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*Research Article*

# Merit Order as a Generation Portfolio Optimization Mechanism in PLN and PLN Nusantara Power

## (A Systematic Analysis of Operational Efficiency, PJBTL Contract Structure, and Digital Transformation)

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**Abstract**: This study aims to analyze the role of the merit order as a portfolio optimization mechanism for power generation within PLN and PLN Nusantara Power (PLN NP) by linking three key dimensions: operational efficiency, the structure of Power Purchase Agreements (PJBTL), and digital transformation. The method employed is a Systematic Literature Review (SLR) of journal articles, corporate reports, regulations, and official documents related to merit order, PJBTL, generation portfolio strategy, and the digitalization of Indonesia's electricity system over the period 2010–2025. The findings indicate that the implementation of the merit order in PLN and PLN NP has evolved from a classical model based solely on marginal cost into a "hybrid merit order" that integrates thermal efficiency indicators (SFC, NPHR), unit reliability (EAF, EFOR), and generation mix, supported by digital platforms such as Dispatch Optimization, i-CORE, and the Nusantara InnoVision Center. The PJBTL structure is found to be ambivalent: IPP contracts based on take-or-pay schemes and long-term primary energy contracts limit dispatch flexibility and reduce the effectiveness of the merit order, while PJBTL arrangements with industrial customers contribute to stabilizing base load and expanding operational flexibility. From a commercial perspective, this study confirms that growth in electricity sales only improves performance when additional demand is supplied by low-cost units that are competitive within the merit order. Otherwise, increased TWh sales risk becoming "pseudo-growth," where production costs (BPP) remain high and margins do not significantly improve.

**Keywords**: Digital Transformation; Merit Order; PLN Nusantara Power; Power Generation Portfolio; Power Purchase Agreement (PJBTL).

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## 1. Introduction

Electric power generation efficiency is largely determined by the magnitude of the costs incurred in producing energy. One of the most fundamental approaches to optimizing production costs is the implementation of a merit order system. Through this method, power plants with the lowest marginal costs are prioritized for operation first, followed by units with higher costs until the electricity demand is fully satisfied (Wikarsa, 2010). The merit order represents an approach applied within the economic dispatch process to determine the operational sequence of power generation units. This method is widely recognized as one of the simplest techniques for scheduling power plants based on cost efficiency (Safarudin et al., 2020). According to Redaktur: Dunia Sinergi, (2018) PLN continues to implement the merit order system, in which coal-fired power plants (PLTU) remain the priority for dispatch due to their relatively low production costs. PLN data indicate that electricity generated from coal-

fired power plants averages around US$6 cents per kWh, which is lower than other energy sources whose costs range between US$8–11 cents per kWh.

A Power Purchase Agreement (PPA) is a contractual arrangement between an independent power producer and an energy buyer. In the Indonesian context, a PPA is referred to as a Perjanjian Jual Beli Tenaga Listrik (PJBTL). The buyer may be a utility company, such as PLN, or large corporations requiring a substantial electricity supply (AEER, 2024). However, the PJBTL scheme for renewable energy still faces structural challenges, as many contracts adopt a take-and-pay model, which may create a bias against clean energy sources. Under ideal conditions, developers obtain a combination of minimum dispatch and take-and-pay arrangements, allowing PLN to pay only for the electricity actually absorbed while facilitating the integration of renewable energy within the merit order, particularly when take-or-pay contracts for fossil-fuel-based generation remain dominant. A take-or-pay contract obligates payment for electricity capacity even when it is not utilized. A similar issue occurred when a 75 MW wind power plant (PLTB) was connected to the Sulawesi grid in 2018 and when a 5 MW solar power plant (PLTS) was integrated into the Kupang grid in 2015, where network limitations created a risk of curtailment. This risk subsequently led lenders to impose higher interest rates on renewable energy projects (Hamadi, 2020).

