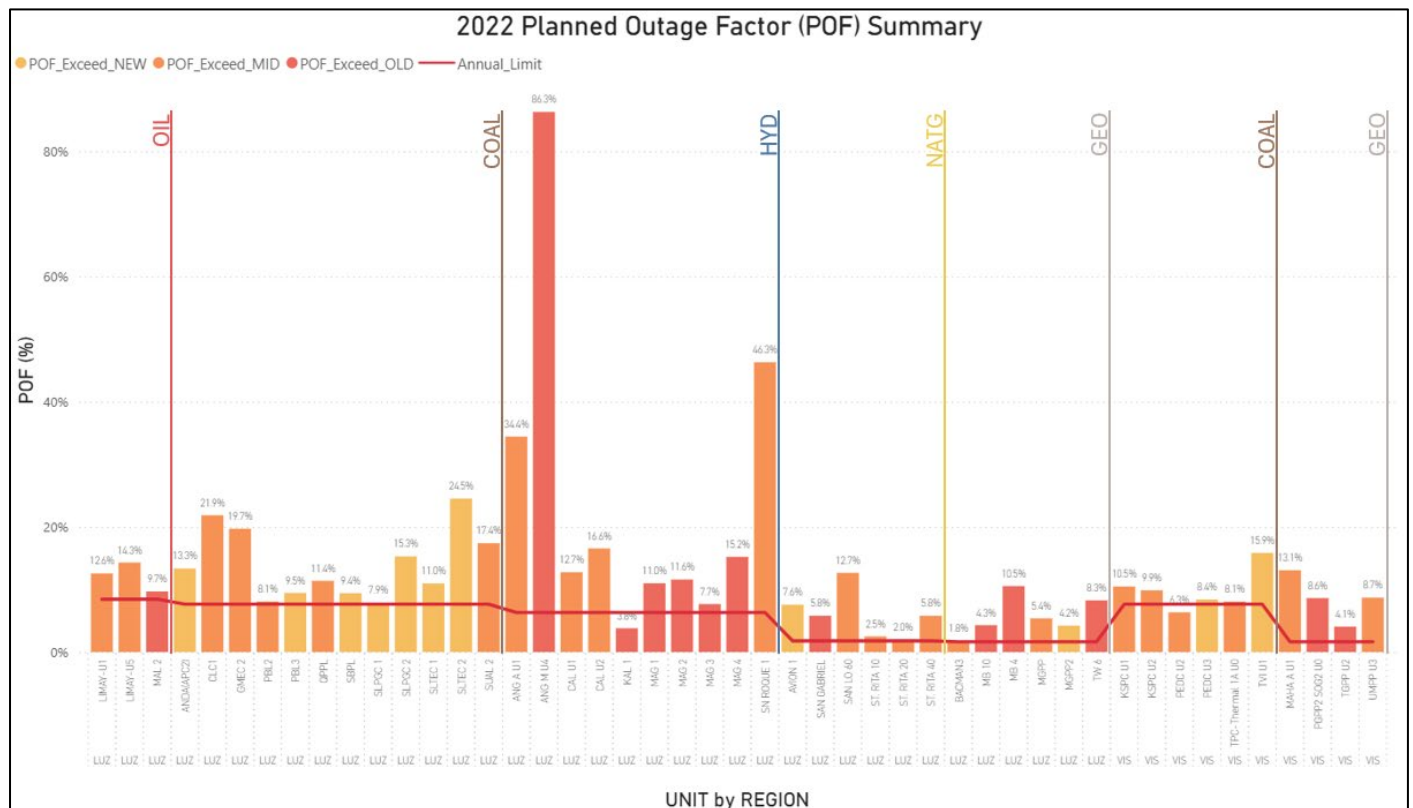


Figure 4. 2022 Planned Outage Factor Summary

For unplanned outages during same period, 41.72% of units representing 17.51% of capacity were units that did not undergo unplanned outage, 45.22% (58.40% of capacity) were within the acceptable unplanned outage limits, and 13.06% (24.09% of capacity) exceeded it, comprising 2.52% old units, 8.42% mid-aged units, and 13.15% new units. Similarly, exceedances largely concentrated among mid-aged units, particularly Coal Plants mostly in Luzon and Geothermal Plants mostly in Visayas region where Geothermal units experienced repeated outages mainly due to protection trips, condenser-related issues, auxiliary equipment faults, and scheduled maintenance activities, while among new units, the exceedances were observed in Coal Plants mostly in Luzon region where the units experienced repeated trips and shutdowns caused by protection actuations, equipment failures, and abnormal operating conditions.(see Table 8 and Figure 5)

Table 8. Unplanned Outage Factor (January – December 2022)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Unplanned Outage Threshold	142	45.22%	11,468	58.40%	7.94% Old Units 39.30% Mid-aged Units 11.16% New Units
Exceeded Unplanned Outage Threshold	41	13.06%	4,729	24.09%	2.52% Old Units 8.42% Mid-aged Units 13.15% New Units

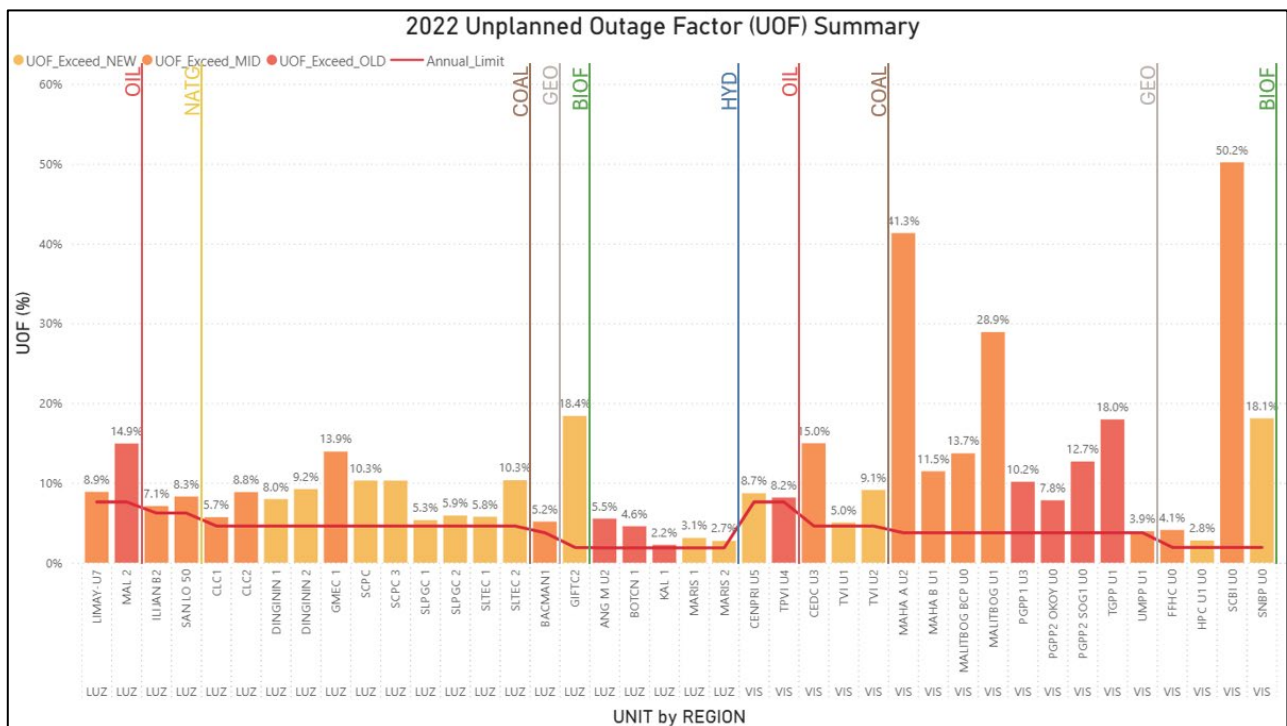


Figure 5. 2022 Unplanned Outage Factor Summary

**January to December 2023**

As shown on Table 9 and Figure 6, from January to December 2023, 57.77% of units, accounting 36.07% of total capacity, were units that did not undergo planned outage. Meanwhile, 29.93% of units (35.37% of total capacity) were within the allowable planned outage limits, and 12.30% (28.56% of total capacity) exceeded it, comprising of 3.12% old units, 15.80% mid-aged units, and 9.64% new units. Most exceedances observed fell under mid-aged Coal, Hydro and Natural gas Plants mostly in Luzon, while among new units, the exceedances were observed in Coal and Natural gas Plants mostly in Luzon.

Table 9. Planned Outage Factor (January – December 2023)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Planned Outage Threshold	129	29.93%	8,431	35.37%	4.43% Old Units 18.28 Mid-aged Units 12.66 New Units
Exceeded Planned Outage Threshold	53	12.30%	6,807	28.56%	3.12% Old Units 15.80% Mid-aged Units 9.64% New Units

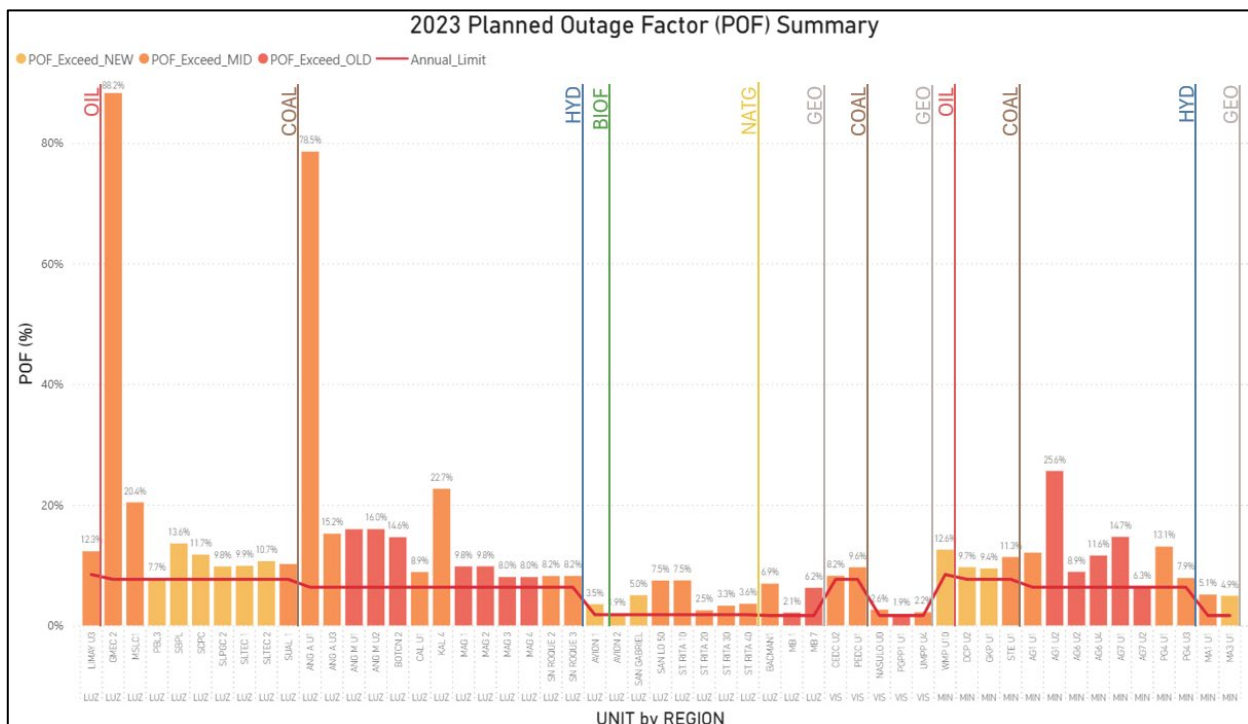


Figure 6. 2023 Planned Outage Factor Summary

For unplanned outages during same period, 34.57% of units representing 10.07% of capacity were units that did not undergo unplanned outage, 51.74% (69.18% of capacity) were within the unplanned outage threshold, and 13.69% (20.75% of capacity) exceeded it, comprising 3.35% old units, 10.75% mid-aged units, and 6.65% new units. Exceedances largely concentrated among mid-aged units, particularly Coal and Hydro Plants mostly in Luzon and Geothermal plants mostly in Visayas region where Geothermal units experienced multiple outages mainly due to control, protection, condenser, steam leak, and vibration issues, along with scheduled maintenance, while among new units, the exceedances were observed in Coal and Biofuel Plants in Luzon region, where the unit experienced repeated unplanned trips and shutdowns caused by various equipment faults, protection actuations, and operational abnormalities as well as in Coal Plants in Mindanao, where the unit experienced multiple unplanned outages driven mainly by boiler issues, equipment faults, and protection-related shutdowns. (see Table 10 and Figure 7)

