ความยั่งยืนทางพลังงานและการขับเคลื่อนศูนย์ข้อมูลสีเขียวเพื่ออนาคตเศรษฐกิจดิจิทัลไทย

Energy Sustainability and Driving Green Data Centers for Thailand's Digital Economy Future

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บทคัดย่อ

เนื่องจากประเทศไทยกำลังวางตำแหน่งตัวเองเป็น "ประตูสู่ดิจิทัล" ชั้นนำของอาเซียน อุตสาหกรรมศูนย์ข้อมูลของไทยจึงเติบโตอย่างไม่เคยปรากฏมาก่อน อย่างไรก็ตาม การขยายตัวอย่างรวดเร็วนี้เผชิญกับความท้าทายที่สำคัญระหว่างการเติบโตของโครงสร้างพื้นฐานดิจิทัลและความยั่งยืนด้านพลังงาน งานวิจัยนี้ศึกษาความท้าทายของความต้องการพลังงานที่เพิ่มสูงขึ้นจากการทำงานของปัญญาประดิษฐ์ (AI) ซึ่งต้องการพลังงานสูงถึง 300 กิโลวัตต์ต่อแร็ค ในสภาพภูมิอากาศเขตร้อนของประเทศไทย ซึ่งระบบทำความเย็นคิดเป็น 40% ของการใช้พลังงานทั้งหมดอยู่แล้ว

จากการวิเคราะห์ภูมิทัศน์ด้านพลังงานในปัจจุบัน งานวิจัยนี้ระบุถึงจุดอ่อนเชิงโครงสร้าง รวมถึงการพึ่งพาก๊าซธรรมชาติสูง (57.57%) และรูปแบบตลาด "ผู้ซื้อรายเดียวที่ได้รับการปรับปรุง" (Enhanced Single Buyer: ESB) ที่ไม่ยืดหยุ่น ผ่านกรอบนโยบายที่อิงหลักฐาน งานวิจัยนี้ประเมินทางเลือกเชิงกลยุทธ์สี่ประการ ได้แก่ การเปิดเสรีตลาดสีเขียว การปรับปรุงโครงข่ายไฟฟ้าให้ทันสมัยด้วยระบบจัดเก็บพลังงานแบตเตอรี่ (BESS) แรงจูงใจสำหรับศูนย์ข้อมูลสีเขียว และกลไกการเปลี่ยนผ่านที่เป็นธรรม

งานวิจัยสรุปว่า นโยบายแบบสองทาง—ที่ผสมผสานการปฏิรูปโครงสร้างตลาดผ่านการเข้าถึงโดยบุคคลที่สาม (TPA) และข้อตกลงซื้อขายไฟฟ้าโดยตรง (Direct PPA) เข้ากับการใช้งานเทคโนโลยีสมาร์ทกริดอย่างจริงจัง—เป็นแนวทางที่ดีที่สุด ซึ่งจะช่วยให้มั่นใจได้ถึงความเป็นผู้นำทางเศรษฐกิจในระยะยาวและความยั่งยืนด้านสิ่งแวดล้อมในยุคดิจิทัลของภูมิภาค

คำสำคัญ: ศูนย์ข้อมูล, ความยั่งยืนด้านพลังงาน, โครงสร้างพื้นฐาน AI, พลังงานหมุนเวียน, การเปิดเสรีตลาด

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Abstract

As Thailand positions itself as a premier "Digital Gateway" for ASEAN, its data center industry has seen an unprecedented surge. However, this rapid expansion faces a critical nexus between digital infrastructure growth and energy sustainability. This research examines the challenges of escalating power demands driven by Artificial Intelligence (AI)—requiring up to 300 kW per rack—within Thailand's tropical climate, where cooling systems already account for 40% of total energy consumption.