The market share of a power generation company is determined by the magnitude of its net dependable capacity contribution through the electricity market mechanism. In the Java–Bali–Madura power system, this mechanism is regulated by PLN P2B as the operator of the interconnected system, which establishes competition based on energy prices and the availability of dependable generation capacity through an efficiency-based merit order scheme. Under these conditions, each power generation company strives to maintain its ranking by ensuring the availability, reliability, and cost efficiency of electricity production. One strategy to sustain profitability is the management of the heat rate or plant calorific rate (Fernandes & Anggaini, 2021). According to Satria, (2021) the merit order determines the operational priority of thermal power plants based on the net plant heat rate (NPHR) and fuel prices. Power plants with lower rankings will experience load reduction earlier. The NPHR serves as a key indicator of efficiency, where a lower value reflects better performance. At PLTU Rembang, the determination of NPHR when two generating units operate simultaneously is often less accurate because part of the auxiliary power consumption of one unit may be supplied by the other unit.

Research conducted by Pariaman et al., (2023) highlights that a merit order strategy is required to assist power plant management in determining the most efficient and economical generating units to be dispatched. The study proposes an economic dispatch optimization for PLTU Tanjung Awar-Awar in Java and PLTU Tenayan in Sumatra using the Lagrange multipliers method to obtain the lowest generation cost according to the load requirements of each unit. The analysis results indicate that Unit 1 at both the Tanjung Awar-Awar and Tenayan power plants exhibits more economical operating costs compared to Unit 2. Meanwhile Hendra & Mangkusubroto, (2022) state that PT PLN Batubara (PLNBB) is a subsidiary of PLN established to ensure the availability of coal supply for coal-fired power plants (PLTU) as well as Independent Power Producers (IPP). The company also plays a role in providing coal at the lowest possible cost and maintaining adequate supply during crisis conditions at coal-fired power plants.

Within the corporate structure of PLN, PLN Nusantara Power (PLN NP) plays a strategic role as the generation subholding. According to the company profile, PLN Nusantara Power was established on 3 October 1995 and currently manages a generation capacity of 18,573 MW distributed across various regions in Indonesia. In addition, PLN Nusantara Power has expanded its business through several subsidiaries engaged in power plant operation and maintenance services, generation investment through joint venture companies (JVCs), and the provision of spare parts and other supporting services (PT PLN (Persero), 2023). Furthermore, as the generation subholding of PT PLN (Persero), PLN Nusantara Power manages a generation portfolio of 18,573 MW and in 2023 recorded electricity production of 66.8 million MWh, surpassing its target and reinforcing its position as the largest power generation company in Southeast Asia. The company also supports the energy transition through co-firing implementation in 25 generating units, producing 511 GWh of clean energy and a total of 5,666 GWh from renewable energy sources. Decarbonization efforts are further strengthened through the operation of hydropower and solar power plants, including the 192 MWp Cirata Floating Solar Power Plant and the IKN Solar Power Plant, both of which contribute significantly to emission reduction. In addition, PLN NP has accelerated

the digitalization of power plants through the ICORE innovation, which has been implemented in 16 generating units (Corpoate: PLN Nusantara Power, 2024).

PLN Nusantara Power also recorded strong performance throughout 2024, with electricity sales reaching 63.41 TWh, 17% above the target, alongside a 11.4% reduction in the cost of electricity production (BPP) through the optimization of the energy mix, improvements in plant reliability, and consistent operational transformation. In addition to achieving Beyond kWh revenue of Rp985.59 billion, reducing carbon emissions to 110% of the target, and obtaining the highest GCG score within the PLN Group, PLN NP has continued to expand its clean energy portfolio and completed the development of power plants with a total capacity of 1,589.9 MW across Indonesia (Corpoate: PLN Nusantara Power, 2025). From the digitalization perspective, PLN, through its generation subholding PLN Nusantara Power, launched the Nusantara InnoVision Center (NIC), an integrated digital center for real-time monitoring and operational control of 621 generating units. This initiative represents a strategic step in accelerating digital transformation and supporting the integration of renewable energy into the national electricity system. Through the consolidation of big data and comprehensive operational dashboards, NIC strengthens managerial decision-making, creates new corporate value, and supports the PLN Group's vision of becoming a top 500 global company and the preferred energy solutions provider for customers (Siaran Pers PLN, 2024).