Table 10. Unplanned Outage Factor (January – December 2023)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Unplanned Outage Threshold	223	51.74%	16,489	69.18%	6.99% Old Units 35.50% Mid-aged Units 26.69% New Units
Exceeded Unplanned Outage Threshold	59	13.69%	4,945	20.75%	3.35% Old Units 10.75% Mid-aged Units 6.65% New Units

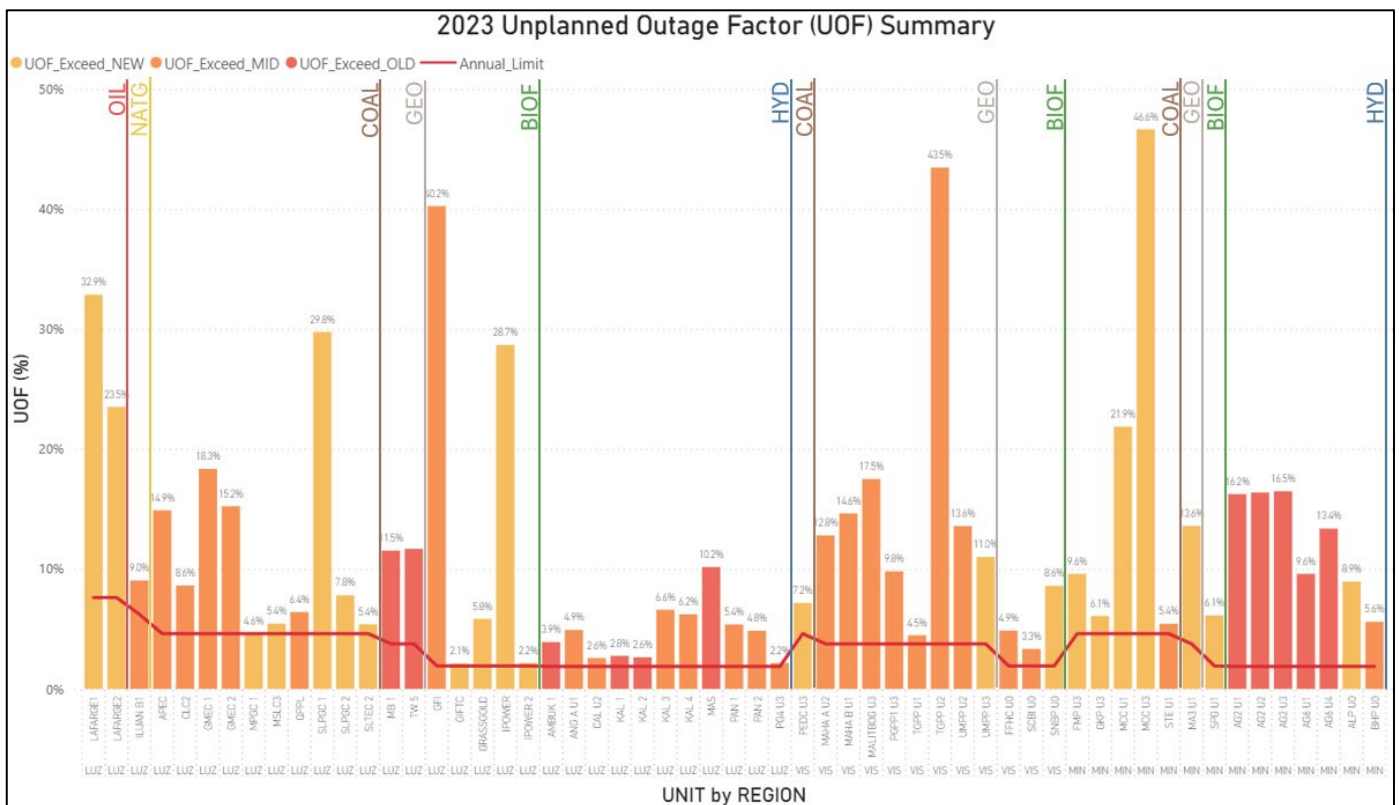


Figure 7. 2023 Unplanned Outage Factor Summary

**January to December 2024**

As shown on Table 11 and Figure 8, from January to December 2024, 54.91% of units, accounting 38.86% of total capacity, were units that did not undergo planned outage. Meanwhile, 32.59% of units (26.63% of total capacity) were within the allowable planned outage range, and 12.50% (34.51% of total capacity) exceeded it which comprises of 4.57% old units, 22.99% mid-aged units, and 6.95% new units. Most exceedances observed were under mid-aged in Coal and Natural gas mostly in Luzon, while among new units, the exceedances were observed in Hydro Plants in Mindanao.

Table 11. Planned Outage Factor (January – December 2024)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Planned Outage Threshold	146	32.59%	6,805	26.63%	2.64% Old Units 9.37% Mid-aged Units 14.63% New Units
Exceeded Planned Outage Threshold	56	12.50%	8,817	34.51%	4.57% Old Units 22.99% Mid-aged Units 6.95% New Units

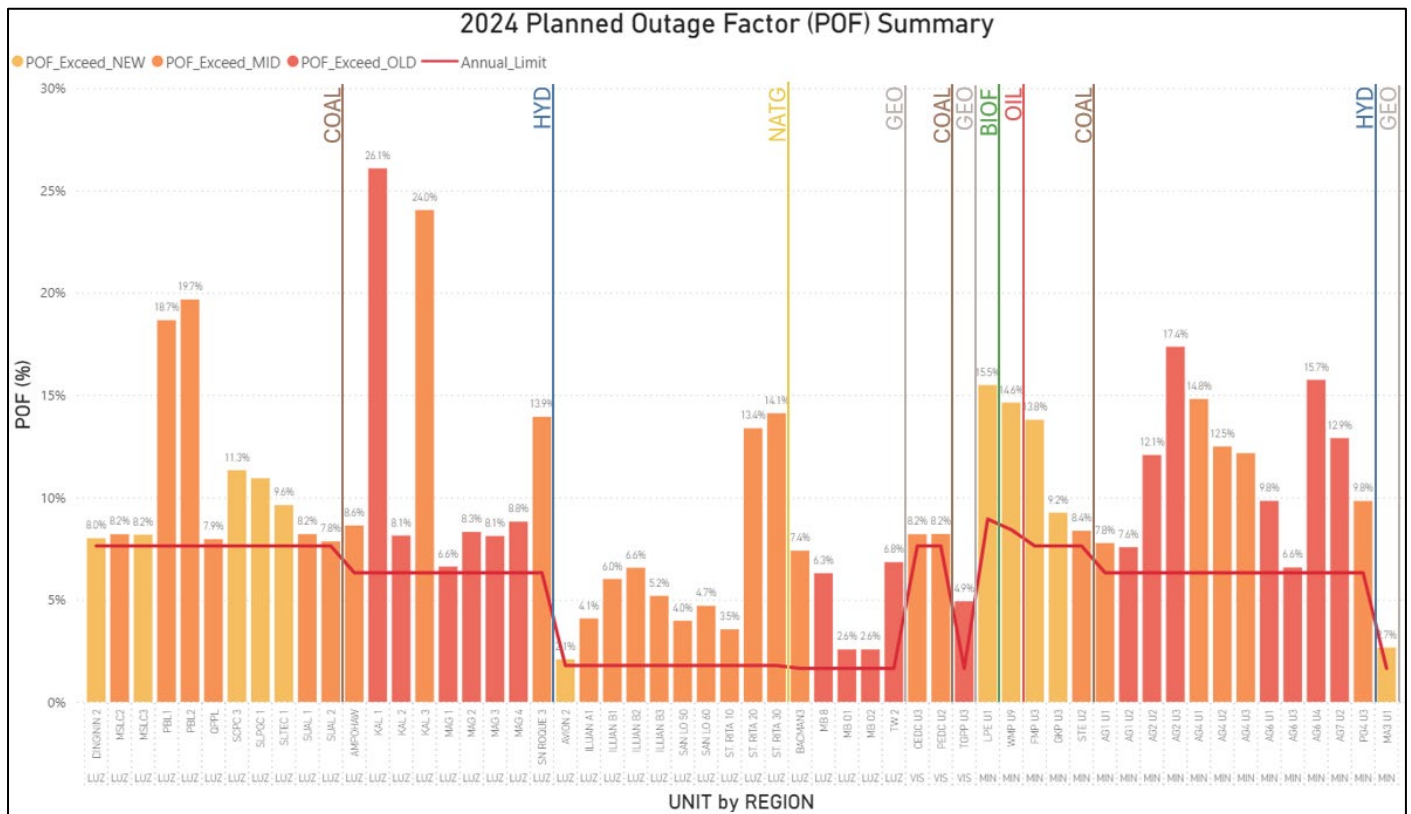


Figure 8. 2024 Planned Outage Factor Summary

For unplanned outages during same period, 17.86% of units representing 5.41% of capacity were units that did not undergo unplanned outage, 62.95% (72.59% of capacity) were within the unplanned outage threshold, and 19.20% (22.00% of capacity) exceeded it, comprising 3.26% old units, 10.38% mid-aged units, and 8.36% new units. Exceedances largely concentrated among mid-aged units, particularly Coal Plants mostly in Luzon and Visayas regions and Hydro Plants in Mindanao region where the Hydro units encountered repeated outages mainly due to governor and excitation faults, protection relay operations, hydraulic and cooling system issues, grid-related disturbances, and scheduled maintenance activities, while among new units, the exceedances were observed in Coal, Biofuel Plants mostly in Luzon, and Oil and Hydro Plants in Visayas and Coal Plants in Mindanao. In all three regions, the affected Coal units underwent multiple unplanned outages primarily due to boiler-related issues, equipment faults, and protection-initiated trips, along with several scheduled maintenance. (see Table 12 and Figure 9)

Table 12. Unplanned Outage Factor (January – December 2024)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Unplanned Outage Threshold	282	62.95%	18,547	72.59%	5.78% Old Units 35.52% Mid-aged Units 31.29% New Units
Exceeded Unplanned Outage Threshold	86	19.20%	5,621	22.00%	3.26% Old Units 10.38% Mid-aged Units 8.36% New Units

