**European Journal of Management and Marketing Studies**
ISSN: 2501 - 9988
ISSN-L: 2501 - 9988
Available on-line at: http://www.oapub.org/soc

DOI: 10.46827/ejmms.v11i1.2214 Volume 11 │ Issue 1 │ 2026

# A RESILIENCY MODEL FOR RENEWABLE ENERGY SYSTEMS AGAINST EXTREME NETWORK GRID STRESS: THE 2020 COVID-19 PANDEMIC IN MINDANAO

**Erick George Uy**[i]
Mindanao Field Office,
Department of Energy (DOE),
Philippines
College of Development Management,
University of Southeastern Philippines,
Davao City, Philippines

**Abstract:**
The COVID-19 pandemic has highlighted critical vulnerabilities in global power systems, particularly in regions like Mindanao, Philippines. This study aims to develop a comprehensive resiliency model for renewable energy (RE) systems by leveraging existing power system metrics in Mindanao. The model is structured into four profiles: energy balance, energy mix, cost, and reliability, each representing various aspects of the power system's performance before and during the pandemic. The findings reveal that the energy balance and energy mix profiles experienced slight impacts due to reduced demand and pre-pandemic planning, achieving resiliency scores of 16.33/18 and 13.5/18, respectively. The cost profile remained unaffected with a perfect resiliency score of 6/6, attributed to pre-pandemic power purchase agreements, while the reliability profile showed minimal disruption with a score of 4.67/6. Overall, the study achieved an aggregate resiliency score of 40.5/48, indicating that the Mindanao power system maintained stable operations during the pandemic. The research successfully incorporated RE performance into the resiliency model, though it acknowledges the model's limitations and suggests the inclusion of additional metrics for further refinement. This study contributes valuable insights into enhancing power system resilience, particularly in developing regions, amid unprecedented global challenges.

**JEL:** Q42, Q48, L94, C52, H12

**Keywords:** renewable energy systems, resilience modeling, power grid stability, extreme network stress, COVID-19 pandemic impact, Mindanao energy sector

[i] Correspondence: euy@doe.gov.ph

 

## 1. Introduction

The power sector is a cornerstone of modern economies, providing essential energy to industries, services, and households. Its role becomes even more critical during crises, such as the COVID-19 pandemic, which underscored the need for a reliable and resilient power infrastructure. The pandemic accelerated existing trends, reshaping both business and societal interactions while revealing vulnerabilities in the Philippines' power market [1]. The Department of Energy (DOE) reported significant reductions in electricity demand across the country during the pandemic—30% in Luzon, 17% in Visayas, and 25% in Mindanao—reflecting the impact of lockdown measures on industrial and commercial activities, contrasted with increased residential consumption [2]. These fluctuations in electricity demand are illustrated in Figure 1, which shows the demand-supply situation in Mindanao during the pandemic.

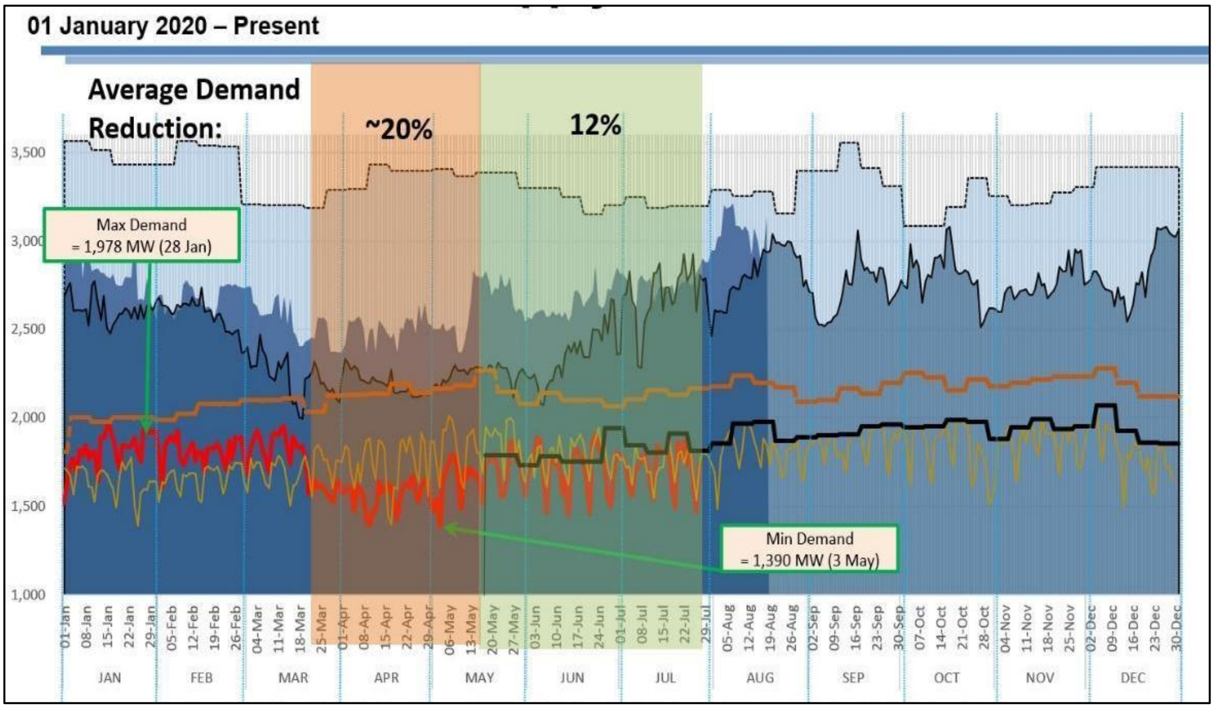


**Figure 1:** Mindanao Demand-Supply Situation

The need for a resilient power system in Mindanao is particularly pressing. The region has faced numerous power interruptions, with causes ranging from system failures and transient faults to external factors such as vegetation and wildlife [6]. These interruptions underscore the importance of developing a robust resilience model that can account for such disruptions and ensure reliable power supply under both normal and crisis conditions.