In addition, structural changes in Indonesia's electricity system, increasingly influenced by renewable energy penetration and national energy policy interventions, require the merit order mechanism to be understood as a strategic framework that affects the entire power generation value chain and electricity market governance. The prioritization of generation dispatch does not only influence marginal cost efficiency, but also affects unit utilization, energy absorption from Independent Power Producers (IPP), and contractual payment obligations under PJBTL schemes. In a system still dominated by take-or-pay contracts, dispatch decisions may generate significant financial consequences, including increased electricity production costs (BPP), portfolio imbalances, and reduced operational flexibility in integrating clean energy. Therefore, a comprehensive understanding of merit order is essential not only from a technical perspective, but also from regulatory, contractual, and strategic business perspectives, particularly for PLN and PLN NP as the largest power generation portfolio managers in Indonesia.

Subsequently, the digitalization of power plants through ICORE and the Nusantara InnoVision Center (NIC) strengthens the relationship between merit order implementation and improvements in energy sales performance through optimized monitoring, load forecasting, unit control, and real-time data integration, enabling the merit order to be applied dynamically. This transformation indicates that power plant efficiency is no longer solely determined by conventional operational practices, but increasingly depends on the company's ability to process big data and implement analytics-based dispatch decisions. Digitalization has demonstrably contributed to reducing BPP, improving the utilization of efficient generating units, and increasing PLN NP's electricity sales to 63.41 TWh in 2024. Consequently, the relationship between merit order implementation, digital integration, and corporate commercial performance has become increasingly interconnected, requiring a systematic literature review to map how global trends and best practices can be adapted within the context of the PLN Group.

The novelty of this study as a Systematic Literature Review (SLR) lies in three main contributions. First, this study represents the first SLR that specifically maps the relationship between merit order mechanisms, PJBTL contract structures, power generation portfolio strategies, and digital transformation in the Indonesian electricity sector, a relationship that has previously been discussed only separately in individual studies. Second, this study provides a comprehensive gap analysis that identifies inconsistencies between classical merit order theory, economic dispatch practices in developing countries, and the structural conditions of PLN influenced by long-term fossil fuel contracts and system constraints. Third, this study develops a conceptual synthesis in the form of an "Integrated Merit Order Portfolio Framework," a new conceptual framework that explains how technical, contractual, and digital-operational factors should be analyzed holistically in optimizing power generation portfolios. This novelty provides a strong theoretical foundation for future research as well as strategic decision-making within PLN and PLN Nusantara Power.

## 2. Method

This study employs the Systematic Literature Review (SLR) method, an approach aimed at identifying, reviewing, evaluating, and interpreting all research relevant to a particular topic based on predefined research questions. Through SLR, the process of reviewing and identifying scientific sources is conducted in a structured and systematic manner, following previously formulated research stages and protocols (Triandini et al., 2019). This study aims to identify, analyze, and synthesize the literature related to the implementation of merit order, PJBTL contract structures, power generation portfolio strategies, and digital transformation in Indonesia's electricity sector. This method was selected to ensure that the literature review process is objective, minimizes bias, and remains reproducible by relying on explicit protocols and systematic procedures. Consequently, this study is expected to encompass all relevant evidence on the topic and produce credible and reliable findings.

The literature search strategy focuses on reputable scientific databases and official websites, using combinations of keywords related to merit order, PJBTL contracts, power generation portfolio strategies, and PLN's digital transformation, within the publication period 2010–2025. The inclusion criteria consist of peer-reviewed journal articles and official web sources published between 2010 and 2025 that are relevant to the research topic. Meanwhile, literature outside this time range, not related to the research topic, duplicate records, or publications that are not academic journal articles (such as technical reports or non-peer-reviewed articles) are excluded based on the exclusion criteria.

## 3. Result and Discussion

### Implementation of Merit Order at PLN and PLN Nusantara Power

The implementation of the merit order within the generation systems of PLN and PLN Nusantara Power (PLN NP) is structured based on the principles of lowest marginal cost, technical efficiency, and power plant reliability performance. Corporate documents indicate that PLN NP manages a very large generation portfolio, with a total installed capacity of 18,573 MW in 2023, consisting of coal, gas, diesel, hydro, and solar power plants. This capacity data is important because the greater the contribution of low-cost generation sources (such as coal-fired power plants and hydropower plants), the higher their priority within the merit order (PLN Nusantara Power, 2024). This generation mix structure directly determines the dispatch order, with coal-fired and hydropower plants occupying the top positions due to their relatively low marginal costs.