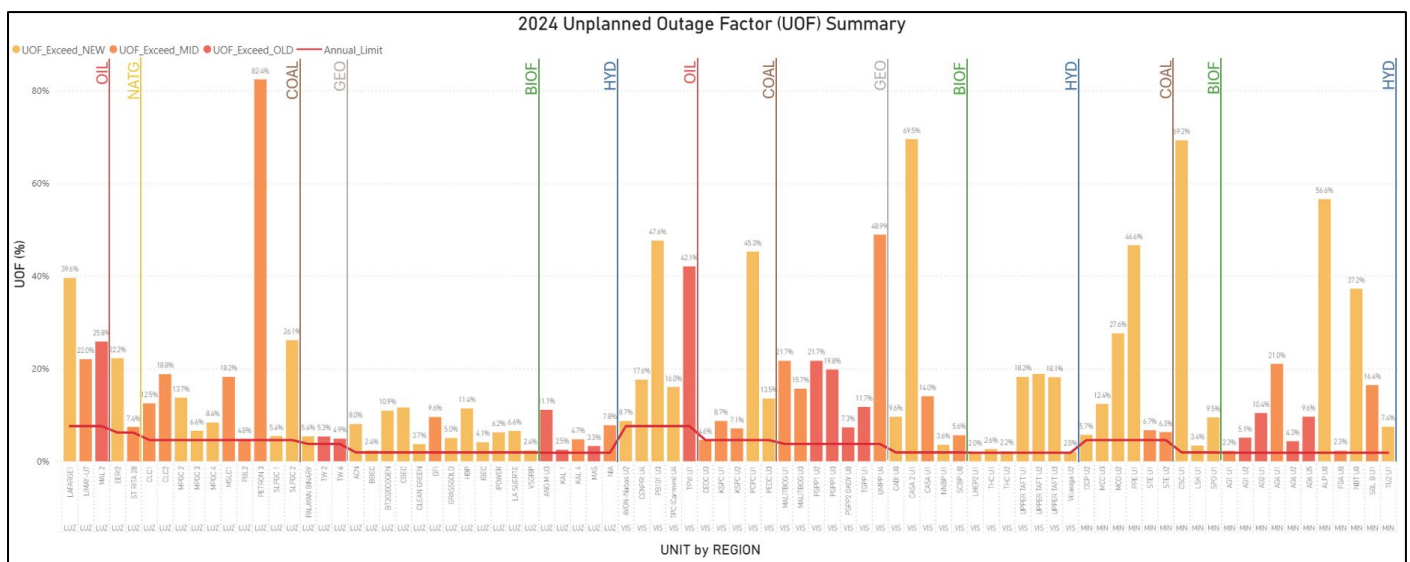


Figure 9. 2024 Unplanned Outage Factor Summary

**January to June 2025**

As shown on Table 13 and Figure 10, from January to June 2025, 76.72% of units, accounting 70.19% of total capacity, were units that did not undergo planned outage. Meanwhile, 19.95% of units (21.94% of total capacity) were within the allowable planned outage threshold, and 3.33% (7.87% of total capacity) exceeded it which comprises of 1.41% old units, 3.73% mid-aged units, and 2.74% new units. Most exceedances observed in mid-aged and new units Hydro and Coal Plants.

Table 13. Planned Outage Factor (January – June 2025)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Planned Outage Threshold	90	19.95%	5,612	21.94%	3.59% Old Units 12.08% Mid-aged Units 6.27% New Units
Exceeded Planned Outage Threshold	15	3.33%	2015	7.87%	1.41% Old Units 3.73% Mid-aged Units 2.74% New Units

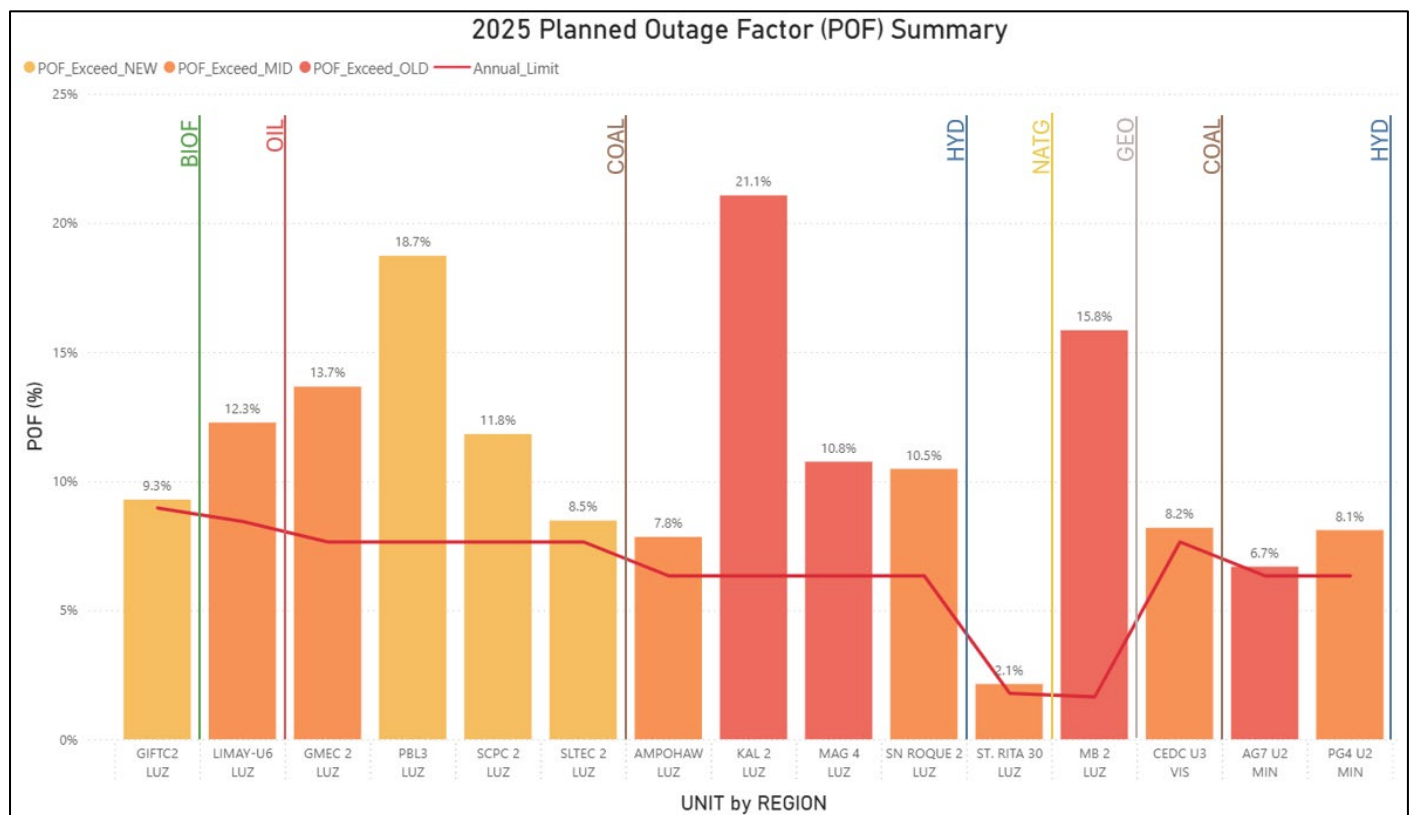


Figure 10. 2025 Planned Outage Factor Summary

For unplanned outages during same period, 28.60% of units representing 18.28% of capacity were units that did not undergo unplanned outage, 64.52% (71.36% of capacity) were within the unplanned outage threshold, and 6.88% (10.36% of capacity) exceeded it, comprising 0.13% old units, 2.46% mid-aged units, and 7.76% new units. Exceedances largely concentrated among new units, particularly Natural Gas, Biofuel Plants in the Luzon region and Hydro Plants in the Mindanao region where Hydro units experienced recurring outages mainly due bearing and mechanical issues, grid fluctuations, protection trips, and scheduled maintenance activities. (see Table 14 and Figure 11)

Table 14. Unplanned Outage Factor (January– June 2025)

Category	Number of Units	Percentage of Units (%)	Total Capacity (MW)	Percentage of Total Capacity (%)	Breakdown of Capacities per Age Type
Within Unplanned Outage Threshold	291	64.52%	18,259	71.36%	8.08% Old Units 36.01% Mid-aged Units 27.27% New Units
Exceeded Unplanned Outage Threshold	31	6.88%	2,651	10.36%	0.13% Old Units 2.46% Mid-aged Units 7.76% New Units

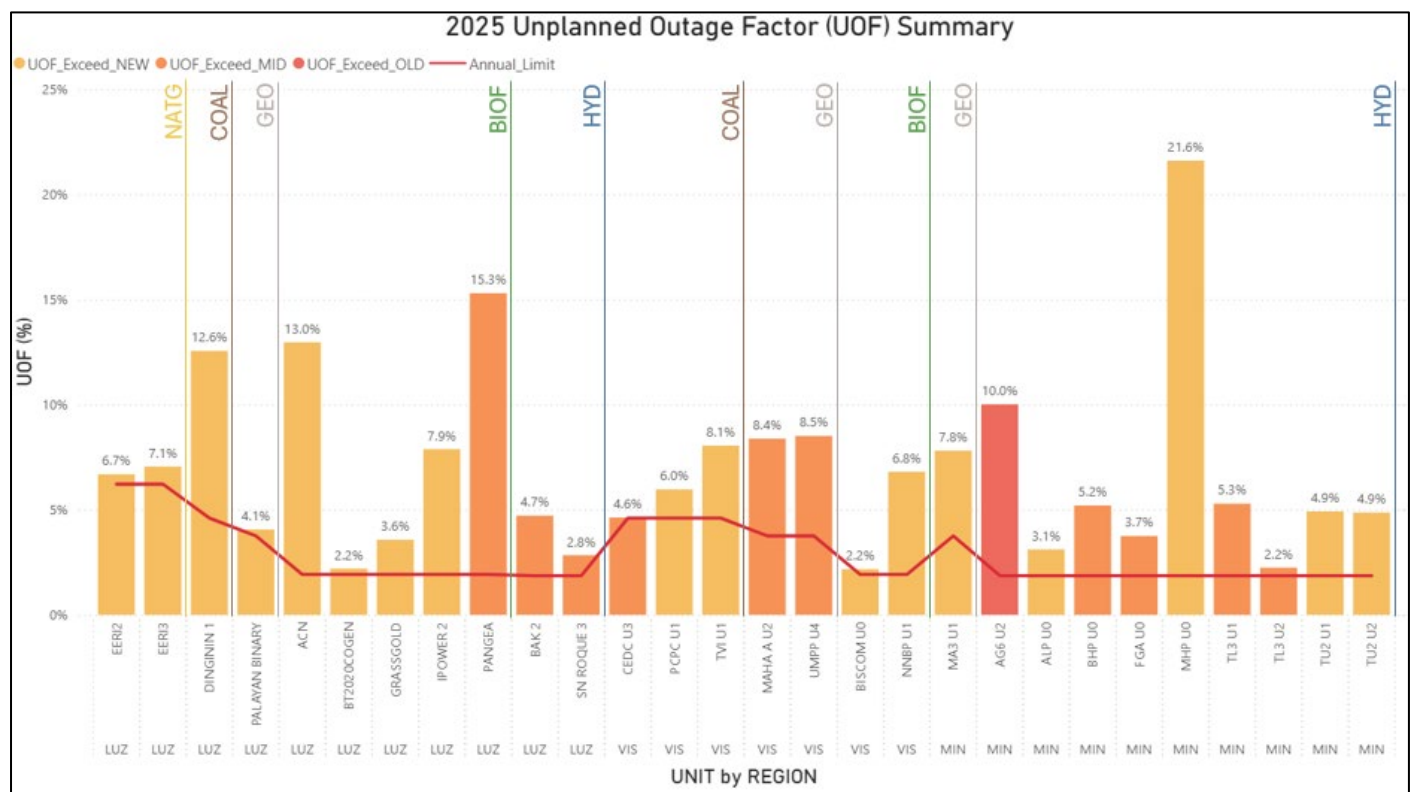


Figure 11. 2025 Unplanned Outage Factor Summary

## **B. USING THE KAPLAN-MEIER SURVIVAL CURVE ASSESSMENT**

The Kaplan-Meier Survival Curve Assessment (KMSCA) was conducted using three analytical perspectives: per capacity, per unit, and per region to determine which plant types exhibit the longest operational survival days following the completion of planned maintenance. This assessment provides insight into how long different plant types continue to operate before requiring subsequent maintenance interventions or experiencing forced outages.

To ensure methodological consistency across all generating units, each Kaplan-Meier survival curve begins at the completion of a unit's planned maintenance, which serves as the standardized time-zero across all generating units and plant types. From this point, operational days accumulate until the unit experiences its first forced outage, which is treated as the failure event. This approach standardizes the starting point of all curves and enables meaningful comparison of post-maintenance survival performance across plant types, capacities, and regions. In addition, all generating units that completed their planned maintenance within the year were considered for that year.