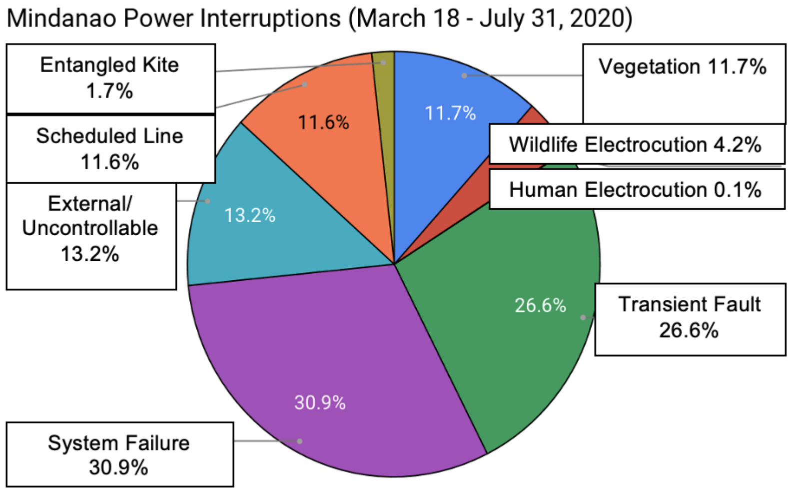


**Figure 2:** Mindanao Power Interruptions (March 18 - July 31, 2020)

### 1.1 Problem Statement

The COVID-19 pandemic has exposed significant weaknesses in the power systems of many regions, including Mindanao. The increased demand for electricity, driven by factors such as urbanization, industrialization, and the automation of production processes, combined with the growing importance of uninterrupted power for digital communication, highlights the need for a resilient and adaptable power system. The current power infrastructure, however, is not fully equipped to handle such disruptions, leading to productivity losses and long-term economic consequences [2], [6]. Figure 3 provides an overview of the types of losses incurred by end-users during power outages, emphasizing the broader economic impact.

| Primary Electricity User | Direct Components of Outage Costs | Indirect Components of Outage Costs |
|---|---|---|
| Residential | • Welfare: Inconvenience, lost leisure, stress<br>• Monetary: Spoilage and property damage<br>• Health and Safety effects | • Spilover effects: Household members and firms |
| Industrial, Commercial, and Agricultural Firms | • Opportunity costs of idle resources such as land, labor, and capital<br>• Shutdown and restart costs<br>• Spoilage and damage<br>• Health and safety effects | • Spilover effects: Firms requiring intermediate goods<br>• Welfare: Reduced supply of final goods<br>• Health and safety related externalities |
| Infrastructure and Public | • Opportunity costs of idle resources<br>• Spoilage and damage | • Spilover effects: Impact on consumers and firms<br>• Health and safety externalities<br>• Potential for social costs in terms of looting, |

Source: Munasinghe & Sanghvi 1988, Centollela et. Al. 2006, additional inputs from the Office of Senator Win Gatchalian

**Figure 3:** Types of Losses Incurred During Power Outages by End-User

## 2. Literature Review and Proposed Solution

The concept of power system resilience is relatively nascent, emerging from the recognition that traditional reliability metrics do not fully capture the impacts of low-frequency, high-impact events such as those seen during the COVID-19 pandemic [12], [10]. Resilience, distinct from reliability, is defined as the ability of the power system to recover from such significant disruptions. Resilience models, as outlined by Raoufi et al., should be comprehensive, considering spatial-temporal effects, decision-making utility, and the differentiation between operational and infrastructural resilience [10]. However, the application of these models in the context of developing regions like Mindanao, particularly during an unprecedented global health crisis, remains underexplored.

Existing literature highlights several gaps in resilience research, particularly in the integration of renewable energy sources into resilience models. Denholm and Hand, as well as Cochran et al., emphasize the importance of flexibility in power systems, which includes the ability to respond to changes in net load, incorporating renewable energy, and adjusting to unforeseen conditions [10], [9]. However, many existing models do not adequately address the unique challenges posed by renewable energy variability and the specific socio-economic conditions of regions like Mindanao [8], [11]. Furthermore, traditional reliability metrics such as SAIFI, SAIDI, and MAIFI, though useful, fall short in capturing the full scope of resilience needed for modern power systems [7], [13].

This study proposes the development of a power system resilience model specifically tailored to the Mindanao electricity grid. By integrating resilience metrics with an emphasis on renewable energy performance, the model seeks to enhance the flexibility and robustness of the region's power infrastructure. This approach not only fills the gap in existing literature but also provides a practical framework for addressing the unique challenges faced by the power sector in Mindanao during crises such as the COVID-19 pandemic.

### 2.1 Innovation and New Value of Research

The research introduces a novel resilience model that incorporates both traditional reliability metrics and new resilience metrics tailored to the specific conditions and challenges of the Mindanao power sector. Unlike existing models, which primarily focus on developed regions with more stable power infrastructures, this model is designed to address the complexities of a developing region with a high reliance on renewable energy sources. The model’s novelty lies in its comprehensive approach, which includes the integration of spatial-temporal resilience metrics, considering renewable energy variability, and applying these metrics in real-time decision-making processes during crises.

This model provides critical insights for policymakers and industry stakeholders, offering a framework for improving power system resilience in Mindanao and other regions facing similar challenges. The findings will contribute to the broader field of power systems engineering by offering practical solutions that address the vulnerabilities exposed by the pandemic, ultimately enhancing the reliability and sustainability of power systems in the Philippines and beyond.

## 3. Method

### 3.1 Conceptual Framework

The conceptual framework guiding the development of the resiliency model is depicted in Figure 3.1. The primary inputs for the resiliency model were derived from reports maintained by the Department of Energy (DOE), National Grid Corporation of the Philippines (NGCP), and Energy Regulatory Commission (ERC). Expert consultations were also conducted to gain additional insights. The outputs of the resiliency model include the following profiles: energy balance, energy mix, cost, and reliability. These components are integral to the resiliency model, acknowledging that the concept of resiliency is relatively new in the power system. Therefore, the model heavily relies on existing power system metrics [10].