Technical efficiency is a key factor in the merit order because units with lower Specific Fuel Consumption (SFC) and Net Plant Heat Rate (NPHR) generate electricity at the most economical cost. Official PLN NP documents explain that SFC refers to the amount of fuel required to produce 1 kWh of electricity, while NPHR indicates the amount of fuel energy needed to produce 1 kWh of net electricity output. These two indicators form the basis for grouping generating units from low-cost to high-cost categories within the merit order (PLN Nusantara Power, 2019). The lower the heat rate, the lower the production cost, thereby placing the unit as a priority in the dispatch order. PLN Nusantara Power, (2019) n addition to thermal efficiency, merit order considerations also incorporate technical reliability indicators, namely the Equivalent Availability Factor (EAF) and Equivalent Forced Outage Rate (EFOR). These indicators are documented in PLN NP statistical reports. EAF represents the readiness of a unit to operate, while EFOR measures the frequency of forced outages. Units with high EAF and low EFOR automatically receive higher priority in the merit order because they are considered both reliable and economical for operation as baseload or mid-merit units.

The effectiveness of PLN's merit order is also strengthened by the acquisition of strategic power plants, such as PLTGU Sengkang, which resumed operations after previously being inactive. Documentation indicates that this acquisition restored gas supply of 40 million cubic feet per day, thereby increasing the availability of gas-fired units in eastern Indonesia. The improved gas supply enhances the position of combined-cycle gas power plants (PLTGU) in the merit order because they can operate more efficiently and reliably than before (Nusantara Power News, 2023). On the coal-fired generation side, documents indicate significant installed capacity from units such as UP Paiton (800 MW), UP Indramayu (990 MW), UP Rembang (630 MW), UP Pacitan (630 MW), and other coal-fired units, which collectively reach a total capacity of 6,261 MW. This substantial capacity strengthens the

dominance of coal-fired power plants as the backbone of the national merit order system, primarily due to their relatively lower production costs compared to gas and diesel-based generation. Detailed capacity information is presented in the installed capacity tables for each generation unit (PLN Nusantara Power, 2019)

Digital transformation has also supported the optimization of the merit order. PLN NP operates I-CORE (Intelligence Center of Optimization for Reliability & Efficiency), a system used to monitor, analyze, and diagnose power plant performance in real time. This AI-based system ensures that the evaluation of efficiency, reliability, and unit performance for merit order determination is conducted accurately, rapidly, and based on data-driven analysis. Information regarding the functions of I-CORE is clearly documented in the company's supporting business review reports. The implementation of biomass co-firing in coal-fired power plants also influences the merit order because it reduces fuel costs while supporting PLN's green booster policy. Corporate documents note that co-firing has been commercially implemented in 25 power plants, allowing coal-fired units applying this technology to achieve lower marginal costs and greater competitiveness compared to coal units that have not yet adopted the technology (PLN Nusantara Power, 2024).

The implementation of merit order principles within PLN's electricity system is also reflected in the Dispatch Optimization program and the modernization of load dispatch centers. Within the framework of the PLN Transformation Program, Dispatch Optimization is identified as one of 20 digital breakthroughs aimed at ensuring reliable and efficient electricity procurement, alongside other initiatives such as Digital Power Plant and Digitally Enabled Distribution Excellence (Hidayat, 2020). At a later stage, PLN further explained that the Dispatch Optimization program "ensures that electricity system operation remains reliable, high-quality, and economical," contributing to cost savings of approximately Rp 8.91 trillion. This indicates that the load dispatch algorithms are designed to prioritize the combination of generating units with the most efficient costs, consistent with the merit order principle that prioritizes units with the lowest marginal costs (Christian, 2022).

At the generation level, PLN Nusantara Power (PLN NP), as the generation subholding, implements merit order more operationally through coal-fired power plant loading patterns. In the Sustainability Report (when the company was still known as PT Pembangkitan Jawa-Bali, now PLN Nusantara Power), one of the energy efficiency initiatives in power plants is described as the "coal-fired plant loading pattern through optimization of energy price composition (merit order)", implemented alongside other initiatives such as high-calorific coal testing and efficiency improvement programs for boilers and turbines (PJB: Pembangkit Jawa-Bali, 2014). This statement indicates that PLN NP not only focuses on technical unit efficiency, but also organizes the dispatch sequence of coal-fired units based on energy price composition, ensuring that units with lower generation costs receive priority, in accordance with the fundamental principle of merit order. This practice is implemented within a sustainable energy management framework aimed at reducing primary energy consumption and improving the economic performance of power plants, ensuring that PLN NP's operational practices align with merit order policies coordinated at the system level by PLN as the parent company (PJB: Pembangkit Jawa-Bali, 2014).