By examining survival patterns across plant types, capacity levels, individual units, and geographic regions, the study aims to:

- Compare reliability performance among various plant types and capacity classifications.
- Identify units or regions with shorter survival durations that may indicate operational inefficiencies or environmental constraints.
- Evaluate the effectiveness of existing maintenance practices across different categories.
- Highlight plant types or capacities demonstrating strong post-maintenance performance, which may serve as benchmarks for reliability.

## Summary of KMSCA Findings:

### July to December 2021

- **A1. KMSCA 2021:** In terms of survival by generator type and capacity covering the July-December 2021 billing period, it was observed that after 50 days of operation following planned maintenance activities, **Natural Gas**, and **Geothermal** Plants recorded survival ratios of 52%, and 47%, respectively (see Figure 12). The number of units and total capacity per plant type represented in the graph are shown in Table 15.

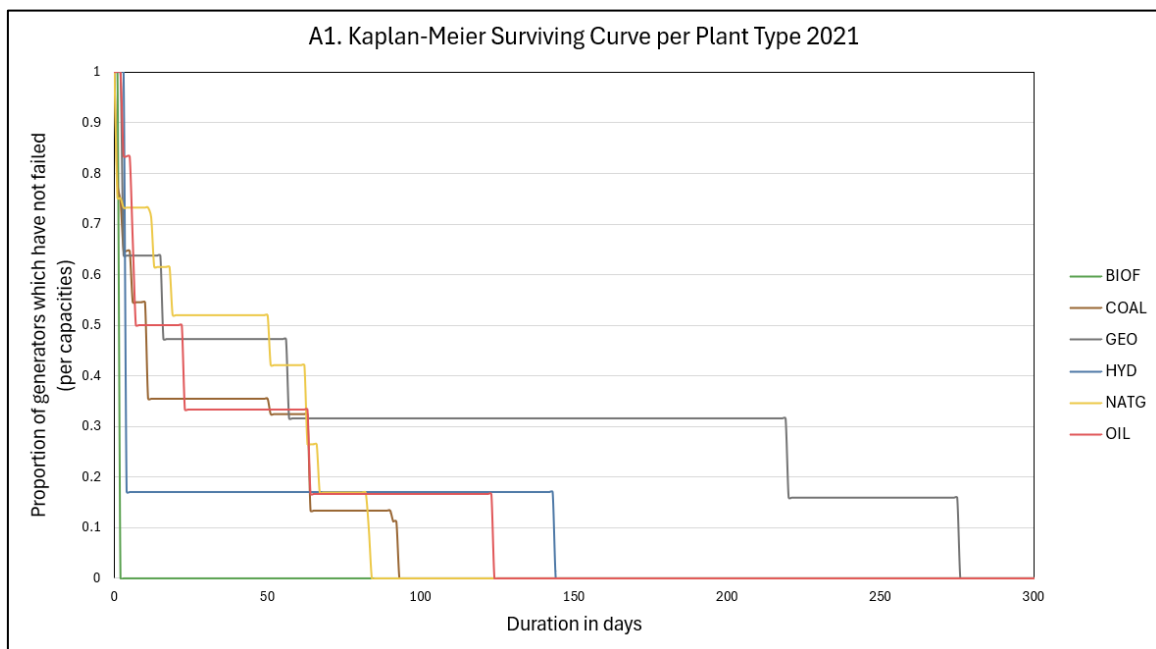


Figure 12. KMSC per Capacity, 2021

Table 15. KMSC Units and Capacities, 2021

Plant Type	No. of Units	Total Capacity (MW)
Biofuel	1	2
Coal	11	3,392
Geothermal	6	364
Hydro	2	217
Natural gas	12	2,685
Oil	6	360

- **A2. KMSCA 2021:** Based on survival by generator type and unit count, it was observed that after 50 days of operation following planned maintenance activities, **Hydro** and **Geothermal** Plants recorded survival ratios of 50% and 50%, respectively (see Figure 13). The number of units and total capacity per plant type represented in the graph are shown in Table 15.

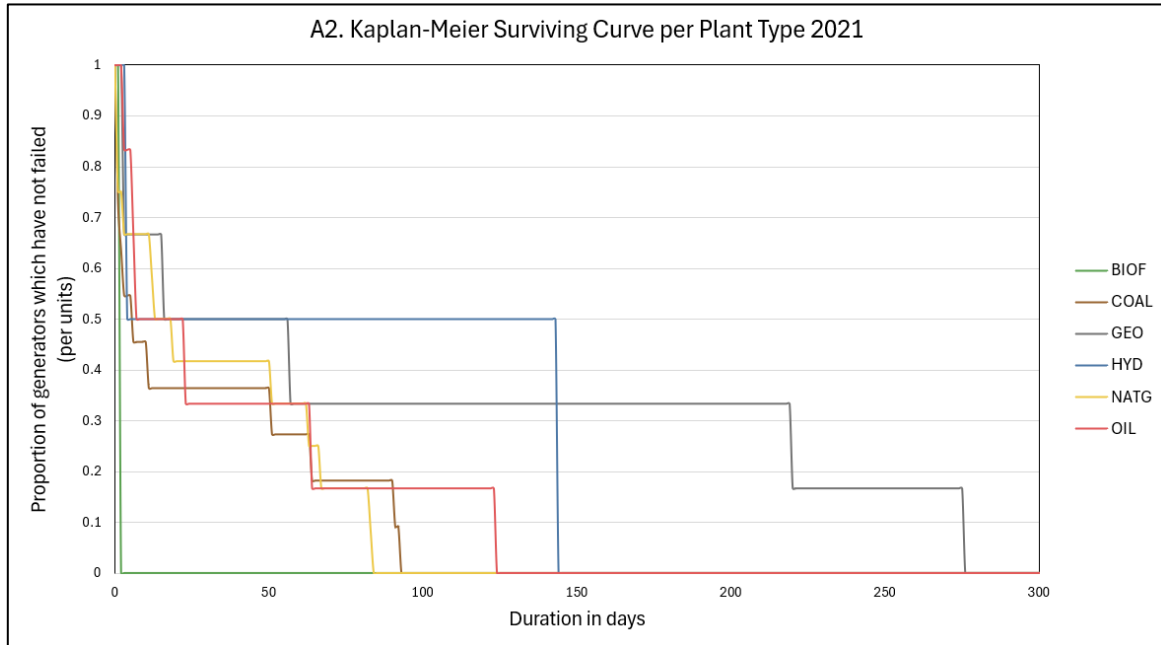


Figure 13. KMSC per Individual Unit, 2021

- **A3. KMSCA 2021:** From a regional survival perspective for the July-December 2021 billing period, it was observed that after 50 days of operation following planned maintenance activities, 40% of Luzon region units remained operational, while in the Visayas region, survival dropped to 20%, indicating better survival performance among Luzon plants. (see Figure 14)

A3. Kaplan-Meier Survival Curve per Region 2021

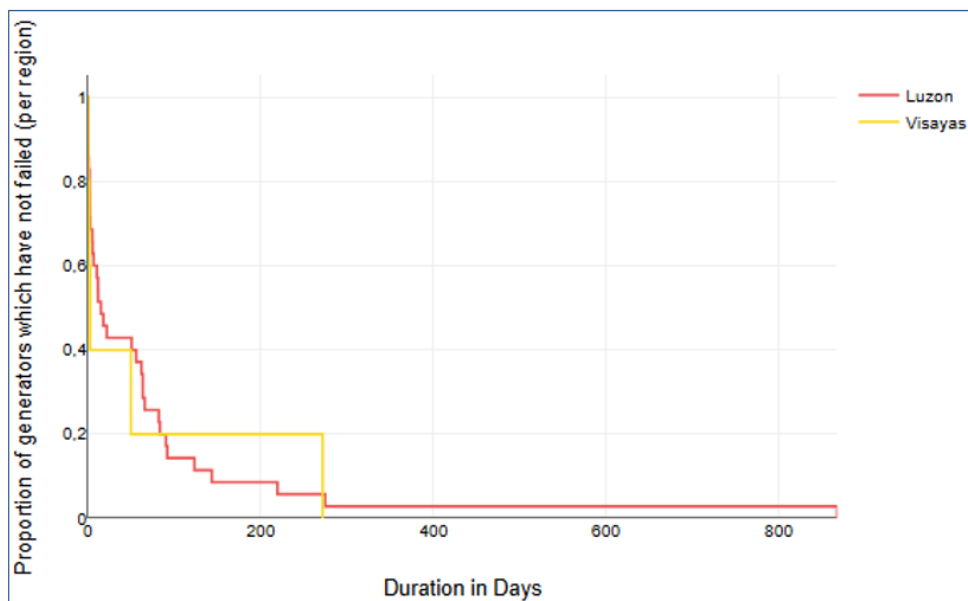


Figure 14. KMSC per Region, 2021

### January to December 2022

- **B1. KMSCA 2022:** In terms of survival by generator type and capacity, covering the January-December 2022 billing period, it was observed that after 50 days of operation following planned maintenance activities, **Biofuel, Hydro, and Oil** Plants recorded survival ratios of 53%, 46%, and 37%, respectively (see Figure 15). The number of units and total capacity per plant type represented in the graph are shown in Table 16.

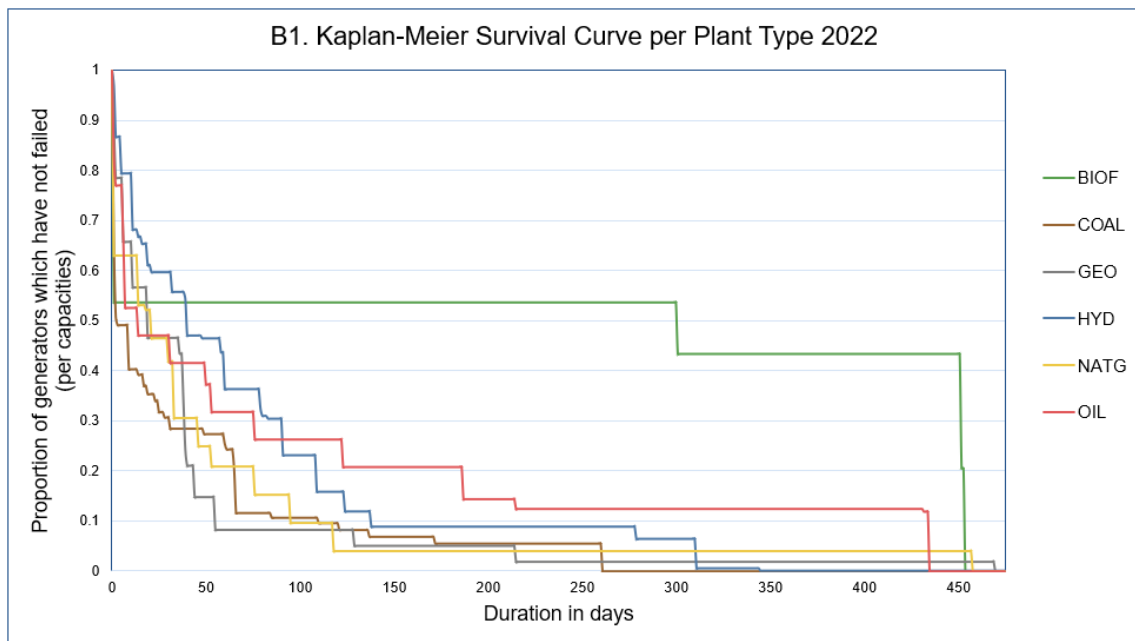


Figure 15. KMSC per Capacity, 2022

Table 16. KMSC Units and Capacity, 2022

Plant Type	No. of Units	Total Capacity
Biofuel	5	52
Coal	30	7,580
Geothermal	17	626
Hydro	33	2,462
Natural gas	19	4,700
Oil	23	1,091

- **B2. KMSCA 2022:** Based on survival by generator type and unit count, it was observed that after 50 days of operation following planned maintenance activities, **Biofuel, Oil, and Hydro** Plants recorded survival ratios of 80%, 60%, and 42%, respectively (see Figure 16). The number of units and total capacity per plant type represented in the graph are shown in Table 16.