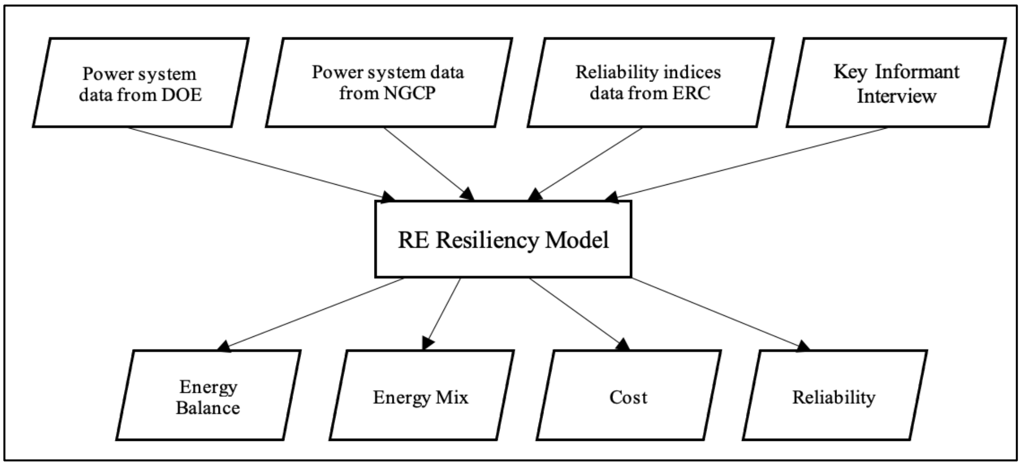


**Figure 4:** Conceptual framework of the study

### 3.2 Information Sources

The study relies on data sourced from the Department of Energy (DOE), National Grid Corporation of the Philippines (NGCP), and the Energy Regulatory Commission (ERC).

These sources provided key metrics, including:

1) Energy Delivery: Total electric energy consumed (MWh).
2) Peak Demand: Highest demand periods (MW).
3) Power Supply-Demand Scenario: Rated and available capacity, peak demand, and reserves (MW).
4) Generation per Fuel Type: MWh generated by coal, oil, geothermal, hydroelectric, solar, and biomass.
5) Conventional-vs-Renewable Generation: Comparative data on conventional and renewable energy.
6) Capacity per Fuel Type: Rated capacity for different energy sources (MW).
7) Average Distribution Rates: Cost of electricity across regions (₱/kWh).

8) Reliability Indices: SAIFI, SAIDI, and MAIFI metrics for distribution utilities.

Table 1 summarizes these information sources, emphasizing their relevance to developing a resiliency model.

| Information | Source |
|---|---|
| Energy Delivery | NGCP Operations (open-source data) |
| Peak Demand | NGCP Operations (open-source data) |
| Power Supply-Demand Scenario | Department of Energy |
| Generation per Fuel Type | Department of Energy |
| Conventional-vs-Renewable Generation | Department of Energy |
| Capacity per Fuel Type | Department of Energy |
| Average Distribution Rates | Mindanao Rates (DOE) |
| Reliability Indices | Mindanao Reliability Indices Summary (ERC) |

Due to time and scope limitations, not all data could be obtained. However, requests were made through the Freedom of Information (FOI) zx in Table 2.

**Table 1:** Data request log from ERC.

| Data Requested | Date | Tracking Code |
|---|---|---|
| Quarterly Reliability Report of DUs in Mindanao | 08/04/2020 | #ERC-544467777343 |
| Mindanao Distribution Utilities Reliability Indices for 2020 | 02/25/2021 | #ERC-196965514224 |
| Tolerable Ranges for SAIFI, SAIDI & MAIFI | 02/26/2021 | #ERC-511850592506 |

### 3.3 General Data Handling Procedure

This study utilizes IEEE 1366 standards to measure power system reliability, focusing on SAIFI, SAIDI, and MAIFI indices. These indices assess outage duration and frequency, complemented by data on power interruptions, demand, electricity rates, and generation mix. Secondary data was obtained through interactions with DOE and NGCP management, aimed at enhancing understanding and direct evaluation of the Mindanao Grid's performance.

Data were analyzed quantitatively to characterize trends and summarize key metrics. These were presented through tables, figures, and summary statistics, with year-to-year comparisons before and during the pandemic. The key data points include:

1) Energy Delivery (2015-2020): Trends in energy consumption.
2) Peak Demand (2013-2020): Yearly peak demand analysis.
3) Power Supply-Demand Scenario (2019-2020): Daily granulation to compare pre- and post-pandemic periods.
4) Generation per Fuel Type (2018-2020): Monthly performance analysis by energy source.
5) Conventional vs. Renewable Generation (2018-2020): Comparison of generation sources.
6) Average Distribution Rates (2016-2020): Regional distribution rates with confidentiality preserved.

7) Reliability Indices: Analysis by Distribution Utility (DU), considering unique circumstances affecting reliability.

### 3.4 Key Informant Interview

A consultation with ASec. Redentor Delola from the Department of Energy centered on the rationale for using existing reliability metrics within the resiliency model. It was noted that reliability metrics such as Loss of Load Expectation (LOLE), Loss of Load Frequency (LOLF), and Loss of Load Probability (LOLP) are seldom employed in the Philippines, necessitating reliance on SAIFI, SAIDI, and MAIFI indices. These indices are maintained by the National Grid Corporation of the Philippines (NGCP) and provide a whole-system perspective crucial for reliability evaluations. Additionally, reliability performance in the Philippines is evaluated through a system of incentives, which raises some transparency issues in reporting. This consultation emphasized the utility of existing metrics for capturing the reliability of the power system, reinforcing their role as essential components of the resiliency model in the Mindanao power grid.

### 3.5 Drafting the Resiliency Model

The development of the resiliency model focused on ensuring that resiliency metrics are measurable, comparable, and replicable using real-world power system data. The model must facilitate comparisons between different systems and within a system before and after resilience enhancement to demonstrate the effectiveness of such strategies. The data sources were categorized into four profiles: Energy Balance, Energy Mix, Cost, and Reliability. These profiles encompass key parameters such as energy delivery, peak demand, generation per fuel type, and reliability indices. Each parameter was assessed using predefined tolerance levels as shown in table 3.3 to determine how the power system's performance during the pandemic deviated from pre-pandemic norms. The overall resiliency score was calculated based on these assessments, providing a practical and replicable framework for evaluating resiliency in future scenarios and similar power systems.

