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Transmission Development in the Philippines, 2026-2050: Demand Growth, Renewable Energy Integration, and Grid Modernization

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ABSTRACT

Increasing electricity demand, renewable energy expansion, and transmission reliability requirements present significant challenges to long-term power system development in the Philippines. This study examined the National Grid Corporation of the Philippines Transmission Development Plan 2026–2050, focusing on demand projections, infrastructure expansion, renewable energy integration, grid modernization, and asset management. A descriptive documentary-analysis design was employed using the plan's executive summary and Chapters 1–10 as primary data sources. Information was examined through structured document review, descriptive comparisons, and thematic analysis covering the Luzon, Visayas, and Mindanao grids. Findings indicated that national peak electricity demand was projected to increase from 19,852 MW in 2026 to 81,151 MW by 2050, requiring substantial transmission development. Major priorities included high-voltage backbone reinforcement, substation expansion, inter-island interconnections, battery energy storage systems, digital substations, and advanced monitoring technologies. The plan also identified ₱83.383 billion in projected operations and maintenance capital expenditures, including ₱53.617 billion for the Substation Reliability Program. Implementation considerations included regulatory requirements, right-of-way acquisition, project scheduling, and coordination with generation development. The study concluded that coordinated infrastructure expansion, technological modernization, and lifecycle-based asset management were central to long-term transmission planning. Prioritizing timely implementation, operational flexibility, systematic maintenance, and continued performance evaluation was recommended to support transmission reliability and renewable energy integration. However, the anticipated benefits remained dependent on project implementation and changing system conditions.

Keywords: *Electricity Demand, Transmission Infrastructure, Renewable Integration, Grid Modernization, Energy Storage, Inter-Island Interconnection, System Reliability, Asset Management*

INTRODUCTION

Electricity transmission planning in the Philippines is increasingly shaped by three simultaneous pressures: sustained demand growth, the entry of large and geographically dispersed generation resources, and the need for a more resilient and flexible grid. The Transmission Development Plan (TDP) 2026–2050 of the National Grid Corporation of the Philippines (NGCP) addresses these pressures through a nationwide program of transmission line expansion, substation development, inter-island interconnection, system modernization, and long-term asset management. The plan treats transmission development as a prerequisite for the reliable delivery of electricity from generating plants to distribution utilities, directly connected customers, and other grid users (National Grid Corporation of the Philippines [NGCP], 2026). This direction is consistent with the Philippine Energy Plan 2023–2050, which establishes a long-term policy framework for transitioning toward a reliable, cleaner, and more resilient energy system (Department of Energy [DOE], 2023). Internationally, the International Energy Agency (IEA, 2023) identifies electricity networks as essential infrastructure for energy security and clean energy transitions, emphasizing that delays in grid development can constrain the connection and effective utilization of new generation resources.

The scale of the required development presents a considerable challenge. As of December 2025, the Philippine transmission grid comprised 23,378.92 circuit-kilometers (ckm) of transmission lines, 64,580.90 MVA of substation capacity, and 226 substations nationwide. Projected demand growth indicates the need for a substantially larger and more capable transmission system by 2050. Planning inputs identified in the TDP include the DOE's updated system peak-demand forecast, generation expansion, committed and indicative power plants, customer development plans, equipment data, and system reliability requirements. Power plants are frequently located according to resource availability, land conditions, fuel logistics, and commercial considerations rather than proximity to existing transmission facilities. Consequently, additional connection facilities and network reinforcements are often required (NGCP, 2026). The IEA (2023) similarly emphasizes that transmission infrastructure must expand and adapt to changing patterns of electricity production and consumption. In Southeast Asia, increasing electricity demand, expanding renewable energy deployment, and growing energy security concerns further reinforce the importance of coordinated infrastructure planning and investment (IEA, 2024b).

The plan also prioritizes renewable energy (RE) integration and digital modernization as foundations of future grid development. Variable renewable energy (VRE) introduces challenges associated with generation variability, transmission congestion, curtailment risk, reduced system inertia, and changing protection and control requirements. To address

these concerns, NGCP combines conventional network reinforcement with battery energy storage systems (BESS), static synchronous compensators (STATCOMs), smart grid technologies, telecommunications, supervisory control and data acquisition/energy management system (SCADA/EMS) modernization, advanced monitoring, and risk-based maintenance (NGCP, 2026). The IEA (2024a) identifies system flexibility, transmission development, operational coordination, and appropriate market and regulatory measures as important requirements for integrating increasing shares of solar and wind generation. Similarly, the International Renewable Energy Agency (IRENA, 2023a) emphasizes the need for expanded transmission networks, energy storage, demand-side flexibility, and integrated system planning to accommodate renewable electricity generation.