Analyzing the current energy landscape, the study identifies structural vulnerabilities, including a high dependency on natural gas (57.57%) and an inflexible "Enhanced Single Buyer" (ESB) market model. Through an evidence-based policy framework, this paper evaluates four strategic options: Green Market Liberalization, Grid Modernization through Battery Energy Storage Systems (BESS), Green Data Center Incentives, and a Just Transition mechanism.

The research concludes that a dual-track policy—combining structural market reform via Third-Party Access (TPA) and Direct Power Purchase Agreements (Direct PPA) with the aggressive deployment of smart grid technologies—is the optimal path. Thailand can foster a competitive ecosystem of Load Aggregators and Virtual Power Plants, ensuring long-term economic leadership and environmental sustainability in the regional digital era.

Keywords: Data Centers, Energy Sustainability, AI Infrastructure, Renewable Energy, Market Liberalization

Introduction

The global data center market is projected to expand significantly, rising from USD 240 billion in 2024 to approximately USD 500 billion by the 2032–2033 period. According to McKinsey (2025), Thailand and Indonesia are emerging as the preeminent hubs for data and AI infrastructure within Southeast Asia. The surge in Artificial Intelligence (AI) adoption has catalyzed a rapid expansion of data center facilities to accommodate intensive computational requirements, consequently driving a substantial increase in national electricity demand.

Thailand's data center and cloud sector is growing rapidly. According to the Board of Investment (BOI, 2025), 36 projects have been approved with investments exceeding THB 728 billion, driven by funding from countries such as the United States, China, Singapore, Australia, and Japan. Alongside foreign investment, local companies are partnering with global firms such as GSA (Gulf, Singtel, AIS) and Evolution DC (CP, Central Pattana, NT). However, data centers use a large amount of energy and face two key challenges: rising electricity demand, fueled by the rapid growth of Generative AI with energy use increasing about 9% annually since 2020 (Ericsson, 2025), and high operating costs, as energy accounts for around 20% of total expenses (GSMA, 2025). Improving energy efficiency is therefore essential to reduce costs and meet sustainability expectations from investors and customers.

Literature Review

The relationship between expanding digital infrastructure and energy consumption is shaped by a key efficiency paradox. Masanet et al. (2020) showed that even though data center workloads increased sixfold worldwide, improvements in hardware, virtualization, and infrastructure management helped limit the rise in total energy use. However, this positive global trend often ignores local factors. In tropical developing countries, climate and infrastructure challenges can significantly reduce the effectiveness of these efficiency gains. Radu (2015) argues that using only traditional measures like Power Usage Effectiveness (PUE) is not enough to evaluate green data centers, especially in hot and humid environments where cooling is less efficient. To improve data centers in tropical regions, we need more comprehensive metrics that consider how local climate conditions reduce efficiency.

This problem becomes even clearer when looking at the idea of "digital extractivism." While global cloud growth may seem positive, it can place heavy environmental and infrastructure burdens on the countries hosting it. Hogan (2022) and Lawrence (2023) explain that large tech companies often shift their energy use and emissions to developing countries by building resource-intensive data centers there. The rapid growth of AI data centers puts serious pressure on public utilities. This means data center expansion should be seen not just as technological progress, but also as a potential risk to energy systems and environmental fairness.

The main challenge comes from how rigid and slow to change centralized energy systems are. Verbong and Geels (2007) explain that electricity systems often resist change because of existing rules, long-standing agreements, and powerful interests. This shows that real improvement requires major structural reform, because new digital solutions alone cannot succeed without changing the underlying energy system.