**Table 2:** Measure of resiliency as a function of percent tolerance.

| Tolerance Levels | Resiliency Points |
|---|---|
| ± 1-5% | 6 |
| ± 6-10% | 5 |
| ± 11-15% | 4 |
| ± 16-20% | 3 |
| ± 21-25% | 2 |
| ± 26-30% | 1 |
| > ± 30% | 0 |

## 4. Results and Discussion

### 4.1 RE Resiliency Model

The developed resiliency model for renewable energy in Mindanao comprises four main profiles: energy balance, energy mix, cost, and reliability (Figure 5). These profiles encompass key parameters such as energy delivery, peak demand, generation per fuel type, average distribution rates, and reliability indices. Each profile serves as a classification of the available and existing power system metrics in Mindanao, facilitating the assessment of the system's resilience.

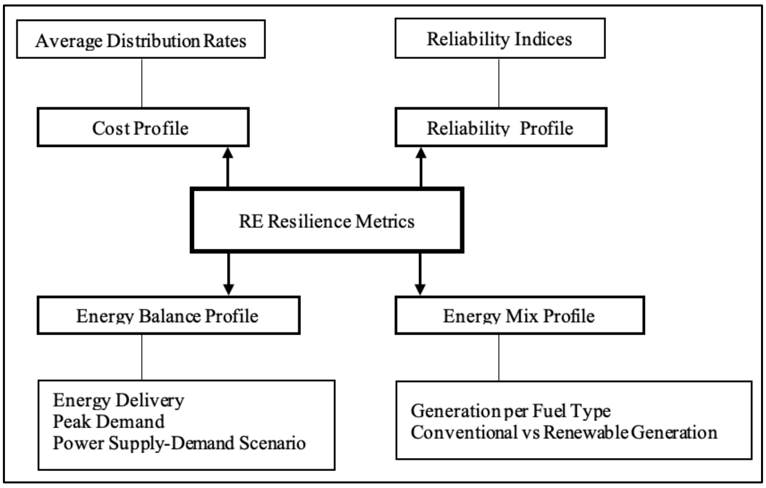


**Figure 5:** Resiliency Model for Renewable Energy in Mindanao

This section, it explains the results of the research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables, and others that make the reader understands easily [10], [15]. The discussion can be made in several sub-sections.

### 4.2 Energy Balance Profile

The energy balance profile assesses the resilience of Mindanao's power system during the pandemic, focusing on energy delivery, peak demand, and the power supply-demand scenario.

#### 4.2.1 Energy Delivery

Energy delivery, measured in MWh, generally increased from 2015 to 2019, with a notable exception in 2017 due to the Marawi Siege, which caused a dip (Figure 6).

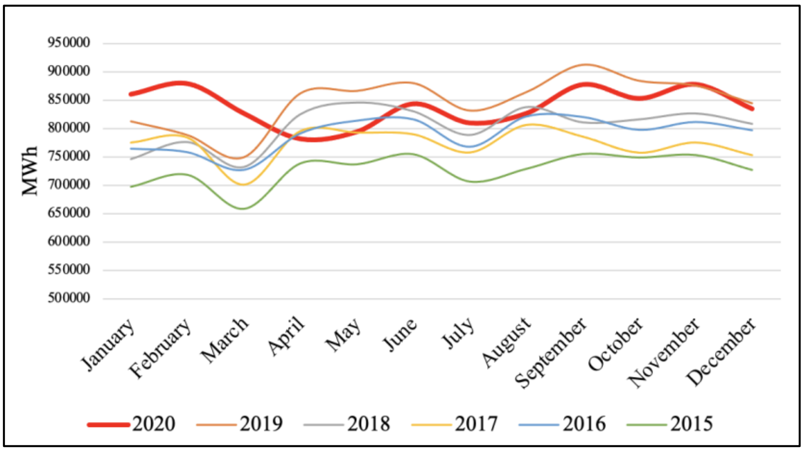


**Figure 6:** Energy delivery for Mindanao from 2015 to present

In 2020, the trend was erratic, reflecting the impact of the pandemic and lockdowns, particularly in April 2020, when energy demand dropped significantly due to community quarantines (Figure 7). A slight recovery began in August 2020 as restrictions were eased. This reduction in energy demand highlights the decreased economic productivity in Mindanao during the pandemic.

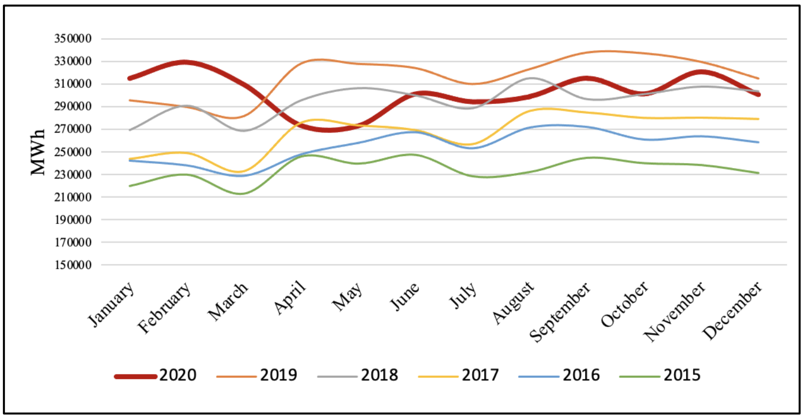


**Figure 7:** Energy delivery for Davao Region from 2015 to present

### 3.2.2 Peak Demand

Peak demand, the highest recorded electric power demand over a period, shows seasonal variations, with peaks usually occurring in the last quarter due to Christmas festivities and during the summer months. In 2020, a significant deviation was noted, with the highest peak demand recorded in February, just before the lockdown, followed by a drop, which gradually recovered by May (Table 5, Figure 8).