Beyond physical infrastructure, grid modernization increasingly involves the integration of digital technologies, advanced monitoring systems, and improved operational management. The IEA (2023) explains that the energy transition requires changes not only in network capacity but also in how electricity grids are planned, operated, and managed. IRENA (2023b) likewise identifies digitalization, smart electrification, and coordinated technological innovation as important elements of modern energy systems. These developments are relevant to the Philippine transmission sector because expanding renewable generation and inter-island electricity exchanges require reliable communication systems, accurate operational information, and effective management of network constraints. Accordingly, the integration of digital substations, automated monitoring, modern protection systems, and condition-based asset management complements conventional transmission development.

Although existing energy planning documents and international studies discuss transmission expansion, renewable energy integration, and power-system modernization, these issues are often examined through individual technical or policy perspectives. The NGCP TDP 2026–2050 brings these dimensions together within a long-term national transmission planning framework. However, interpreting the plan requires attention to the relationships among demand projections, infrastructure investments, operational flexibility, reliability requirements, and implementation constraints. The international literature establishes the importance of integrated electricity system planning (IEA, 2023, 2024a; IRENA, 2023a), while the Philippine Energy Plan provides the broader national energy policy context (DOE, 2023). A focused documentary synthesis of the TDP is therefore useful for clarifying how these considerations are addressed within the Philippine transmission development program and distinguishing planned interventions from outcomes that remain dependent on implementation.

Accordingly, this study examined the NGCP TDP 2026–2050 through descriptive documentary analysis, focusing on demand growth and transmission expansion, renewable energy integration and grid modernization, and reliability, asset management, and system operations. It synthesized the plan's quantitative projections, infrastructure priorities, technology strategies, and implementation considerations to explain how these components collectively contribute to the planned development of a reliable, resilient, and renewable-ready Philippine transmission system.

Research Problem

The Philippine transmission system faces increasing demands arising from projected electricity consumption, renewable energy expansion, and the need for improved grid reliability and operational flexibility. Although the National Grid Corporation of the Philippines (NGCP) Transmission Development Plan (TDP) 2026–2050 identifies major infrastructure investments, technological improvements, and asset-management strategies, these measures require integrated examination to clarify how they address the country's long-term transmission requirements. Accordingly, this study examined the following research questions:

1. What electricity demand projections and transmission expansion requirements were identified in the NGCP TDP 2026–2050?
2. How did the plan address renewable energy integration through transmission reinforcement, energy storage, and grid modernization technologies?
3. What reliability, asset-management, and system-operation strategies were proposed to support long-term transmission performance?
4. What implementation considerations and constraints could influence the realization of the plan's intended outcomes?

Assumptions of the Study

The study was based on the assumption that the NGCP TDP 2026–2050 provided an appropriate documentary source for examining the country's long-term transmission development priorities. Its reported demand forecasts, infrastructure requirements, proposed technologies, and asset-management measures were treated as planning information reflecting the assumptions and conditions adopted in the document. The analysis further assumed that these components could be systematically organized and interpreted through descriptive documentary analysis. Because the study did not independently validate the forecasts or evaluate project implementation, the reported projections and anticipated benefits were interpreted as planning expectations rather than established future outcomes.

Objectives of the Study

The study aimed to examine the NGCP Transmission Development Plan 2026–2050 in relation to projected electricity demand, renewable energy integration, and grid modernization in the Philippines. Specifically, it sought to analyze the reported demand forecasts and corresponding transmission expansion priorities; identify the infrastructure and technological strategies proposed for renewable energy integration; examine reliability, asset-management, and system-operation measures; and synthesize the implementation considerations affecting the development of a reliable, resilient, and renewable-ready Philippine transmission system.

Conceptual or Theoretical Framework

The study adopted an input–intervention–outcome conceptual framework to examine the interrelationships among electricity demand growth, renewable energy integration, and grid modernization in the Philippines. The input component comprised projected electricity demand, generation expansion, renewable energy development, existing transmission infrastructure, N-1 reliability requirements, power-quality needs, and implementation constraints. These factors represented the principal planning considerations identified in the NGCP Transmission Development Plan 2026–2050 (National Grid Corporation of the Philippines [NGCP], 2026).