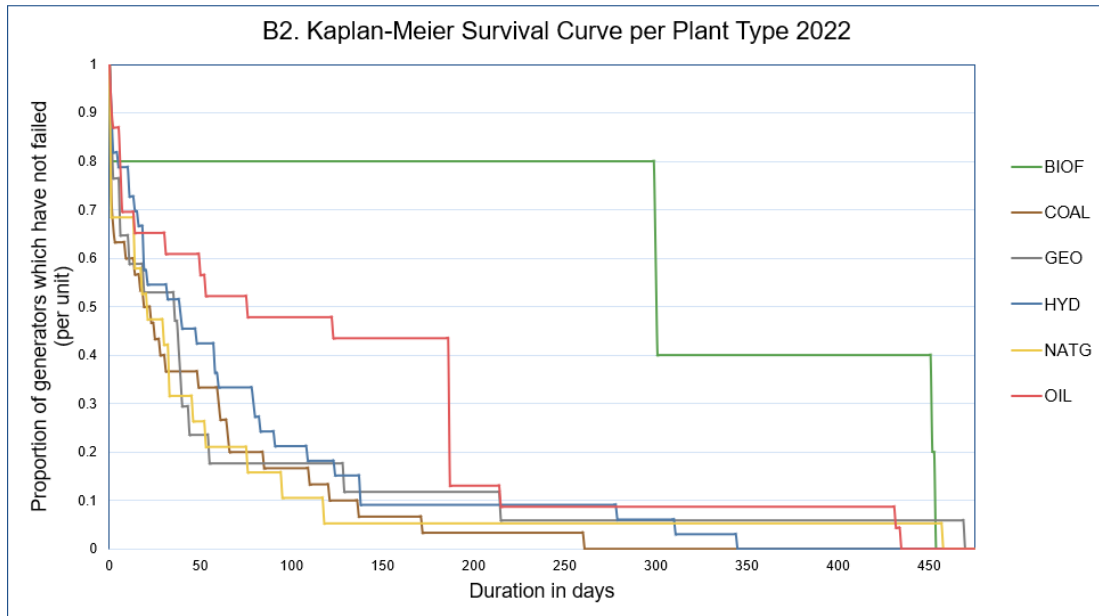


Figure 16. KMSC per Individual Unit, 2022

- **B3. KMSCA 2022:** From a regional survival perspective, it was observed that after 50 days of operation following planned maintenance activities, about 38% of Luzon units and around 40% of Visayas units remained operational. Although the Visayas curve shows a slightly higher survival proportion at this point, this estimate is based on a smaller number of units at risk, resulting in larger step changes. In contrast, the Luzon survival curve is supported by a larger unit population, producing a smoother decline and a more stable survival estimate. (see Figure 17)

B3. Kaplan-Meier Survival Curve per Region 2022

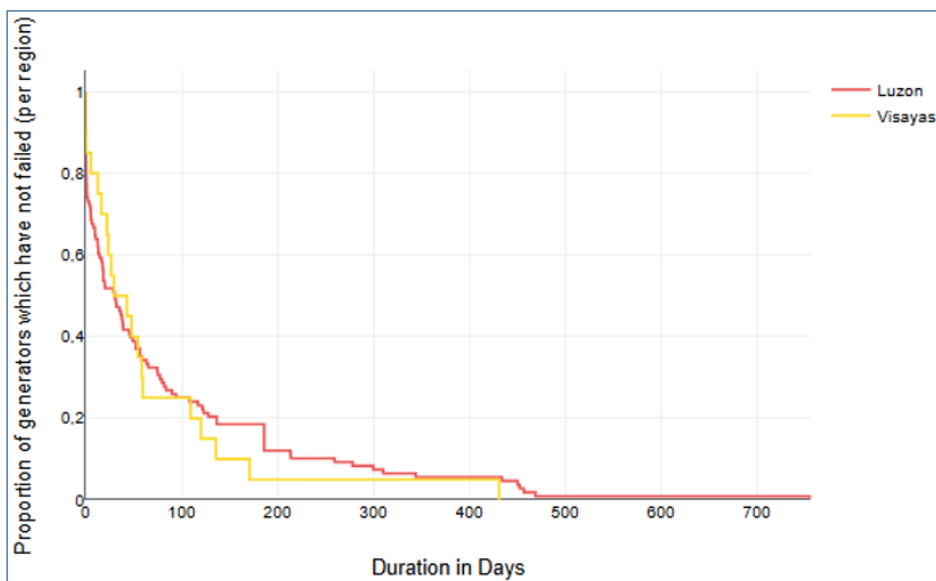


Figure 17. KMSC per Region, 2022

### January to December 2023

- **C1. KMSCA 2023:** In terms of survival by generator type and capacity, covering the January-December 2023 billing period, it was observed that after 50 days of operation following planned maintenance activities, **Oil**, and **Geothermal** Plants recorded survival ratios of 74%, and 43%, respectively (see Figure 18). The number of units and total capacity per plant type represented in the graph are shown in Table 17.

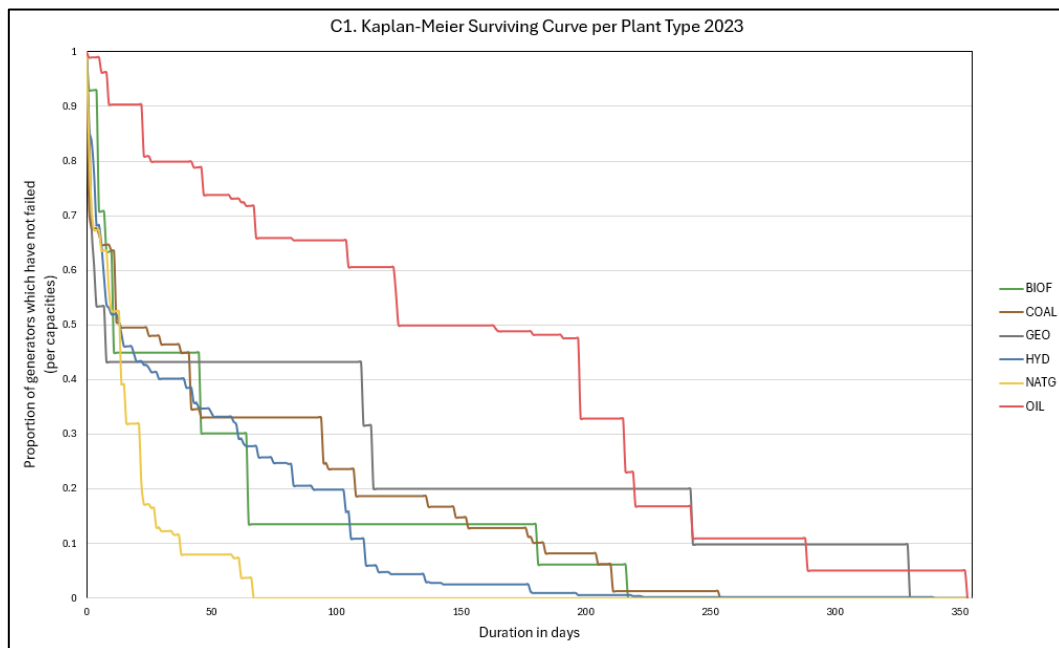


Figure 18. KMSC per Capacity, 2023

Table 17. KMSC Units and Capacity, 2023

Plant Type	No. of Units	Total Capacity
Biofuel	8	81
Coal	34	7,718
Geothermal	11	491
Hydro	83	3,667
Natural gas	28	7,105
Oil	32	1,020

- **C2. KMSCA 2023:** Based on survival by generator type and unit count, it was observed that after 50 days of operation following planned maintenance activities, **Oil**, **Biofuel** and **Geothermal** Plants recorded survival ratios of 75%, 37 and 36%, respectively (see Figure 19). The number of units and total capacity per plant type represented in the graph are shown in Table 17.

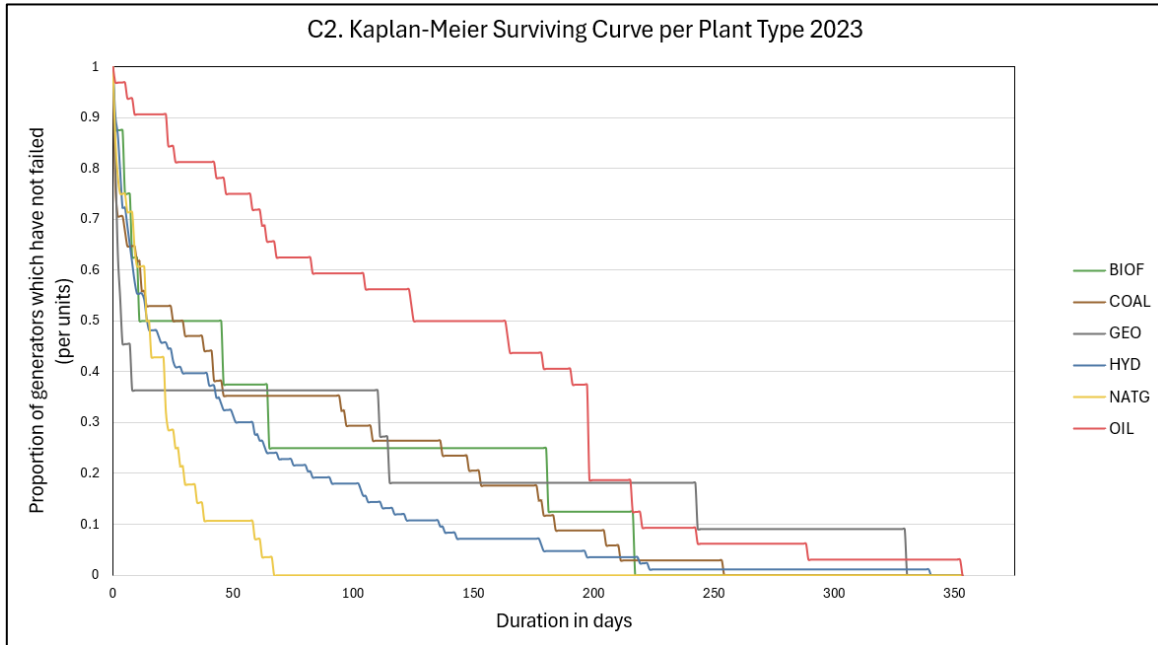


Figure 19. KMSC per Individual Unit, 2023

- **C3. KMSCA 2023:** From a regional survival perspective, it was observed that after 50 days of operation following planned maintenance activities, 60% of Visayas region units remained operational, while Luzon recorded 35% and Mindanao 30% survival rate. This indicates better survival performance among Visayas plants. (see Figure 20)

C3. Kaplan-Meier Survival Curve per Region 2023

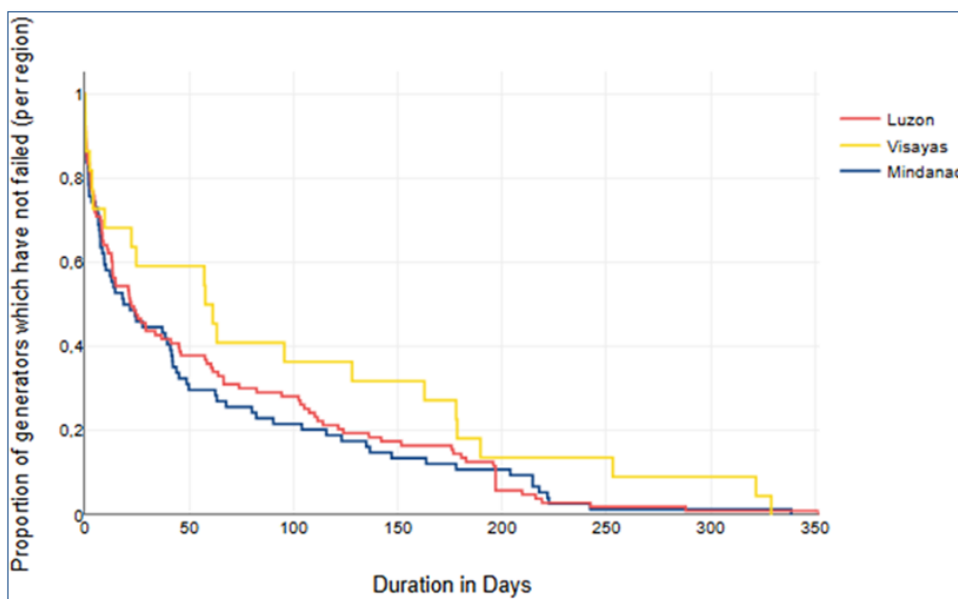


Figure 20. KMSC per Region, 2023

### January to December 2024

- **D1. KMSCA 2024:** In terms of survival by generator type and capacity, covering the January-December 2024 billing period, it was observed that after 50 days of operation following planned maintenance activities, **Geothermal, Hydro, and Oil** Plants recorded survival ratios of 47%41%, and 38%, respectively (see Figure 21). The number of units and total capacity per plant type represented in the graph are shown in Table 18.