**Table 5:** Peak demand in Mindanao from 2013-2020.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 1284 | 1244 | 1245 | 1226 | 1366 | 1364 | 1384 | 1326 | 1256 | 1219 | 1397 | 1428 |
| 2014 | 1354 | 1351 | 1344 | 1310 | 1339 | 1416 | 1390 | 1386 | 1391 | 1441 | 1469 | 1453 |
| 2015 | 1386 | 1380 | 1370 | 1406 | 1438 | 1435 | 1397 | 1446 | 1453 | 1507 | 1517 | 1510 |
| 2016 | 1497 | 1472 | 1485 | 1514 | 1590 | 1585 | 1536 | 1582 | 1592 | 1645 | 1642 | 1653 |
| 2017 | 1589 | 1613 | 1633 | 1697 | 1692 | 1675 | 1624 | 1705 | 1708 | 1699 | 1726 | 1760 |
| 2018 | 1665 | 1704 | 1729 | 1781 | 1847 | 1741 | 1762 | 1821 | 1794 | 1835 | 1833 | 1853 |
| 2019 | 1775 | 1726 | 1817 | 1892 | 2013 | 2001 | 1943 | 1977 | 1960 | 1987 | 1995 | 1992 |
| 2020 | 1960 | 1977 | 1953 | 1673 | 1798 | 1907 | 1867 | 1911 | 1944 | 1896 | 1961 | 1931 |

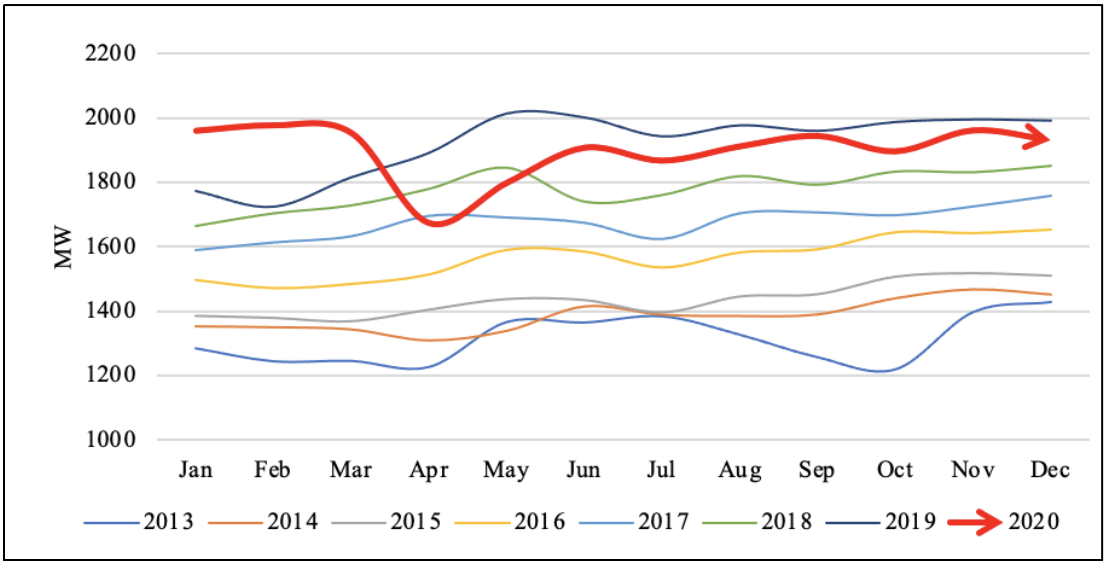


**Figure 8:** Peak demand trends in Mindanao from 2013-2020

### 3.2.3 Power Supply-Demand Scenario

Figure 9 illustrates the energy supply and demand scenario in Mindanao for 2019 and 2020, covering rated capacity, available capacity, peak demand, and gross reserve (MW). In 2020, trends showed slight improvements over 2019, except for peak demand, which decreased during the Enhanced Community Quarantine (ECQ) in April 2020. Despite the pandemic, Mindanao's power supply remained stable, with performance curves generally higher compared to 2019. Regulatory frameworks and dispatch protocols were maintained, ensuring the robustness of the Mindanao Grid during the lockdown.

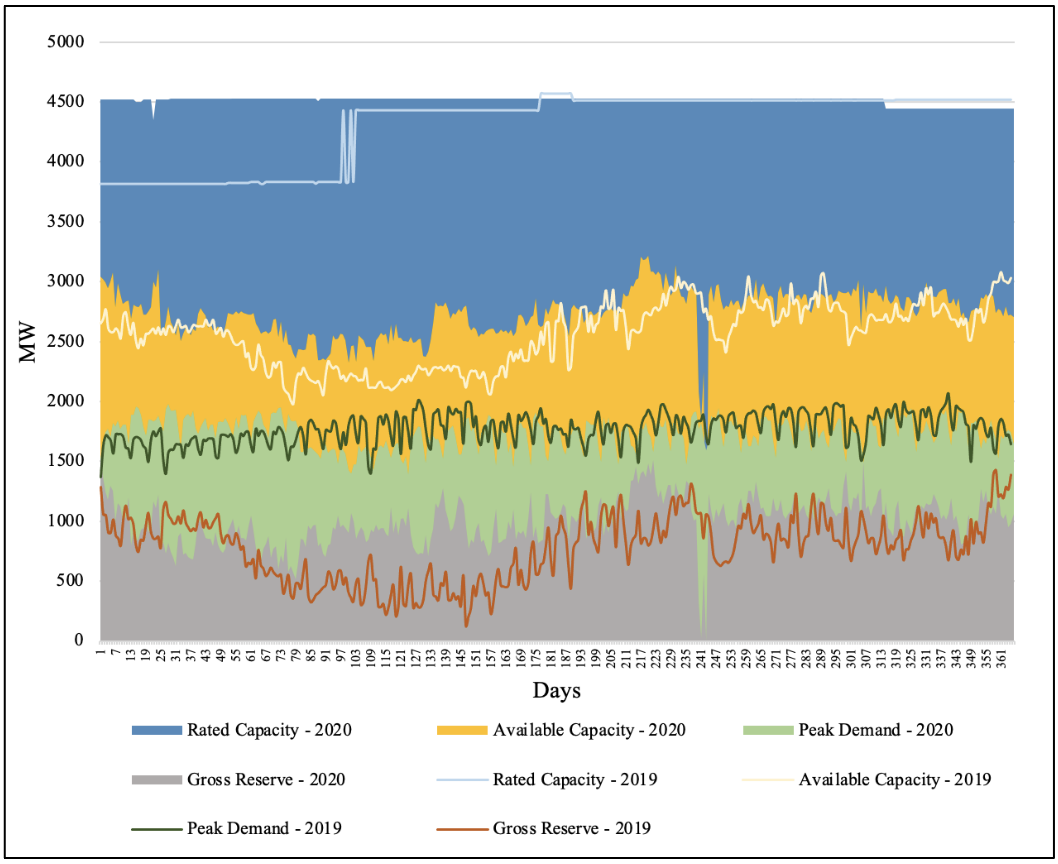


**Figure 9:** Power supply-demand scenario in Mindanao from 2019-2020

### 4.3 Energy Mix Profile

The energy mix profile assesses the resilience of Mindanao's energy supply during the pandemic, focusing on generation per fuel type, conventional vs. renewable generation, and capacity per fuel type.