These findings indicate that the implementation of merit order within PLN and PLN Nusantara Power is not determined solely by the low marginal cost principle assumed in classical dispatch models, but is also influenced by the generation mix structure, technical conditions of generating units, and the company's digital transformation agenda. The dominance of coal-fired and hydropower plants in the dispatch order is consistent with their relatively low marginal cost characteristics; however, the effectiveness of this implementation depends on actual thermal efficiency (SFC and NPHR), unit availability (EAF), and operational stability (EFOR). As a result, PLN's merit order more closely resembles a hybrid merit order, integrating both economic and system reliability considerations.

Cases such as the resumption of PLTGU Sengkang operations illustrate how changes in primary energy supply can shift a unit's position within the merit order, emphasizing that dispatch priorities are dynamic and highly influenced by supply conditions. The integration of digital systems such as I-CORE also demonstrates a paradigm shift from judgment-based merit order decisions toward real-time analytics-based merit order mechanisms, ensuring that efficiency and reliability metrics are directly used as the basis for operational decision-making. Consequently, the implementation of merit order within PLN and PLN NP cannot be understood merely as the selection of generating units based on the lowest cost, but rather as a systematic optimization mechanism that integrates technical efficiency, operational

reliability, and corporate strategies, including co-firing initiatives and digitalization programs aimed at reducing overall operational costs.

### The Impact of PJBTL Contract Structure on Dispatch Flexibility

The rigid structure of PJBTL (PPA) contracts in many IPP power plants creates limitations in dispatch flexibility, as PLN must bear contractual obligations in the form of *take-or-pay* clauses and energy volumes that have already been committed in long-term system contracts. The RUPTL emphasizes that PLN needs to "merancang skema kontrak yang lebih fleksibel dengan pengelola pembangkit, serta melakukan evaluasi terhadap kontrak jual beli tenaga system (PPA) pada pembangkit-pembangkit IPP yang terkoneksi pada system". (PT PLN (Persero), 2025). This statement indicates that the existing contractual structure is considered to constrain PLN's ability to optimize system operations, particularly when demand decreases, when changes occur in the energy mix, or when dispatch adjustments are required to accommodate intermittent renewable energy. As a consequence of these inflexible contractual arrangements, PLN has limited maneuverability to reduce the output of certain power plants, even when doing so would be economically or technically more optimal.

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The PJBTL contract structure between PLN as the offtaker and PT PLN Nusantara Power as the generation subholding is organized into several PJBTL "books" for each regional system, namely five books for Java–Bali, seven for Sumatra, four for Kalimantan, one for Maluku, and five for Sulawesi. These contracts have been amended and restated for the 2023–2032 period, with the most recent amendment dated 28 December 2023 concerning regional expansion. The notes to Nusantara Power's financial statements explain that under each PJBTL, PLN pays for the electricity supplied based on a payment formula that separates capacity costs, energy costs, and operation and maintenance components, the magnitude of which is strongly influenced by the level of energy supplied and other variables stipulated in the agreement. The separation between capacity and energy payments economically reduces the dependence of power plant cost recovery on actual operating hours, thereby allowing dispatch decisions to be more flexible in responding to system reliability requirements and marginal cost efficiency without directly disrupting the capacity revenue stream received by plant owners (PT PLN Nusantara Power, 2023).