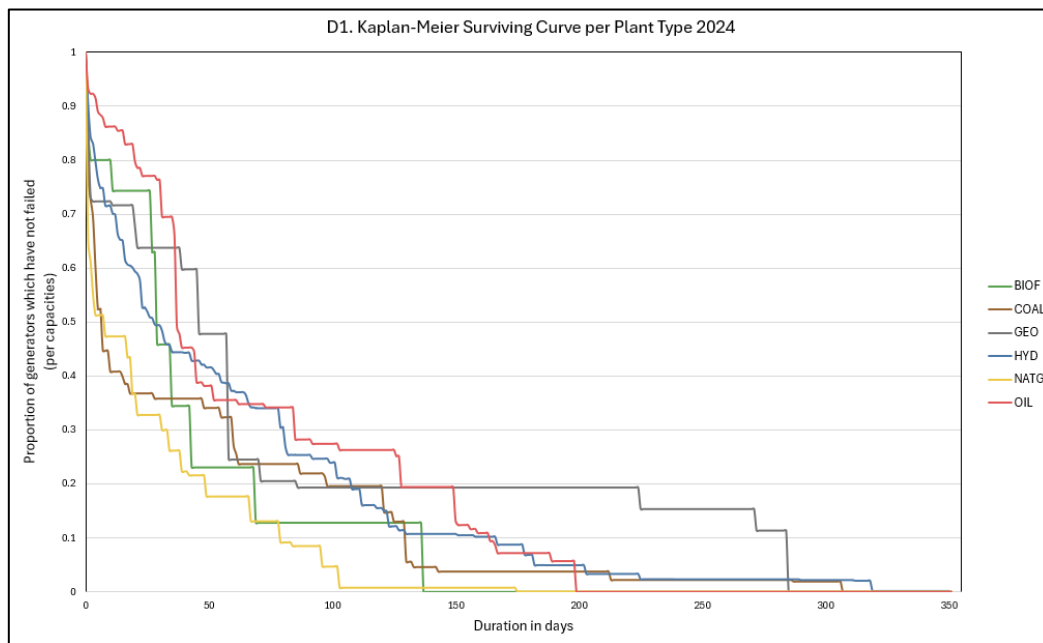


Figure 21. KMSC per Capacity, 2024

Table 18. KMSC Units and Capacity, 2024

Plant Type	No. of Units	Total Capacity
Biofuel	9	105
Coal	36	306
Geothermal	18	501
Hydro	154	5,109
Natural gas	29	6,759
Oil	57	874

- **D2. KMSCA 2024:** Based on survival by generator type and unit count, it was observed that after 50 days of operation following planned maintenance activities, **Geothermal, Coal,** and **Oil** Plants recorded survival ratios of 44%41%, and 36%, respectively (see Figure 22). The number of units and total capacity per plant type represented in the graph are shown in Table 18.

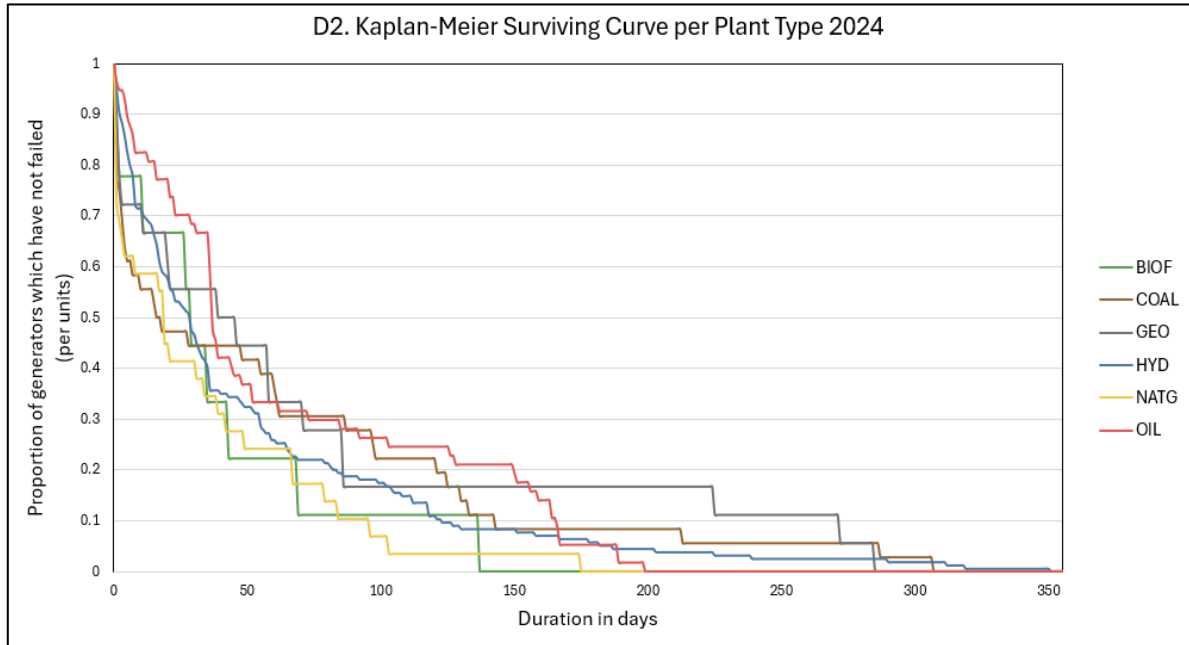


Figure 22. KMSC per Individual Unit, 2024

- **D3. KMSCA 2024:** From a regional survival perspective, it was observed that after 50 days of operation following planned maintenance activities, 40% of Luzon region units remained operational, while Visayas recorded 35% and Mindanao 25% survival. This indicates better survival performance among Luzon plants. (see Figure 23)

D3. Kaplan-Meier Survival Curve per Region 2024

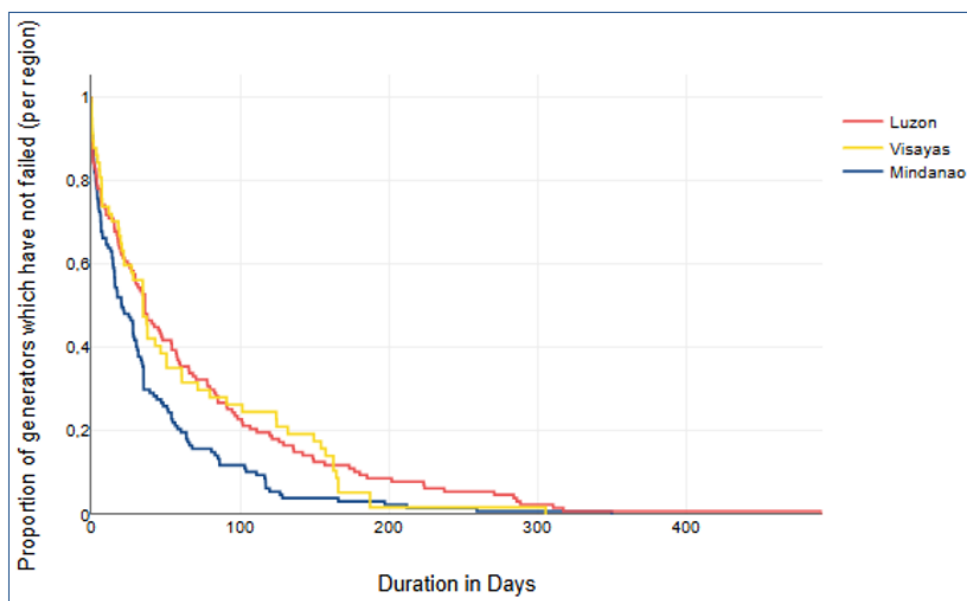


Figure 23. KMSC per Region, 2024

### January to June 2025

- **E1. KMSCA 2025:** In terms of survival by generator type and capacity, covering the January-June 2025 billing period, it was observed that after 20 days of operation following planned maintenance activities, **Natural Gas, Hydro, and Geothermal** Plants recorded survival ratios of 44%, 25%, and 22%, respectively (see Figure 24). The number of units and total capacity per plant type represented in the graph are shown in Table 19.

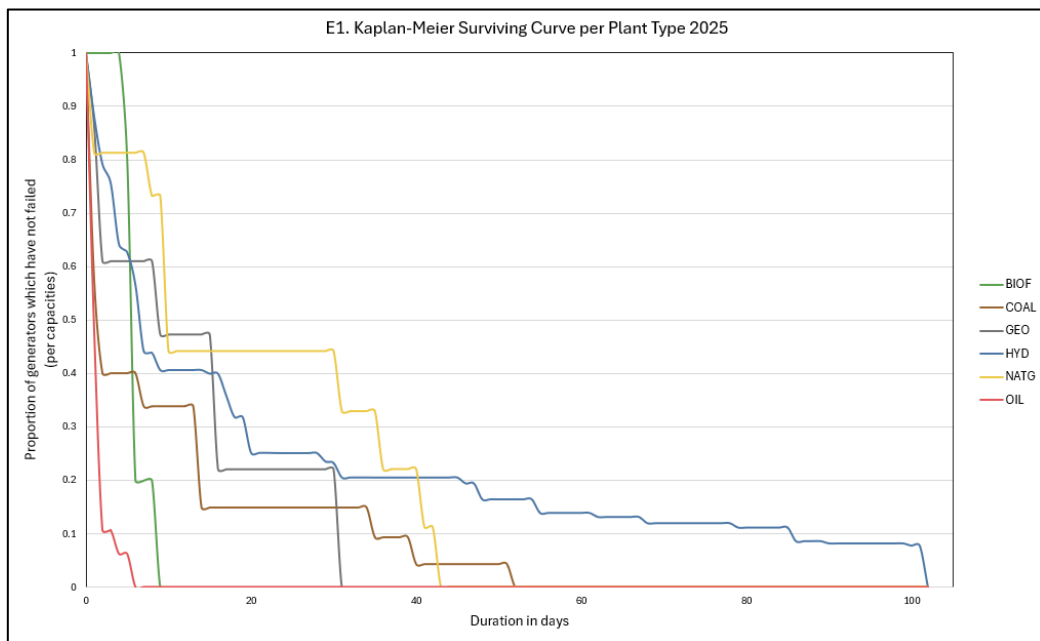


Figure 24. KMSC per Capacity, 2025

Table 19. KMSC Units and Capacity, 2025

Plant Type	No. of Units	Total Capacity
Biofuel	3	30
Coal	11	2,426
Geothermal	5	226
Hydro	56	2,363
Natural gas	8	2,354
Oil	9	113

- **E2. KMSCA 2025:** In terms of survival by generator type and unit count, it was observed that after 20 days of operation following planned maintenance activities, **Natural Gas, Hydro, and Coal** Plants recorded survival ratios of 50%, 33%, and 27%, respectively (see *Figure 25*). The number of units and total capacity per plant type represented in the graph are shown in Table 19.