The intervention component encompassed three complementary development strategies: transmission infrastructure expansion through high-voltage backbone reinforcement, substation development, and inter-island interconnections; technological modernization through battery energy storage systems, static synchronous compensators, digital substations, telecommunications, SCADA/EMS, and cybersecurity; and lifecycle-based asset management through condition assessment, risk-based maintenance, advanced monitoring, and equipment replacement. These strategies reflected the integrated planning approach described in the TDP and were consistent with international recommendations emphasizing coordinated grid expansion and modernization to accommodate renewable energy growth (International Energy Agency, 2023; International Renewable Energy Agency, 2023a).

The outcome component represented the anticipated improvements in transmission capacity, operational flexibility, system reliability, resilience, renewable energy integration, and long-term grid readiness. The framework guided the documentary analysis by organizing the TDP's reported projections, proposed investments, and operational strategies into interconnected planning dimensions. As the study examined a planning document rather than measured project performance, these outcomes were interpreted as intended benefits rather than empirically established effects.

METHODOLOGY

Research Design

The study employed a descriptive documentary-analysis research design to examine the National Grid Corporation of the Philippines (NGCP) Transmission Development Plan (TDP) 2026–2050. This approach was appropriate for systematically examining an official planning document and synthesizing information concerning electricity demand growth, transmission infrastructure development, renewable energy integration, grid modernization, and asset management. Documentary analysis involves the systematic examination and interpretation of existing documents to develop an understanding of the issues under investigation (Bowen, 2009). The study focused on the reported projections, proposed investments, technological strategies, and implementation considerations presented in the TDP without introducing external datasets or conducting independent engineering simulations.

Research Locale or Study Setting

The study focused on the Philippine electricity transmission system, encompassing the Luzon, Visayas, and Mindanao grids. These interconnected and developing transmission networks constitute the geographical coverage of the National Grid Corporation of the Philippines (NGCP) Transmission Development Plan (TDP) 2026–2050. The study examined the transmission development priorities identified across these major island groups, including infrastructure expansion, renewable energy integration, grid modernization, and system reliability. The Philippines served as the geographical context of the analysis, while the NGCP TDP provided the documentary basis for examining long-term transmission planning and development.

Participants or Data Sources

The study did not involve human participants because it employed a descriptive documentary-analysis research design. The primary data source was the NGCP Transmission Development Plan 2026–2050, specifically its executive summary and Chapters 1–10. The document contained electricity demand projections, transmission infrastructure data, proposed development projects, renewable energy integration strategies, grid modernization initiatives, and asset-management programs. It was selected for its direct relevance to the research objectives and its coverage of long-term transmission development across the Philippine power system. No respondent sampling or primary data collection was undertaken, and the analysis was confined to information presented in the selected planning document.

Research Instruments or Materials

The study utilized the National Grid Corporation of the Philippines (NGCP) Transmission Development Plan (TDP) 2026–2050 as its primary research material. A structured document-review approach was employed to identify and organize information relevant to electricity demand projections, transmission infrastructure expansion, renewable energy integration, grid modernization, system reliability, and asset management. The review considered quantitative indicators, including projected peak demand, transmission line lengths, substation capacities, planned development projects, and capital investment requirements, alongside qualitative descriptions of technological strategies and implementation constraints. Information was categorized according to the study's objectives and conceptual framework. The analysis relied on the published planning document rather than questionnaires, interviews, or experimental instruments.

Data Gathering Procedure

Data gathering involved a systematic examination of the NGCP Transmission Development Plan 2026–2050, particularly its executive summary and Chapters 1–10. Relevant information was identified and organized according to three principal areas: demand growth and transmission expansion, renewable energy integration and grid modernization, and reliability and asset management. Quantitative information concerning electricity demand forecasts, transmission infrastructure, project development, and investment requirements was recorded using the numerical values and measurement units presented in the document. Descriptive information on proposed technologies, operational strategies, and implementation considerations was also examined. The collected information was organized to facilitate comparisons across the Luzon, Visayas, and Mindanao grids and to support interpretation of the plan's long-term development priorities.

Data Analysis

The study employed descriptive analysis and thematic organization to examine the information obtained from the NGCP Transmission Development Plan 2026–2050. Quantitative data were analyzed through descriptive comparisons of projected electricity demand, existing transmission infrastructure, and planned development requirements across the Luzon, Visayas, and Mindanao grids. Particular attention was given to the projected changes in national and regional peak electricity demand between 2026 and 2050, as well as the reported transmission capacities, development projects, and investment requirements.

Qualitative information was organized into three analytical themes: demand growth and transmission expansion; renewable energy integration and grid modernization; and reliability, asset management, and system operations. These themes guided the synthesis

of infrastructure priorities, technological interventions, operational strategies, and implementation constraints. The interpretation followed the input–intervention–outcome conceptual framework to explain how the proposed transmission developments addressed the planning requirements identified in the TDP. The analysis remained descriptive and documentary in nature, without inferential statistical testing, independent engineering simulations, or economic optimization modeling.