Research Objectives

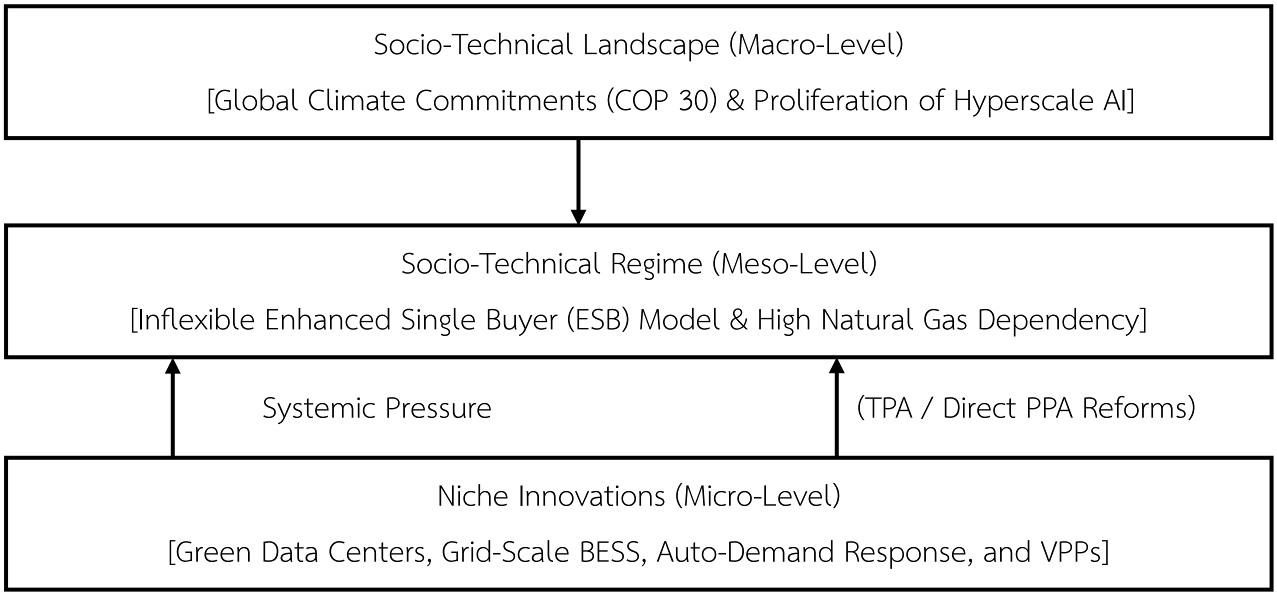
The primary objective of this proposal is to present a framework for efficient energy management within Thailand's data center industry, which is currently experiencing exponential growth driven by global hyperscalers. The proposal focuses on addressing the following key areas:

1. Energy Demand Mitigation: Managing the surge in electricity demand resulting from intensive AI processing.
2. Grid Stability: Ensuring the reliability and stability of the national power grid amidst rising consumption.
3. Environmental Sustainability: Aligning industrial growth with environmental goals to maintain Thailand's competitive edge as a Regional Digital Hub.

Methodology

This research applies the multi-level perspective (MLP) to build an Energy Analysis and Policy Framework for understanding system transitions. MLP, developed by Rip and Kemp (1998) and later refined by Geels (2005, 2024), explains how major changes occur through interactions across three levels: niches, regimes, and the socio-technical landscape. Niches are protected spaces where new ideas and innovations can develop. The regime represents the existing system, comprising technologies, institutions, rules, and actors, which tends to be stable and resistant to rapid change. The socio-technical landscape refers to broader external factors, such as economic trends, political developments, cultural values, and climate change, which are difficult to influence in the short term. Changes at this level can create pressure on existing systems and open opportunities for innovations to grow.

Building on this framework, the study explains transitions across three levels. At the macro level, the socio-technical landscape includes external pressures such as global decarbonization policies (e.g., COP30) and increasing energy demand from generative AI. At the meso level, the socio-technical regime reflects Thailand's current energy system, including the Enhanced Single Buyer (ESB) model and its reliance on natural gas, which tends to remain stable over time. At the micro level, niche innovations refer to emerging technologies such as green data centers, liquid cooling, battery energy storage systems (BESS), and Virtual Power Plants (VPPs). This study examines how pressures from the broader landscape can create opportunities for these innovations to expand and gradually transform Thailand's energy system into a more flexible and liberalized market. The conceptual framework is presented below.