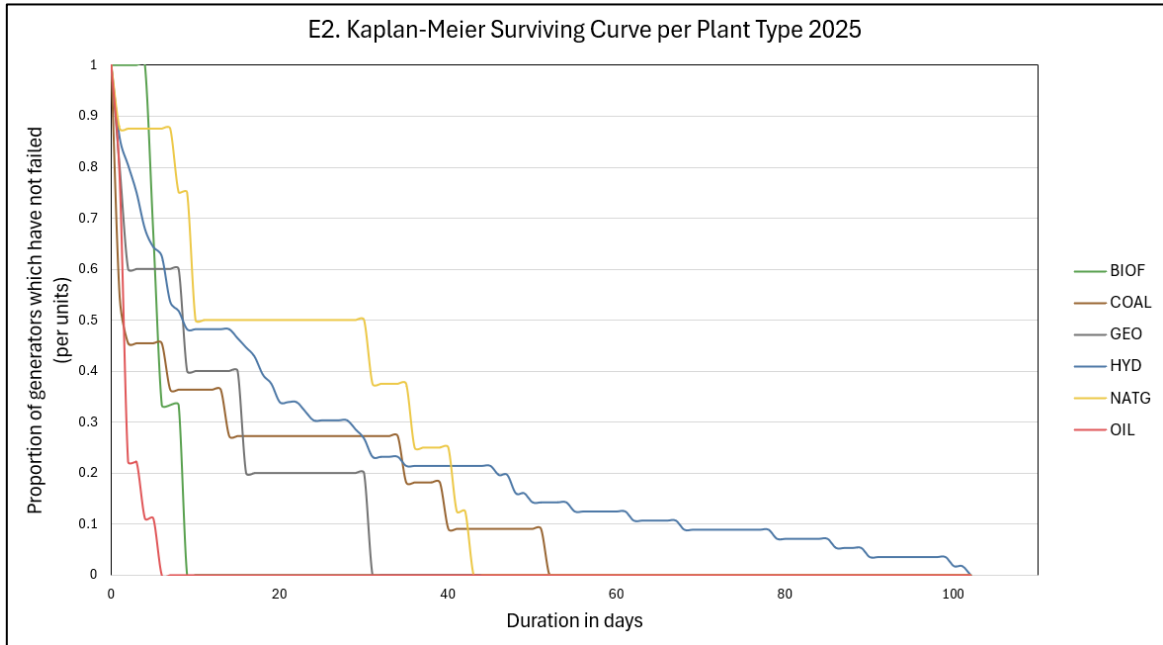


Figure 25. KMSC per Individual Unit, 2025

- **E3. KMSCA 2025:** From a regional survival perspective, it was observed that after 20 days of operation following planned maintenance activities, 40% of Mindanao region units remained operational, while Luzon recorded 25% and Visayas 7% survival. This indicates better survival performance among Mindanao plants. (see *Figure 26*)

E3. Kaplan-Meier Survival Curve per Region 2025

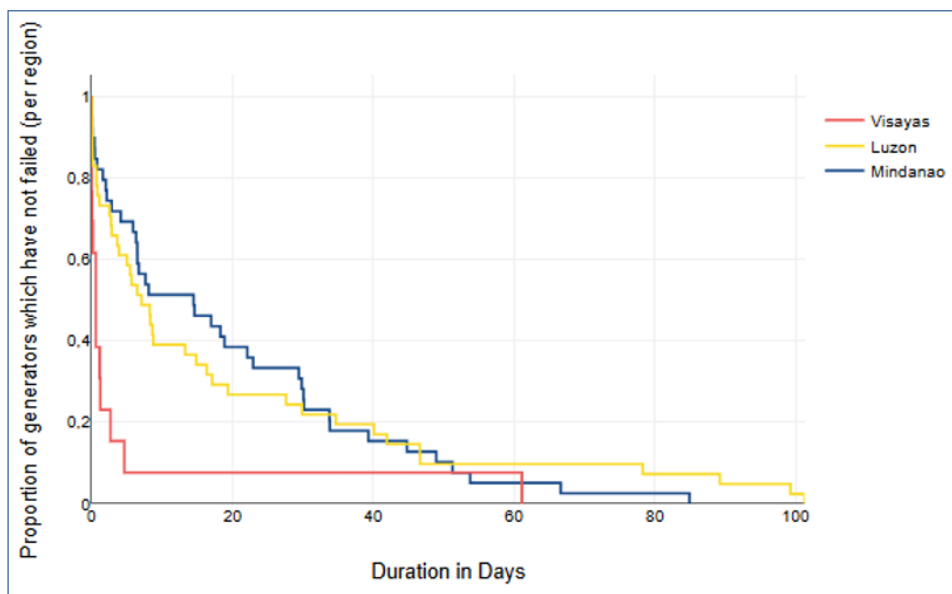


Figure 26. KMSC per Region, 2025

### C. USING THE CORRELATION ANALYSIS BETWEEN THE AVERAGE MARKET PRICE AND OUTAGE

An analysis was also conducted to examine the relationship between the average market price and the average outage level during the summer season (March to May billing months) across all regions. The objective of this assessment was to determine whether variations in outage levels moves with market price behavior, and to evaluate the degree of correlation across different years.

For the Luzon region, based on the 12-month data, the relationship between outages and energy prices in summer is effectively **null**. Pearson ( $r = 0.02$ , 95% CI: **-0.56 to 0.59**) and Spearman ( $\rho = -0.06$ , 95% CI: **-0.77 to 0.61**) both span zero widely, indicating **no reliable linear or monotonic association** in CLUZ’s summer data ( $n = 12$ ). (see Table 20 & Figure 27)

In the Visayas region, based on the 12-month data, the results show **no evidence of a systematic link**. Pearson ( $r = -0.02$ , 95% CI: **-0.59 to 0.56**) and Spearman ( $\rho = -0.01$ , 95% CI: **-0.61 to 0.55**) are near zero with wide CIs including zero, indicating outages are **not a reliable signal** for price shifts in CVIS during summer. (see Table 20 & Figure 28)

For the Mindanao region, based on the 9-month data, there is a **strong positive association** between summer outages and prices. Pearson ( $r = 0.81$ , 95% CI: **0.31 to 0.96**) and Spearman ( $\rho = 0.87$ , 95% CI: **0.36 to 1.00**) are both clearly positive, implying that higher outages tend to coincide with higher prices and that the pattern is **consistently monotonic**. (see Table 20 & Figure 29)

Table 20. Correlation Summary

Region	N (months)	Pearson r	95% CI (Pearson)	Spearman rho	95% CI (Spearman)
Luzon	12	0.020	[-0.560, 0.587]	-0.056	[-0.766, 0.614]
Visayas	12	-0.021	[-0.588, 0.559]	-0.007	[-0.610, 0.552]
Mindanao	9	0.808	[0.312, 0.958]	0.867	[0.358, 1.000]

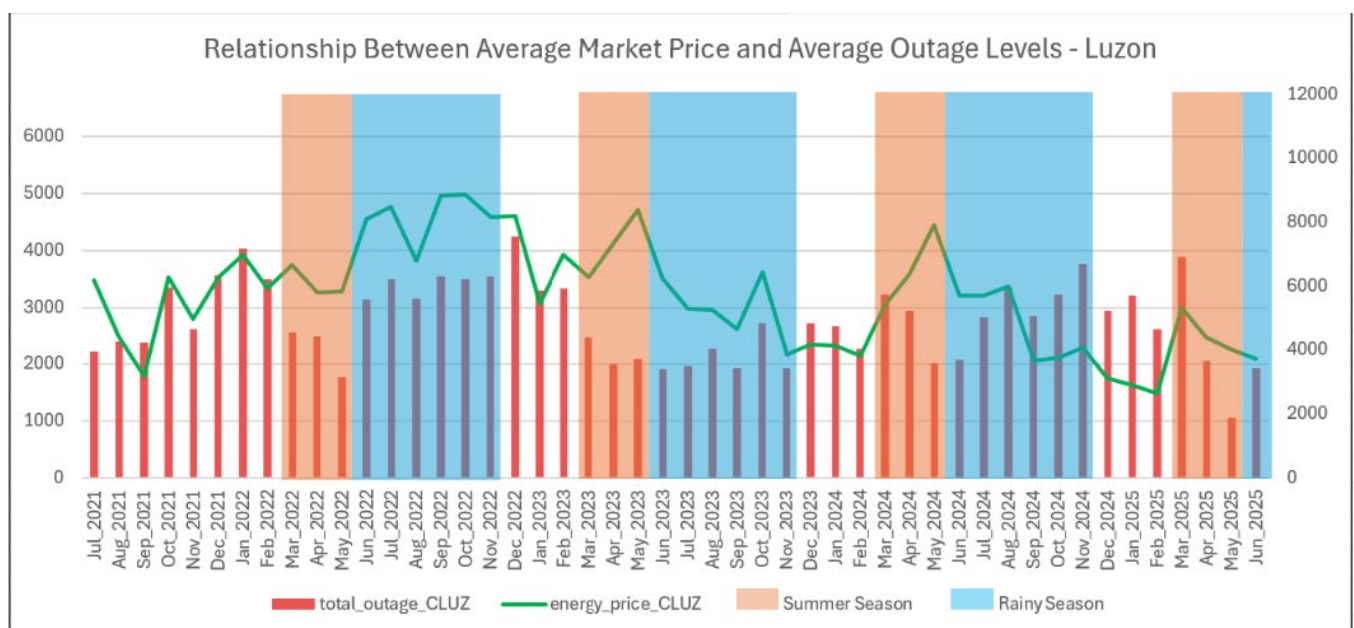


Figure 27. Correlation Between Average Market Price and Average Outage Levels in Luzon During the Summer Season

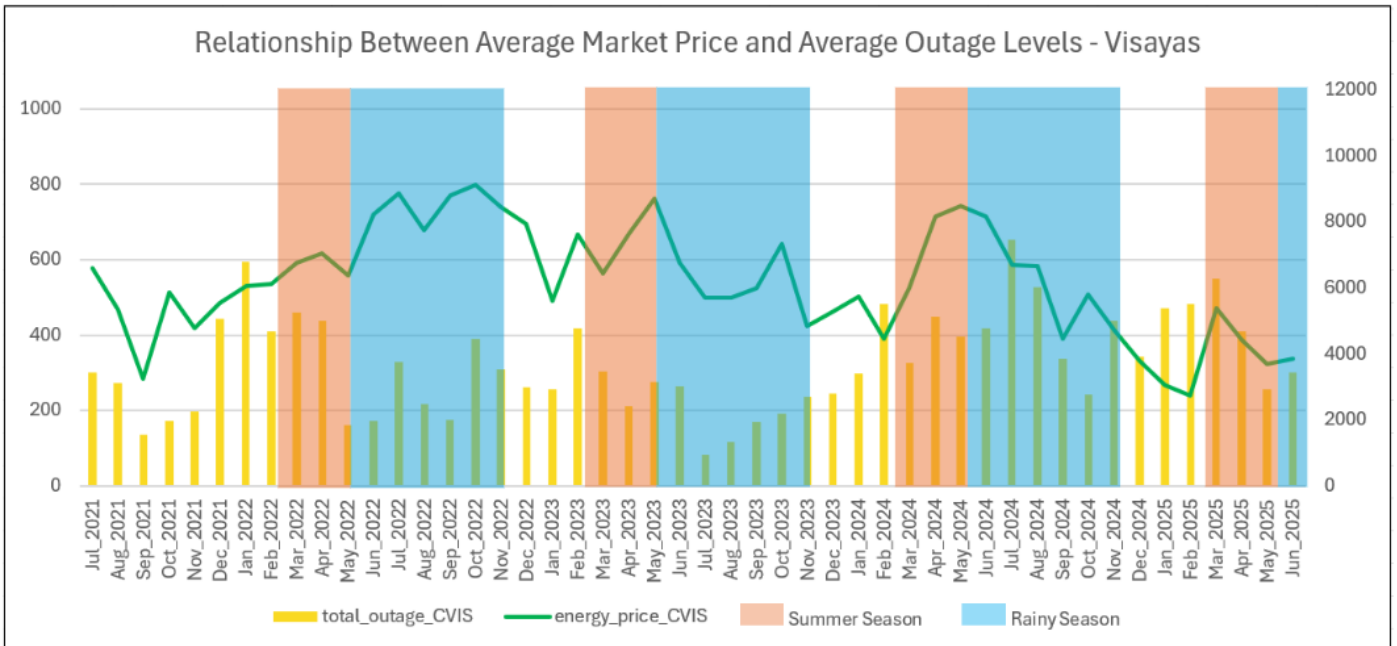


Figure 28. Correlation Between Average Market Price and Average Outage Levels in Visayas During the Summer Season