#### 4.3.1 Generation per Fuel Type

The Mindanao grid utilizes six main power sources: coal, oil-based, geothermal, hydroelectric, solar, and biomass. Over the past three years, coal generation steadily increased from 6.9 TWh in 2018 to 8.5 TWh in 2019. However, the 2020 nationwide lockdown led to a slight decline, with total coal generation reaching 8.9 TWh. Oil-based generation, often used as a backup, showed erratic trends, dropping to 157 GWh in 2020, its lowest in three years.

Renewable sources like geothermal and hydroelectric have shown a decline, with geothermal dropping from 789 GWh in 2018 to 696 GWh in 2020. Hydroelectric generation decreased from 3.6 TWh in 2018 to 2.6 TWh in 2020. Despite these trends, solar and biomass generation saw increases, with solar reaching an all-time high of 106 GWh in 2020, and biomass rising to 99.5 GWh. These trends are illustrated in Figure 10.

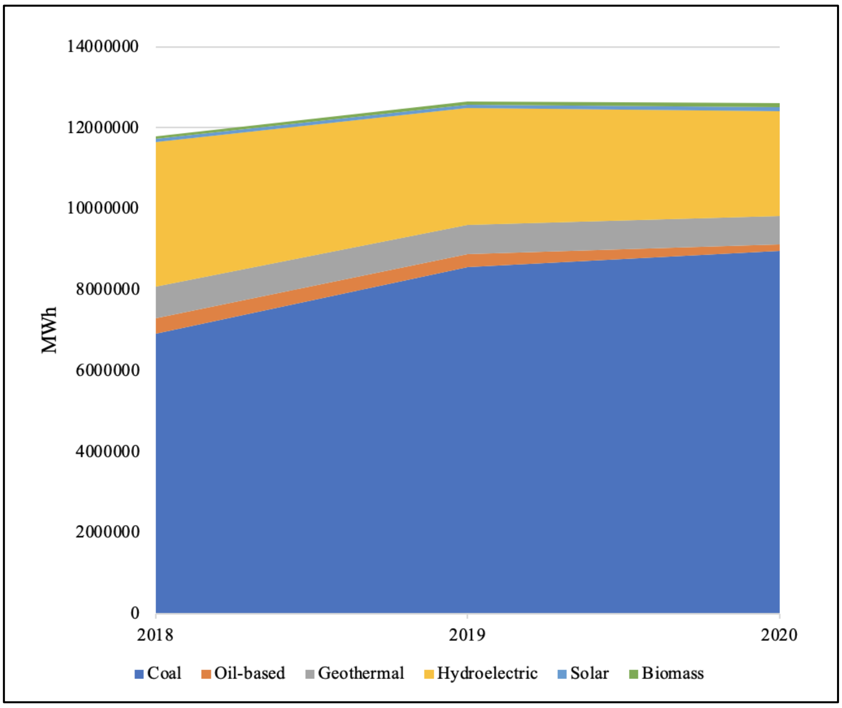


**Figure 10:** Generation per fuel type in Mindanao from 2018 to 2020

### 3.3.2 Conventional vs. Renewable Generation

Conventional sources (coal and oil) have shown a consistent upward trend in generation from 2018 to 2020 (Figure 4.7). Coal remains the dominant energy source in Mindanao, while renewable energy generation, mainly from hydroelectric and geothermal sources, has decreased. This decrease is attributed to the pandemic's impact on energy demand, as seen in Figure 11.

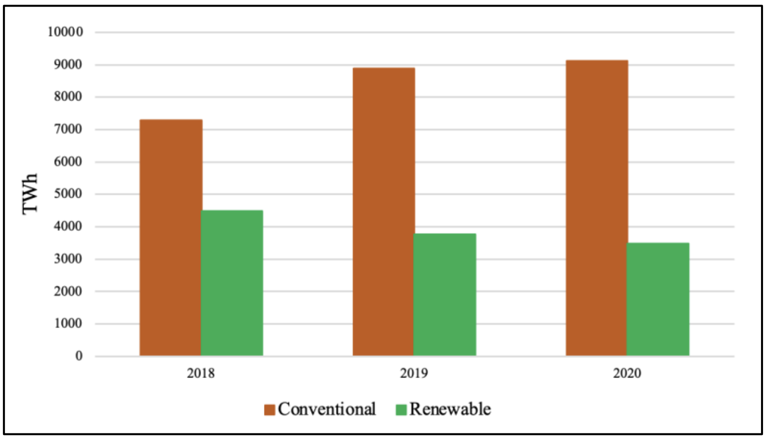


**Figure 11:** Generation comparison between conventional and renewable energy sources in Mindanao from 2018-2020

### 4.3.3 Capacity per Fuel Type

Coal remains the primary energy source in Mindanao, with a significant capacity increase from 2019 to 2020 (Figure 11). Most regions have maintained their generation capacities, with slight year-to-year variations. Region X leads in coal generation capacity, while Region XI has the largest hydro capacity.

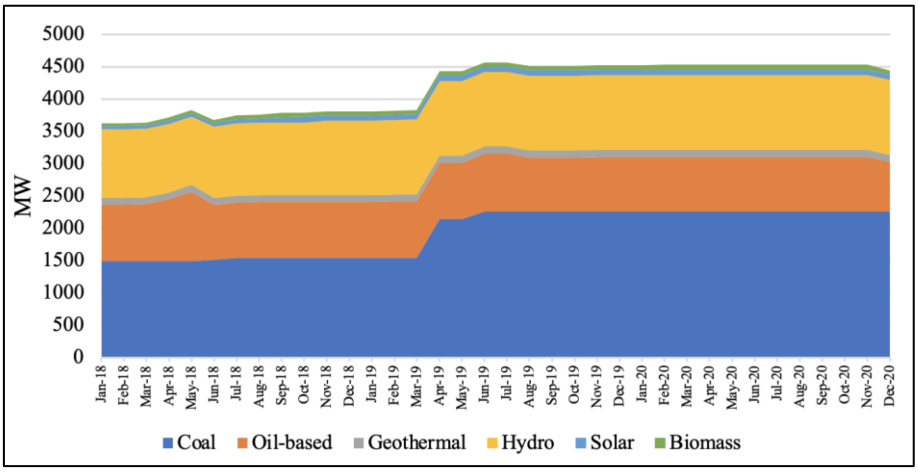


**Figure 11:** Capacity per fuel type in Mindanao

**4.4 Cost Profile**

The cost profile analyzes the average distribution rates across regions in Mindanao, reflecting the cost of energy to consumers. Figure 4.9 presents the average distribution rates from 2016 to 2020. Despite the pandemic, distribution rates remained stable as they were determined by long-term power purchasing contracts. Notably, Region X, which has the highest generation capacity, also has the highest distribution rates, as shown in Figure 12.