Socio-Technical Regime Analysis

Thailand’s electricity sector represents a deeply entrenched socio-technical regime characterized by a structural dependency on fossil fuels and a centralized governance model. Currently, the regime relies on natural gas for approximately 50–60% of its total generation mix, sourced from the shifting reserves of the Gulf of Thailand and supplemented by volatile Liquefied Natural Gas (LNG) imports (EPPO, 2025). This high path-dependency exposes the regime's pricing mechanisms to macroeconomic landscape pressures, rendering national electricity costs highly sensitive to global fuel volatility and exchange rate fluctuations. As the global socio-technical landscape evolves, driven by the rapid proliferation of artificial intelligence (AI), hyperscale data infrastructure, and strict international decarbonization mandates like the EU's Carbon Border Adjustment Mechanism (CBAM), the rigidity of Thailand's current energy regime faces critical friction. To successfully capture global digital infrastructure investments, the regime must undergo structural realignment to secure stable, clean, and competitively priced energy streams. The following sections provide an in-depth analysis of the regime’s structural bottlenecks and emerging niche disruptions

1. Regime Stability, Security, and Systemic Vulnerabilities

From a socio-technical perspective, the Thai power regime maintains a high level of institutional lock-in regarding volumetric security (over-supply), yet it exhibits severe structural vulnerabilities when exposed to future resource dynamics and technical management requirements.

1.1 Institutional Lock-in and High Reserve Margins: Thailand's power generation capacity significantly exceeds actual demand, with a reserve margin of 30–40%, compared to the 15% standard. This surplus is attributed to over-projected demand and long-term Power Purchase Agreements (PPAs) featuring "Availability Payments" (Take-or-Pay clauses), which impose hidden costs on the national electricity tariff (TDRI, 2025).

1.2 Fuel Dependency and Exogenous Landscape Risks: With natural gas dictating 57–60% of the regime's generation mix and domestic reserves projected to deplete by approximately 2035, the regime is forced into an escalating reliance on imported LNG. This growing exposure to global market shocks weakens Thailand's industrial positioning against agile regional competitors. For example, Vietnam's energy regime has actively adapted to landscape pressures by pioneering institutional niche pathways such as Direct PPA mechanisms (Nattachat, 2025).

1.3 Grid Intermittency and the Niche-Regime Friction: The regime faces technical destabilization from the rapid integration of variable renewable energy (VRE), such as solar and wind. The inherent intermittency of these clean sources disrupts conventional grid frequency and voltage stability. Overcoming this regime friction requires strategic deployment of niche innovations, specifically grid-scale Battery Energy Storage Systems (BESS) (GIZ, 2025) and Smart Grid architectures (UNDP, 2025).

1.4 Realigning Reliability Metrics: To better reflect the risks associated with renewable energy, the government is transitioning its security metric from "Reserve Margin" to Loss of Load Expectation (LOLE), targeting a threshold of no more than 0.7 days per year (Energy Policy and Planning Office, 2024).

2. Regime Economic Structures: Price and Cost Friction

Thailand's electricity tariffs are highly susceptible to global fuel price volatility and are burdened by legacy debts, which may hinder the country's competitiveness relative to regional peers.

2.1 The Ft Mechanism as a Regime Defense Structure: The regime's economic architecture relies on a bifurcated tariff composed of a base rate and the Fuel Adjustment Tariff (Ft), which automatically passes global natural gas and currency fluctuations down to consumers. While the state has historically deployed political interventions to freeze household rates at approximately 4.18 THB/kWh via mandated price caps and temporary subsidies, this has generated an unsustainable, legacy debt burden for the state utility (EGAT). This financial deficit must ultimately be clawed back in future billing cycles, signaling a delayed economic shock for the regime cycles (Thailand Development Research Institute [TDRI], 2025).

2.2 Future Socio-Technical Price Trends:

2.2.1 Regime Stressors (Upward Pressures): Escalating structural reliance on imported LNG will inevitably inflate "Pool Gas" costs. This vulnerability is worsened by exogenous landscape stressors, including geopolitical conflicts that drive up global commodity prices and the ongoing societal pass-through of excess, unutilized power plant capacity costs (Nattachat, 2025).