On the other hand, the PJBTL structure between PLN and high-voltage customers also influences dispatch flexibility from the demand side. In a press release dated 30 October 2021, PLN reported the signing of 13 PJBTL agreements and MoUs with a total capacity of 2,270 MVA to supply several smelter projects and industrial/tourism areas, including PT Huadi Nickel-Alloy Indonesia, PT Stargate Mineral Asia, PT Aquila Cobalt Nickel, PT Indonesia Tourism Development Corporation, PT Wahana Lestari Investama, PT Sampoerna Kayu, and PT Gebe Industry Nickel, as well as the purchase of Renewable Energy Certificate products by PT Sumitomo Indonesia (Hidayat, 2021). At the same time, PLN stated that many electricity systems were experiencing surplus capacity, with reserve margins generally exceeding 40%. These reserves are expected to increase further with the commissioning of new power plants from the 35 GW megaproject, which will add approximately 17.9 GW, or about 50% of the existing reserve capacity (Hidayat, 2021). In the context of such excess capacity, PJBTL agreements with large customers function to secure long-term baseload demand, thereby stabilizing the demand profile. The combination of relatively continuous industrial loads and a capacity–energy-based payment structure provides greater flexibility for system operators to dynamically schedule generation dispatch while still fulfilling

commitments regarding reliability, service quality, and competitive pricing promised to industrial customers (Hidayat, 2021).

The review results indicate that the rigidity of PJBTL contract structures, both with IPPs and with the PLN Nusantara Power subholding, constitutes an important determinant limiting the dispatch flexibility of PLN's electricity system. Contractual obligations such as *take-or-pay* clauses, committed energy volumes, and long-term primary energy supply contracts require certain power plants to continue operating even when they are no longer economically optimal or aligned with actual load conditions, thereby reducing the effectiveness of the merit order and the integration of variable renewable energy. Evidence from the RUPTL highlights the need to evaluate PPA contracts that are considered to hinder PLN's ability to adjust operations when demand declines or when changes occur in the energy mix, while the PJBTL payment structure separating capacity and energy costs within PLN Nusantara Power indicates the potential for greater flexibility at the internal PLN level. However, from the demand side, PJBTL agreements with industrial customers help stabilize demand amid national electricity surplus conditions, which in some cases actually expands dispatch maneuverability. These findings suggest that the PJBTL contract structure is inherently ambivalent: contracts with IPPs and primary energy suppliers create rigidity that constrains system adaptability, whereas contracts with large customers can enhance flexibility through the formation of more stable baseload demand.

### The Role of Digital Transformation in Optimizing the Merit Order

Market disruptions, increasing system complexity, the emergence of new technologies, regulatory changes, as well as increasingly volatile electricity supply and demand dynamics are driving many power plants to place greater emphasis on operational flexibility in order to improve availability and the efficiency of generating unit performance (AAB, 2017). PLN has implemented an integrated digitalization program, including the "Dispatch Optimization" initiative as part of its digital transformation agenda, aimed at improving the efficiency of the electricity system through more reliable and cost-effective management of generation to distribution. According to a PLN press release dated June 1, 2022, the program has delivered savings of up to IDR 8.91 trillion through the digitalization of power system operations: *"The Dispatch Optimization program enables a reliable, high-quality, and economical power system operation. This digitalization of the electricity system has resulted in savings of up to IDR 8.91 trillion."* (Christian, 2022). Such initiatives enable PLN to perform load control, optimize generation, and monitor assets in real time, which conceptually supports the merit order principle selecting power plants with the lowest marginal cost to ensure a more efficient electricity system.

On the other hand, PLN's digital transformation also emphasizes the integration of operational data across generation, transmission, and distribution to enable fast, data-driven decision-making. For instance, PLN stated that since April 21, 2020, it has launched the "PLN Transformation" program, with 13 out of 20 breakthroughs being digitally driven, including Digital Power Plant, Digital Procurement, Digitally Enabled Distribution Excellence, Dispatch Optimization, Anti Blackout, Green Booster, Billing and Collection Organization, Fiber Optics Rollout, Electric Vehicle Infrastructure, Captive Power, Outage Management, PLN Mobile Relaunch, and the Digitally Enabled Execution Machine (Hidayat, 2020). With enhanced data capacity and more advanced monitoring systems, PLN can improve generation reliability, reduce energy losses, and better arrange the dispatch order of power plants based on operational costs and efficiency—directly contributing to the optimization of the merit order in power generation and electricity delivery systems.