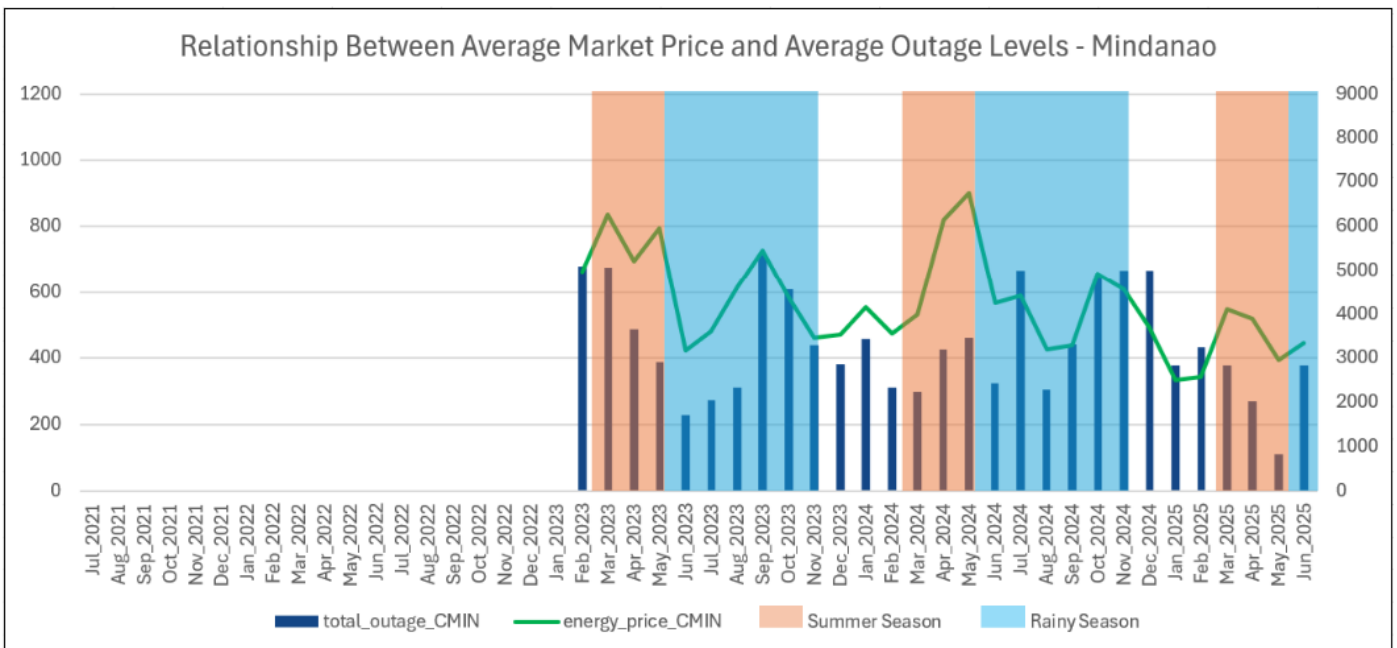


Figure 29. Correlation Between Average Market Price and Average Outage Levels in Mindanao During the Summer Season

## 7.0 CONCLUSIONS

This Generator Outage Study provides an evaluation of the reliability performance of power plants in the Philippines from July 2021 to June 2025 using Reliability Performance Indices, outage trend analysis, and Kaplan-Meier Survival Curve Assessment (KMSCA). The findings highlight persistent challenges in both planned and unplanned outage management across multiple plant types, particularly among mid-aged and newly commissioned units. While most generating units operated within allowable limits, a significant portion exceeded planned and unplanned outage thresholds for planned outage factor (POF) and unplanned outage factor (UOF).

The data shows that exceedances followed a distinct pattern over the five-year period, rising sharply in 2022, dropping slightly in 2023, and presenting a mixed profile again in 2024 with notably high values in several metrics, before improving significantly in 2025. The year 2022 recorded the highest POF exceedances both in terms of units at **14.33%** and total capacity at **34.65%**, narrowly surpassing the 2024 capacity level. For UOF, the highest percentage of affected units appeared in 2024 at **19.20%**, while the highest total capacity exceedance occurred in 2022 at **24.09%**. Across all years, exceedances were largely driven by **Coal units**, both mid-aged and new, especially in Luzon, with **Natural Gas** and **Hydro Plants** also contributing significantly. These coal related outages were predominantly driven by boiler integrity issues, rotating equipment vibration, auxiliary system failures, and protection system activations. **Geothermal units** were most prominent in the Visayas, while **Hydro** along with some Coal units were frequently observed in Mindanao during 2023-2024, with Geothermal related outages were generally occurring due to equipment and electrical failures, control system issues, and environmental or external grid-related factors. Hydro units commonly experienced outages due to mechanical or electrical equipment failures, and protection or control system trips that automatically shut down the units to prevent damage.

Year	POF Exceeded			UOF Exceeded		
	Percentage of Units (%)	Total Capacity (MW & %)	Details	Percentage of Units (%)	Total Capacity (MW & %)	Details
2021	5.41%	3,378 MW (17.20%)	15.30% Mid-aged Units: <b>Natural Gas</b> and <b>Coal</b> Plants mostly in <b>Luzon</b> .	9.56%	2,786 MW (14.19%)	6.07% Mid-aged Units: <b>Coal</b> and <b>Geothermal</b> Plants mostly in <b>Visayas</b> & 7.15% New Units: <b>Coal</b> Plants mostly in <b>Luzon</b>
2022	14.33%	6,804 MW (34.65%)	19.10% Mid-aged Units: <b>Coal</b> , <b>Hydro</b> and <b>Natural Gas</b> Plants in mostly in <b>Luzon</b> & 11.67% New Units: <b>Coal</b> Plants mostly in <b>Luzon</b> .	13.06%	4,729 MW (24.09%)	8.42% Mid-aged Units: <b>Coal</b> Plants in <b>Luzon</b> and <b>Geothermal</b> Plants mostly in <b>Visayas</b> & 13.15% New Units: <b>Coal</b> Plants mostly in <b>Luzon</b> .
2023	12.30%	6,807 MW (28.56%)	15.80% Mid-aged Units: <b>Coal</b> , <b>Hydro</b> and <b>Natural Gas</b> Plants mostly in <b>Luzon</b> & 9.64% New Units: <b>Coal</b>	13.69%	4,945 MW (20.75%)	10.75% Mid-aged Units: <b>Coal</b> and <b>Hydro</b> Plants mostly in <b>Luzon</b> . And <b>Geothermal</b> Plants mostly in

Year	POF Exceeded			UOF Exceeded		
	Percentage of Units (%)	Total Capacity (MW & %)	Details	Percentage of Units (%)	Total Capacity (MW & %)	Details
			and <b>Natural Gas</b> Plants mostly in <b>Luzon</b> .			<b>Visayas</b> & 6.65% New Units: <b>Coal</b> and <b>Biofuel</b> mostly in <b>Luzon</b> and <b>Coal</b> in <b>Mindanao</b> .
<b>2024</b>	12.50%	8,817 MW (34.51%)	22.99% Mid-aged Units: <b>Coal</b> , and <b>Natural Gas</b> Plants mostly in <b>Luzon</b> and <b>Hydro</b> Plants in <b>Mindanao</b>	19.20%	5,621 MW (22.00%)	10.38% Mid-aged Units: <b>Coal</b> Plants mostly in <b>Luzon</b> and <b>Visayas</b> and <b>Hydro</b> mostly in <b>Mindanao</b> & 8.36% New Units: <b>Coal</b> and <b>Biofuel</b> Plants mostly in <b>Luzon</b> and <b>Oil</b> and <b>Hydro</b> Plants in <b>Visayas</b> and <b>Coal</b> Plants in <b>Mindanao</b> .
<b>2025</b>	3.33%	2015 MW (7.87%)	3.72% Mid-aged Units: <b>Hydro</b> Plants mostly in <b>Luzon</b> & 2.74% New Units: <b>Coal</b> Plants in <b>Luzon</b> .	6.88%	2,651 MW (10.36%)	7.76% New Units: <b>Natural Gas</b> and <b>Biofuel</b> Plants mostly in <b>Luzon</b> and <b>Hydro</b> Plants in <b>Mindanao</b> .

The survival analysis revealed distinct variations in operational performance across plant types. Newly and mid-aged Coal, Hydro, and Natural Gas plants experienced outages immediately or within one to three months following planned maintenance, while older plants, particularly Geothermal and Hydro, also exhibited short-term outages within the same period. Overall, technologies such as Geothermal, Hydro, and Oil demonstrated relatively longer survival durations following planned maintenance in several years, whereas Coal and Biofuel plants consistently exhibited shorter operational periods before encountering forced outages.

The examination of market conditions further showed evolving relationships between outage levels and average market prices. From 2022 to 2024, outage levels generally lacked correlation with market prices in Luzon and Visayas, implying that other system factors may have exerted greater influence.

Based on the 2021–2025 GOMP data, a clear and consistent pattern emerges across all grids: strict adherence to original, planned maintenance schedules is a predictor of long-term plant reliability. Luzon remained the most volatile due to aging coal units and reactive maintenance, while Visayas showed gradual stabilization from newer capacity additions despite ongoing issues among small diesel units. Mindanao demonstrated the highest overall stability, supported by disciplined, seasonally aligned maintenance of hydro and geothermal units. Overall, the findings suggest that unplanned or unscheduled maintenance activities reduce the stability and reliability of the grid, whereas disciplined compliance with planned outages significantly reduces forced outages and improves system stability.

## 8.0 RECOMMENDATIONS

Based on the findings of the study, several recommendations are proposed to strengthen outage management and enhance the reliability of the Philippine power system. First, maintenance planning and operational discipline must be improved, particularly for Coal, Natural Gas, and Biofuel Plants, which frequently exceed allowable outage limits. This includes improving the execution of scheduled maintenance. Additionally, the coordination process under the Grid Operating and Maintenance Program (GOMP) involving policymakers, regulations, and generating companies (Gencos) should be enhanced to ensure more effective collaborations.

For consideration in future studies is to review the current penalty structure under ERC Resolution No. 10, Series of 2020 to determine whether the fines imposed on generators exceeding the allowable outage days are commensurate with the operational risks and market impacts they cause. A penalty framework that considers outage duration, frequency, capacity size, and economic consequences may help improve the compliance.

The study further suggests that survival analysis tools may be considered as a reference in updating DOE and ERC evaluation processes, considering the limitations of existing reliability assessment approaches developed in earlier periods. This tool can provide systematic insights into technology specific reliability performance and help identify units susceptible to early forced outages. Generation companies are likewise encouraged to incorporate similar analytical methods into their internal maintenance and reliability programs.

Finally, the study emphasizes that outage levels, while increasingly correlated with market prices in recent years, are not the sole drivers of price fluctuations. Market assessments should consider other influencing factors, such as fuel supply constraints, system supply and demand patterns, transmission limitations, and bidding behavior. Integrating outage data with broader operational and economic indicators will provide a more comprehensive understanding of price formation.