Ethical Considerations

The study adhered to principles of research integrity, transparency, and responsible use of documentary information. As the research relied exclusively on the NGCP Transmission Development Plan 2026–2050, it did not involve human participants, personal information, or direct interaction with respondents. Ethical considerations primarily involved accurate representation of the published information, appropriate acknowledgment of the documentary source, and preservation of the reported numerical values and technical descriptions. Particular care was taken to distinguish existing transmission infrastructure and completed projects from proposed developments, as well as projected outcomes from independently demonstrated results. The analysis avoided unsupported interpretations and maintained consistency between the research objectives, documentary evidence, and reported findings.

RESULTS AND DISCUSSION

Demand Growth and Transmission Expansion

The National Grid Corporation of the Philippines (NGCP) Transmission Development Plan (TDP) 2026–2050 identified increasing electricity demand as a major driver of long-term transmission development. Between 2009 and 2025, NGCP completed or energized 5,633 circuit-kilometers (ckm) of new and upgraded transmission lines and added 44,145 MVA of substation capacity. During this period, peak demand increased by 112%, while installed generation capacity grew by 102%. As of December 2025, the national transmission system comprised 23,378.92 ckm of transmission lines, 64,580.90 MVA of substation capacity, and 226 substations (NGCP, 2026). National peak demand was projected to increase from 19,852 MW in 2026 to 81,151 MW by 2050, with a reported compound annual growth rate of 5.93%. Regional projections indicated increases from 13,872 MW to 58,839 MW in Luzon, 2,942 MW to 10,606 MW in Visayas, and 3,038 MW to 11,705 MW in Mindanao, which recorded the highest reported regional growth rate of 6.07% (NGCP, 2026).

To accommodate projected demand and generation expansion, the TDP prioritized reinforcement of Luzon's 500 kV transmission backbone, particularly around Metro Manila, alongside 230 kV network development, additional substations, and inter-island connections. Proposed developments included expansion of the Luzon–Visayas high-

voltage direct current interconnection and transmission links involving Mindoro, Panay, and Palawan. The existing Mindanao–Visayas interconnection provided 450 MW of transfer capability, with another 450 MW proposed for future development (NGCP, 2026). These priorities align with the International Energy Agency's (IEA, 2023) emphasis on transmission expansion for electricity security and with Crespo del Granado et al. (2023), who highlighted the importance of coordinating flexibility resources in electricity systems with increasing renewable generation. The findings indicate that transmission planning must consider not only demand projections but also generation locations, network constraints, and implementation schedules. However, projected demand remains an estimate, and the effectiveness of planned investments depends on timely implementation and stakeholder coordination.

Renewable Energy Integration and Grid Modernization

The TDP identified renewable energy integration as a major consideration in transmission development. Increasing solar and wind generation introduces challenges involving variability, congestion, curtailment, voltage regulation, and system stability. To address these requirements, NGCP proposed transmission reinforcement alongside battery energy storage systems (BESS), static synchronous compensators (STATCOMs), digital substations, telecommunications improvements, supervisory control and data acquisition/energy management system (SCADA/EMS) modernization, and advanced monitoring technologies (NGCP, 2026). Proposed BESS installations included the Laoag, Gamu, and Santiago 230 kV substations and Victoria 138 kV gas-insulated substation. The Smart and Green Grid Plan Phase 2 identified 172 projects in Luzon, 147 in Visayas, and 99 in Mindanao. The proposed storage investments are consistent with Zhao et al. (2023), who identified frequency regulation, voltage support, and energy management as important applications of grid-connected BESS. Kebede et al. (2022) likewise emphasized matching storage technologies with specific renewable energy integration requirements. Nevertheless, the suitability of individual installations depends on engineering, operational, and economic conditions that were not independently evaluated in this study.

Digital modernization was also emphasized to improve system visibility, communication, and operational control. Kataray et al. (2023) and Mahmood et al. (2024) identified smart-grid technologies and digitalization as important mechanisms for integrating renewable generation and improving system management. However, increased connectivity also creates cybersecurity vulnerabilities, as discussed by Achaal et al. (2024). Accordingly, the TDP's modernization strategies indicate the need to coordinate physical infrastructure, energy storage, digital control systems, and cybersecurity. Their anticipated contributions to congestion reduction, renewable energy accommodation, and system stability remain dependent on implementation and operational performance.