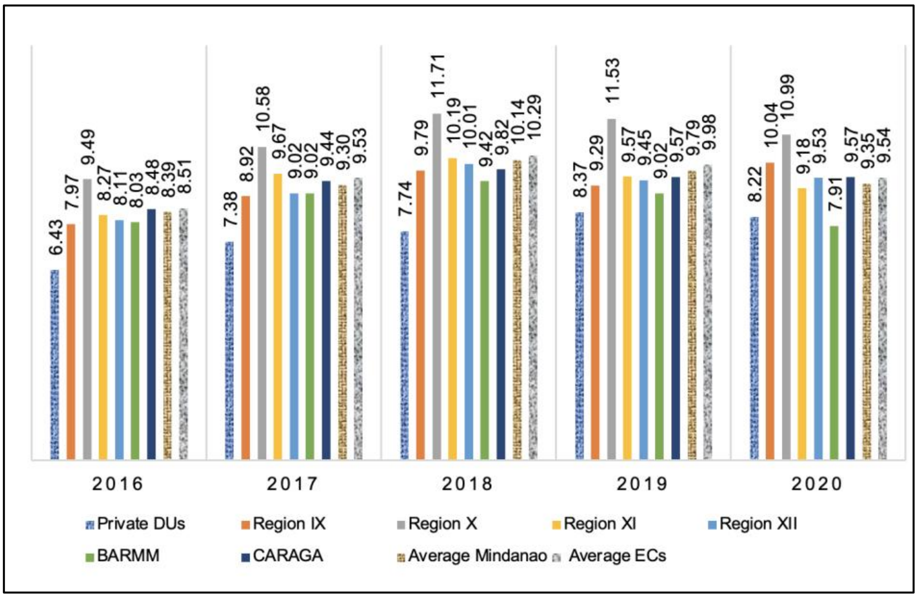


**Figure 12:** Average distribution rates (PhP/kWh) in Mindanao per region

**3.5 Reliability Profile**

The Mindanao power system's reliability is measured using the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index

(SAIDI), and Momentary Average Interruption Frequency Index (MAIFI). These indices reflect the frequency and duration of power interruptions, which are essential for assessing the system's resilience. Although interruptions are typically rare, their impact can be significant. The study highlights that while some regions face interruptions due to specific issues like terrorism, overall reliability in Mindanao has improved from 2015 to 2020 (Figure 13). This improvement suggests enhanced system resilience, particularly in maintaining energy supply during the pandemic.

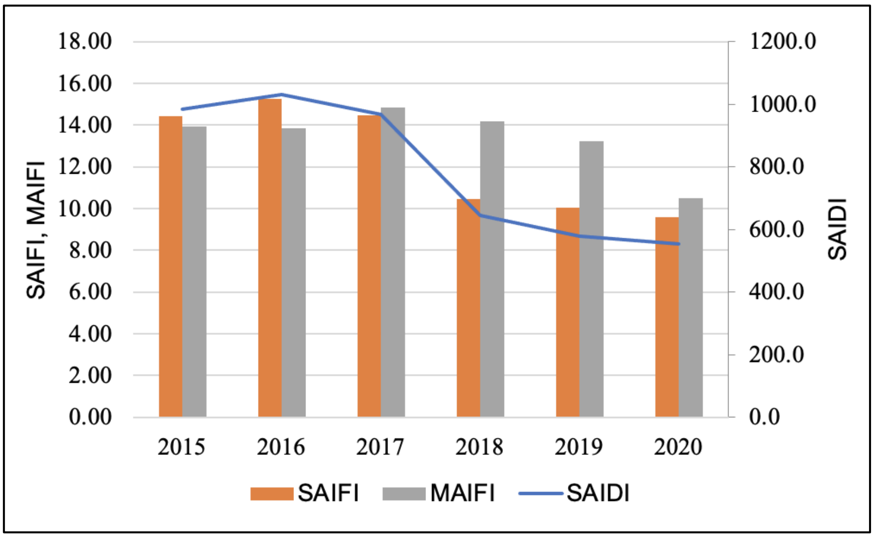


**Figure 13:** Reliability indices (average) in Mindanao from 2015-2019

### 3.6 Implications for the Resiliency of Renewable Energy During Extreme Events

The resiliency model for renewable energy in Mindanao, which includes energy balance, energy mix, cost, and reliability profiles, demonstrated that most metrics showed minimal disruption during the 2020 pandemic. The overall resiliency score, based on the changes in these metrics, was 40.5, indicating strong performance (see Table 6 for detailed metrics).

**Table 6:** Summary of effect of Pandemic to the RE resiliency profiles.

| RE Resiliency Metric Profiles | Profile Components | Reference (baseline) | Points | Categories |
|---|---|---|---|---|
| Energy Balance profile | Energy delivery | 2018-2019 | 6 | Tolerable |
| | Peak demand | 2013-2019 | 6 | Tolerable |
| | Power supply-demand scenario | 2019 | 3.67 | Tolerable |
| Energy Mix profile | Generation per fuel type | 2018-2019 | 4 | Tolerable |
| | Conventional vs renewable generation | 2018-2019 | 5.5 | Tolerable |
| | Capacity per fuel type | 2018-2019 | 4 | Tolerable |
| Cost profile | Average distribution rates | 2016-2019 | 6 | Tolerable |
| Reliability profile | Reliability indices | 2015-2019 | 3.67 | Tolerable |
| | | **Total** | **40.5 / 48** | |

### 4.7 Limitations of the Resiliency Model

The resiliency model measures the system's response to the pandemic using existing metrics, but has several limitations. It lacks predictive capabilities, as it doesn't incorporate probabilistic metrics like VOLE/LOLP/VOLP. The model also doesn't account for future power cost projections or financial operations, which could have provided insights into the long-term sustainability and financial health of the power system during the pandemic.