Within the PLN Nusantara Power (PLN NP) environment, power plant digitalization has been implemented through the i-CORE platform, an intelligent analytics solution that leverages operational, maintenance, and engineering data to enhance the performance of generating units. The "Economic Dispatch" module in i-CORE is specifically designed to *"provide recommendations for the most economical unit to operate through the Economic Dispatch feature."* (PLN Nusantara Power, 2025a). Thus, PLN NP implicitly reinforces the merit order structure selecting power plants with the most optimal conditions or lowest costs through digitalization even though the term "merit order" is not explicitly stated. In addition, PLN NP reported that as of January 2024, all 46 generating units with a total capacity of 7,360 MW have been digitally interconnected through a centralized system based in Surabaya (Qorib, 2023). This digital connectivity enables real-time monitoring and more responsive control, which is crucial for activating an efficient dispatch order, allowing power plant operations to be aligned with cost-efficiency conditions and operationally supporting the merit order concept.

These findings underscore that digital transformation plays a strategic role in strengthening the implementation of the merit order within PLN's electricity system. Digitalization enables a more accurate, adaptive, and cost-efficient data-driven dispatch process compared to conventional mechanisms that rely heavily on operator judgment. The Dispatch Optimization program, which has generated savings of up to IDR 8.91 trillion, demonstrates that digitalization is not merely technological infrastructure, but an efficiency instrument that directly influences dispatch order by identifying the lowest marginal cost generation mix in real time.

At the corporate level, the implementation of various digital breakthroughs such as Digital Power Plant, Outage Management, and Green Booster has created an integrated data ecosystem spanning from generation to distribution, allowing dispatch decisions to simultaneously consider cost parameters, reliability, and network conditions. At the operational level within PLN Nusantara Power, i-CORE illustrates how full digital connectivity across generating units enables the Economic Dispatch module to automatically recommend the most economical units to operate, functionally replicating the merit order principle, even if not explicitly stated. Thus, digital transformation not only enhances system efficiency and reliability, but also reshapes the merit order into a more precise and responsive mechanism, capable of adapting to load dynamics, renewable energy variability, and uncertainties in the energy market.

**Implications of the Merit Order on Sales Performance and Portfolio Strategy**

In PLN NP operational performance report, it is stated that in 2024 the company successfully increased electricity sales to 63.41 TWh approximately 17% above the target while reducing the cost of production (BPP) by 11.4% through energy mix optimization and overall efficiency improvements (PLN Nusantara Power, 2025). This operational optimization strategy indicates that the company is increasingly prioritizing a more efficient generation dispatch order (merit order), with lower-cost power plants dispatched first to increase sales volume while reducing costs. The direct implication for sales performance is higher volume combined with lower cost margins, which in turn strengthens PLN NP's position within a more competitive and efficient generation portfolio.

Meanwhile, in studies on PLN's power plant gasification program, it is noted that merit order–based dispatch using a "least-cost" approach is increasingly prioritized. As coal-fired IPP plants have lower production costs (BPP) compared to gas-fired plants, gas utilization is therefore likely to decline significantly (Direktur Monitoring KPK, 2022). From a portfolio strategy perspective, this indicates that PLN faces increasing pressure to structure its generation portfolio by prioritizing the lowest-cost units in order to remain competitive within the merit order. This implies that the generation portfolio must be managed not only in terms of capacity, but also in terms of dispatch order and cost margins, ensuring that generating units can "win" in the dispatch sequence and positively impact sales performance through improved reliability and lower costs.

The management of dispatch order or the ranking of power plants through the merit order mechanism has a direct impact on operational efficiency and the profitability of power generation companies. For example, a study on a thermal power plant shows that a reduction in heat rate significantly increases operating income: *"The dynamic system built shows evidence of a relationship between increased operating income and decreased heat rate value in the Priok Combined Cycle Power Plant,"* at a power generation company in Indonesia (Fernandes & Anggaini, 2021). This indicates that if a power plant occupies a more favorable position in the merit order (due to lower production costs), its potential energy sales performance and margins will increase making it highly relevant for the generation portfolio of PT PLN (Persero) and its subsidiaries to remain competitive and secure dispatch priority.