2.2.2 Niche-Driven Mitigation (Downward Potentials): Conversely, the co-location of solar PV with BESS innovations presents a technological pathway to displace expensive gas-fired peaking plants during maximum demand periods. As the cost curves for BESS continue to drop, this renewable niche will eventually achieve economic parity, eroding the financial justification for fossil-fuel-based regime path-dependency (TDRI, 2025; GIZ, 2025).

2.3 Utility Green Tariff (UGT) and Regulatory Barriers: While the industrial sector increasingly demands clean energy to meet Carbon Neutrality targets and comply with the EU's Carbon Border Adjustment Mechanism (CBAM), the current UGT structure includes a "premium" cost. This elevated price point increases production costs for businesses in Thailand, especially when compared to competitors like Vietnam, which has adopted a more liberalized Direct PPA market (TDRI, 2025).

Policy Options

Option 1: Green Market Liberalization

- Objective: Establish competitive pricing to attract global data center investments.
- Policy Proposal: Upgrade EPPO (2024)'s restrictive pilot sandbox by unbundling the market away from the centralized Enhanced Single Buyer (ESB) monopoly. This reform transforms EGAT's transmission unit into an independent Transmission System Operator (TSO), applies fair Wheeling Charges (transitioning from a Postage Stamp to a Power Flow-Based model), and accelerates Third-Party Access (TPA) for Direct PPAs to serve all large-scale, CBAM-affected consumers. To manage grid stability, an energy imbalance framework will deploy a short-term Banking Mechanism followed by a long-term, real-time Balancing Market.
- Supporting Rationale: The current ESB structure ties tariffs to volatile gas costs and EGAT's debts via the Ft mechanism. Liberalization cuts private sector costs, bypasses the slow fossil-fuel phase-out of the current PDP, and satisfies hyperscalers demanding 100% clean energy who would otherwise pivot to regional rivals like Vietnam.

Option 2: Grid Modernization and Energy Storage

- Objective: Secure the power system against variable renewable energy intermittency.
- Policy Proposal: Prioritize a national agenda for deploying grid-scale Battery Energy Storage Systems (BESS) at substations alongside Hybrid PV+BESS projects to guarantee a continuous, dispatchable power supply.
- Supporting Rationale: As renewable integration hits 51% by 2037 under PDP2024, BESS is vital to shift surplus daytime solar power to the evening peak, reducing reliance on high-cost gas peaking plants and lowering the national Loss of Load Expectation (LOLE) (EPPO, 2025).

Option 3: Green Data Center Incentives and Efficiency Standards

- Objective: To enhance energy efficiency and minimize the industrial carbon footprint.
- Policy Proposal: Expand BOI privileges for data centers adopting liquid cooling or AI-driven energy management to slash energy use by 20–40%. Simultaneously, enforce strict Power

Usage Effectiveness (PUE) benchmarks and encourage project clustering inside designated Renewable Energy Zones near hydro-solar floating arrays.

- Supporting Rationale: Cooling constitutes up to 40% of data center energy consumption in tropical climates; deploying AI analytics directly reduces this aggregate grid load (Christ & Jim, 2018; UNDP, 2025).

Option 4: Just Transition and Green Finance

- Objective: Mobilize capital for infrastructure while promoting socio-economic equity.
- Policy Proposal: Issue Sustainability-Linked Bonds to fund grid modernizations and support supply-chain SMEs, build an international-grade Carbon Credit Market, and implement clean tech and AI reskilling initiatives to transition fossil-fuel workers into new green jobs.
- Supporting Rationale: Navigating the energy transition requires over THB 2.2 trillion in investments, necessitating alternative green financing while mitigating labor displacements within legacy industries under UNDP guidelines (UNDP, 2025).