## 5. Conclusion

The study successfully developed a resiliency model for the Mindanao power system during the COVID-19 pandemic, utilizing existing performance and reliability metrics. However, these metrics are not specifically designed for resilience, highlighting a gap in dedicated resiliency measures for power systems. Renewable energy (RE) systems demonstrated resilience in terms of generation and capacity during the pandemic, largely due to pre-pandemic planning and existing policies that ensure fair market performance alongside conventional energy systems.

## 6. Recommendations

The study recommends establishing dedicated resiliency metrics for power systems, including renewable energy (RE) systems, to better capture resilience beyond standard reliability measures. Incorporating predictive and probabilistic metrics such as VOLE, LOLP, and VOLP into the existing framework would provide a more comprehensive assessment. Furthermore, extending the study to include power systems across the entire Philippines, particularly in the competitive electricity markets of Luzon and Visayas, could offer broader insights into RE resilience. Additionally, further research is needed to develop a more robust resiliency model for REs, one that considers a wider range of factors, including economic, social, political, safety, and public health impacts. Such research should aim to establish logical correlations between these areas and the power system's resilience, especially in the context of rare events like pandemics.

## Acknowledgements

With deep gratitude, I thank God for His grace and wisdom. I appreciate my family, especially my parents, siblings, and wife, Marigold, for their support. Thanks to my advisers, panel committee, DOE, NGCP, ERC, colleagues, and friends for their invaluable contributions and encouragement throughout this study.

**Conflict of Interest Statement**

The authors declare no conflicts of interest.

**About the Author(s)**

Erick George Uy has been a public servant through the Department of Energy (DOE) Philippines for more than 9 years. He is currently a Supervising Science Research Specialist (Supervising SRS) and is mandated to assist in planning, formulation, implementation, coordination, review, evaluation, and monitoring of the Department's programs, projects, and activities related to research, development, management, and utilization of energy resources in Mindanao. Engr. Uy obtained his bachelor's degree in electrical engineering from the University of Southeastern Philippines (USEP). In addition to his undergraduate degree, he is also a master's degree holder in Renewable Energy from Ateneo de Davao University. Currently, he is a Ph.D. Candidate in Urban and Regional Development Administration at USEP College of Development Management. Moreover, he is a part-time faculty member at the School of Engineering and Architecture at Ateneo de Davao University. In 2021, he was selected as one of the recipients of the Young Leaders Program on Regional Revitalization of Disaster-Prone Area, organized by the Japan International Cooperation Agency (JICA) under the International Cooperation Program of the Government of Japan. His research interests are Renewable Energy, Energy Resiliency, and the Electric Power Industry. He can be contacted at email: euy@doe.gov.ph.

**References**

[1] S. J. Ahmed, "Philippines Power Sector Can Reach Resilience by 2021," COVID-19 Reveals Regulatory Weaknesses and the Need for Improved Incentives and Policies, Jun. 2020. Retrieved from https://ieefa.org/resources/philippines-power-sector-can-reach-resilience-2021

[2] International Finance Corporation, "The Impact of COVID-19 on the Power Sector," Jun. 2020. Retrieved from https://ppp.worldbank.org/sites/default/files/2021-05/IFC-Covid19-PowerSector-final_web_rev.pdf

[3] T. Lowder, N. Lee, and J. E. Leisch, "COVID-19 and The Power Sector in Southeast Asia: Impacts and Opportunities," Jun. 2020. Retrieved from https://docs.nrel.gov/docs/fy20osti/76963.pdf
[4] E. Hillberg, "Flexibility needs in the future power system," Mar. 2019. Retrieved from https://doi.org/10.13140/RG.2.2.22580.71047
[5] E. Taibi, L. Gutierrez, J. Kiviluoma, S. Rissanen, T. Nikolakakis, C. Fernandez del Valle, and T. J. Lindroos, "Power System Flexibility for the Energy Transition," Nov. 2018. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/%20%20%20%20Publication/2018/Nov/IRENA_Power_system_flexibility_1_2018.pdf
[6] Office of Senator Win Gatchalian, "Policy Brief on Energy: The Costs of Power Outages in the Philippines," vol. 1, no. 1, Aug. 2016.
[7] R. Goodall, R. Dixon, and V. M. Dwyer, "Operational Reliability Calculations for Critical Systems," in Fault Detection, Supervision and Safety of Technical Processes 2006, vol. 2, Elsevier, 2007, pp. 771–776. https://doi.org/10.3182/20060829-4-CN-2909.00128
[8] H. Lund, "Electric grid stability and the design of sustainable energy systems," International Journal of Sustainable Energy, vol. 24, no. 1, pp. 45–54, 2005. https://doi.org/10.1080/14786450512331325910
[9] P. Denholm and M. Hand, "Grid flexibility and storage required to achieve very high penetration of variable renewable electricity," Energy Policy, vol. 39, no. 3, pp. 1817–1830, 2011. https://doi.org/10.1016/j.enpol.2011.01.019
[10] J. Cochran, M. Miller, O. Zinaman, M. Milligan, D. Arent, B. Palmintier, M. Omalley, S. Mueller, E. Lannoye, A. Tuohy, B. Kujala, M. Sommer, H. Holttinen, J. Kiviluoma, and S. K. Soonee, "Flexibility in 21st Century Power Systems," 2014. Retrieved from https://www.researchgate.net/publication/290559378_Flexibility_in_21st_Century_Power_Systems
[11] J. R. Pillai, K. Heussen, and P. A. Østergaard, "Comparative analysis of hourly and dynamic power balancing models for validating future energy scenarios," Energy, vol. 36, no. 5, pp. 3233–3243, 2011. Retrieved from https://doi.org/10.1016/j.energy.2011.03.014
[12] Energy Regulatory Commission, "Res. 21, A Resolution Adopting the Grid Management Committee's Proposed Amendments to ERC Resolution No. 17, Series of 2013," 2016.
[13] H. Raoufi, V. Vahidinasab, and K. Mehran, "Power Systems Resilience Metrics: A Comprehensive Review of Challenges and Outlook," Sustainability, 2020. https://doi.org/10.3390/su12229698