PLN recorded electricity sales of 288.44 TWh in 2023, an increase of 5.36% compared to 2022. This achievement was driven by various marketing innovations, including intensification programs such as power upgrade promotions, captive power customer acquisition, and electrifying lifestyle campaigns, as well as extensification programs such as electrifying agriculture and marine, the dieselization reduction (dedieselization) program, and the development of electric vehicle infrastructure (Syofiadi, 2024). The increase in PLN's electricity sales to 288.44 TWh (+5.36% in 2023) indeed reflects the success of its intensification and extensification marketing programs. However, its implications for sales performance cannot be separated from the generation merit order. Growth in demand will only truly improve margins if the additional load is primarily supplied by low-cost generators

(such as base-load plants or renewable energy), rather than forcing the dispatch of high-cost plants like gas turbines (PLTG) or diesel (PLTD). This means that the generation portfolio strategy must be aligned so that market expansion initiatives such as electrifying lifestyle, agriculture, and marine programs are concentrated in regions and segments that can be served efficiently under the merit order. Otherwise, increased electricity sales (TWh) may result in "pseudo-growth," where volume rises but production costs (BPP) remain high, preventing any significant improvement in financial performance.

These findings confirm that operational data from PLN NP and PLN indicate that the merit order has direct implications for sales performance and generation portfolio strategy. The increase in sales to 63.41 TWh and the 11.4% reduction in BPP in 2024 are clearly not merely the result of market expansion, but rather a consequence of successfully prioritizing low-cost units in the dispatch order. The gasification study by the KPK further shows that a least-cost orientation within the merit order has led to gas-fired plants being displaced by coal-based IPPs with lower BPP, indicating that external pressures are pushing PLN to manage its portfolio not solely based on installed capacity, but on the cost competitiveness of each unit to "win" in the dispatch competition. This consistency is reinforced by empirical evidence from Fernandes & Anggaini (2021), which shows that a reduction in heat rate increases operating incomehighlighting that a plant's position in the merit order directly affects energy sales margins.

Moreover, the increase in PLN's sales volume to 288.44 TWh in 2023 demonstrates that market expansion only strengthens performance when additional demand is served by low-cost base-load generation. Otherwise, demand growth risks creating "pseudo-growth," where sales volume increases but profitability stagnates due to high BPP. Thus, the merit order functions as an economic mechanism linking operational strategy, cost structure, and portfolio diversification direction. Consequently, PLN's generation portfolio must be deliberately designed to align with the principle of low marginal cost, rather than merely responding to demand growth.

## 4. Conclusion

This study demonstrates that the implementation of the merit order in PLN and PLN Nusantara Power has evolved from a classical marginal cost–based dispatch mechanism into a hybrid merit order system that integrates technical efficiency indicators (SFC, NPHR), reliability parameters (EAF, EFOR), generation mix considerations, and digital optimization platforms. This evolution reflects a fundamental shift from static and cost-only dispatch decisions toward a dynamic, data-driven operational model that incorporates multiple technical and strategic dimensions. However, the findings reveal that the effectiveness of the merit order is significantly constrained by the rigidity of PJBTL contract structures, particularly take-or-pay schemes and long-term primary energy supply agreements, which limit dispatch flexibility and reduce the system's ability to fully optimize operational efficiency and integrate renewable energy. At the same time, PJBTL arrangements with industrial customers play a positive role in stabilizing demand and supporting baseload optimization. From a commercial perspective, this study also confirms that electricity sales growth does not necessarily lead to improved financial performance unless additional demand is supplied by low-cost generation units, as otherwise it may result in pseudo-growth characterized by high production costs and stagnant profit margins.

These findings imply that for PLN, the merit order should be repositioned as a strategic portfolio management instrument rather than merely a technical dispatch tool, requiring alignment between generation planning, contract structures, and system operations. For PLN Nusantara Power, strengthening digital-based dispatch systems such as I-CORE and other optimization platforms is essential to improve real-time efficiency, reliability, and cost competitiveness. At the sectoral level, enhancing PJBTL contract flexibility becomes a critical factor in supporting energy transition and enabling more adaptive integration of renewable energy within the electricity system. Based on these findings, this study recommends that PLN gradually reform PJBTL contracts toward more flexible schemes, enhance investment in AI-based and data-driven dispatch optimization systems, and align generation portfolio strategies toward low-cost and high-efficiency units to maintain competitiveness within the merit order framework. Furthermore, future research is encouraged to develop quantitative models to measure the financial impact of merit order optimization, explore simulation approaches for

renewable energy integration, and examine the role of regulatory reforms and advanced digital technologies in improving real-time dispatch efficiency in developing country contexts.

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