Recommended Policy and Implementation Plan

Optimal Strategy: A dual-track policy of Green Market Liberalization integrated with Grid Modernization and Energy Storage.

This approach synergizes global investment attraction with rigorous resource management through the following implementation plan:

1 Market Reform: Immediate Implementation of Third-Party Access (TPA) and Direct PPAs

- Execution: The state must authorize private power producers to sell clean electricity directly to large-scale users—such as data centers and industrial estates—via the national transmission grid (Direct PPA). This requires a fair and cost-reflective Wheeling Charge.
- Objective: To ensure that target industries (New S-Curve) have access to clean energy at competitive prices and can claim carbon footprint reductions according to international standards (e.g., RE100, CBAM), which the current "Pool Gas" system does not facilitate.

- Timeline: Implementation must be finalized within Phase 1 of the Medium-Term Smart Grid Plan (or within 1–2 years) to remain competitive amidst the global trend of manufacturing base relocation.

2 Technological Upgrades: Mandatory Demand Response (DR) and RE Forecasting Systems

Market liberalization introduces inherent system volatility; therefore, technologies from the Smart Grid Master Plan must be leveraged to manage Grid Stability as an alternative to building excessive and unnecessary reserve power plants.

2.1 Demand Response (DR): Transition from voluntary cooperation to the establishment of a formal "Demand Response Market" (DR Market). This mechanism allows the private sector to generate revenue by reducing electricity consumption during peak periods. The primary focus should be on Auto-DR (automated load reduction) within large-scale industrial sectors, aiming for the Master Plan's target of a 350 MW peak reduction.

2.2 RE Forecast Center: Establish a National Renewable Energy Forecasting Center to provide the National Control Center (NCC) with precise data to manage fluctuations from solar and wind energy—projected to reach a 50% share under the PDP2024. Accurate forecasting will significantly reduce the operational costs associated with maintaining spinning reserves.

2.3 Grid Modernization: Invest in Advanced Metering Infrastructure (AMI) and 5G communication systems to facilitate real-time data exchange between Prosumers (entities that both produce and consume energy) and the centralized control centers.

3 Sustainability and Social Impact: A Just Transition

To ensure that the energy transition does not impose an undue financial burden on the general public and adheres to the UNDP's "Leave No One Behind" principle, the following measures are proposed:

3.1 Pricing Mechanisms and Mitigation: Revenue generated from Wheeling Charges (grid access fees) paid by large-scale private entities should be strategically managed to subsidize or freeze base electricity tariffs for households. Alternatively, these funds could support the Power Development Fund to finance solar rooftop installations for vulnerable groups.

3.2 Reskilling and Workforce Development: Implement comprehensive training programs in smart grid technologies, EV charger installation and maintenance, and Energy Storage Systems (ESS). This ensures the workforce is prepared for the emerging roles created by the technological shift.

3.3 Energy Imbalance Management: Establish regulatory frameworks that hold Independent Power Producers (IPPs) financially accountable for Imbalance Costs if they fail to meet contracted production levels. This prevents the cost of maintaining system balance from being passed on to general electricity consumers.

Conclusion

Thailand’s success in establishing itself as the "Digital Gateway" of ASEAN is not merely contingent upon the physical number of data center facilities constructed, but rather on the capacity to provide a secure and sustainable energy supply. Given the energy-intensive nature of data center processing, closing the infrastructure and energy gaps through public-private synergy is paramount. By doing so, Thailand can transition from being a passive investment destination to becoming a proactive leader in the regional digital economy.

Implementing these reforms will enhance investor confidence and shift the national security metric from a reliance on excessive reserve margins toward system flexibility and a minimized Loss of Load Expectation (LOLE). Furthermore, dismantling traditional monopolies will foster a dynamic business ecosystem, giving rise to innovative energy services such as Load Aggregators, Energy Service Companies (ESCOs), and Virtual Power Plants (VPPs). Ultimately, this strategic integration of digital and energy infrastructure will ensure Thailand’s competitive and sustainable standing in the global digital era.

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