Reliability, Asset Management, and System Operations

The TDP emphasized lifecycle-based asset management to maintain transmission reliability amid increasing electricity demand and network complexity. Proposed strategies included equipment-condition assessment, diagnostic monitoring, risk-based maintenance, asset replacement, and operational improvements (NGCP, 2026). For 2026–2050, projected operations and maintenance capital expenditures totaled ₱83.383 billion, including ₱53.617 billion for the Substation Reliability Program. These allocations demonstrate the importance of maintaining existing infrastructure alongside transmission expansion.

Jin et al. (2023) identified condition assessment, health indices, fault diagnosis, and remaining-life evaluation as important considerations in transformer asset management. Similarly, Toftaker et al. (2023) examined how equipment condition and preventive retirement could inform power-system reliability analysis. These findings support the TDP's emphasis on condition-based and risk-prioritized maintenance, although their effectiveness depends on reliable monitoring information and appropriate maintenance decisions. The plan also incorporated telecommunications improvements, SCADA/EMS modernization, advanced monitoring, and cybersecurity measures to strengthen system operations. Achaal et al. (2024) emphasized the security challenges associated with increasingly interconnected digital power systems. Collectively, these measures indicate that transmission reliability requires coordinated equipment maintenance, operational monitoring, infrastructure modernization, and system protection rather than network expansion alone.

Implementation Considerations and Integrated Discussion

The TDP identified project scheduling, right-of-way acquisition, regulatory requirements, coordination with generation developers, and investment timing as important implementation considerations. Delays could limit the availability of transmission capacity needed to accommodate increasing demand and new generation projects (NGCP, 2026). These challenges demonstrate that infrastructure expansion, renewable energy integration, and asset management must be coordinated rather than implemented independently. This interpretation aligns with the IEA (2023) and studies emphasizing system flexibility, energy storage, and smart-grid development (Crespo del Granado et al., 2023; Kataray et al., 2023; Zhao et al., 2023). Within the study's input–intervention–outcome framework, demand projections, generation expansion, grid conditions, and reliability requirements represented planning inputs. Transmission reinforcement, inter-island interconnections, grid-enabling technologies, and lifecycle-based maintenance constituted proposed interventions. Intended outcomes included improved transmission capacity, operational flexibility, reliability, resilience, and renewable energy readiness. However, infrastructure expansion without operational flexibility may leave renewable integration challenges unresolved, while

digital modernization without adequate maintenance may not address equipment-related risks.

Overall, the NGCP TDP 2026–2050 presented an integrated strategy combining transmission expansion, technological modernization, and long-term asset management. The supporting literature establishes the technical relevance of these strategies but does not independently confirm the performance of specific NGCP projects. Consequently, the anticipated benefits should be interpreted as planning objectives requiring implementation, monitoring, and subsequent evaluation.

GENERAL DISCUSSION

The study concluded that the National Grid Corporation of the Philippines (NGCP) Transmission Development Plan 2026–2050 presented an integrated approach to addressing increasing electricity demand, renewable energy integration, and grid modernization. The projected growth in national peak demand from 19,852 MW in 2026 to 81,151 MW by 2050 highlighted the need for substantial transmission expansion, including high-voltage backbone reinforcement, substation development, and inter-island interconnections. The findings also emphasized the importance of battery energy storage systems, digital technologies, and lifecycle-based asset management in supporting operational flexibility, reliability, and long-term grid readiness. Accordingly, the study recommends prioritizing coordinated transmission investments, renewable energy integration technologies, condition-based maintenance, and effective regulatory and project implementation strategies. Continued monitoring and evaluation of planned developments are also recommended to assess their actual contributions to transmission capacity, system resilience, and operational performance.

This study was limited to documentary analysis of the National Grid Corporation of the Philippines (NGCP) Transmission Development Plan 2026–2050 and did not independently verify project costs, implementation schedules, demand forecasts, or anticipated reliability benefits. As the TDP is a planning document, its projections and proposed investments remain subject to regulatory approvals, project implementation, generation development, and changing system conditions. The analysis also did not include project-level power-flow simulations, stability assessments, economic evaluations, or probabilistic reliability modeling.

Future research may compare successive TDP editions to assess project implementation and schedule changes, examine the accuracy of demand forecasts against actual system peaks, and evaluate the operational performance of grid-forming battery energy storage systems (BESS) and static synchronous compensators (STATCOMs). Further studies may investigate the effectiveness of health-index and risk-based maintenance programs in

reducing forced outages and lifecycle costs. Project-level assessments could also quantify the contributions of major interconnections and smart-grid investments to congestion reduction, renewable energy curtailment, system resilience, and electricity market efficiency.

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