American Journal of Economics and Business Management

**Vol. 8 Issue** 11 | **pp.** 5916-5923 | **ISSN:** 2576-5973

**Available online @** https://www.globalresearchnetwork.us/index.php/ajebm

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# The Effect of Artificial Intelligence on The Energy Industry Sector

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**Abstract:** This study examines the transformative impact of artificial intelligence (AI) on the global energy industry, focusing on its role in enhancing efficiency, optimizing system operations, and accelerating the transition toward sustainable energy models. Advances in AI technologies such as machine learning, predictive analytics, digital twins, and intelligent automation are reshaping the generation, transmission, distribution, and consumption of energy. The research highlights how AI-driven forecasting models significantly improve renewable energy integration by predicting solar and wind patterns with higher accuracy, reducing system instability, and enabling smart grid management. Moreover, AI contributes to reducing energy consumption in data centers, industrial facilities, and public infrastructure through real-time monitoring and optimization.

**Keywords:** Artificial Intelligence; Energy Sector; Smart Grid; Renewable Energy; Energy Efficiency; Data Centers; Machine Learning; Energy Forecasting; Digitalization; Sustainability; Energy Security; Intelligent Automation.

**Citation:** Gulchexra. A. The Effect of Artificial Intelligence on The Energy Industry Sector. American Journal of Economics and Business Management 2025, 8(11), 5916-5923

Received: 10th Aug 2025
Revised: 16th Sep 2025
Accepted: 24th Oct 2025
Published: 29th Nov 2025

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## 1. Introduction

Artificial intelligence represents a paradoxical force in the energy sector: simultaneously demanding unprecedented quantities of electricity while offering transformative solutions for energy production, distribution, and management. Global data center electricity consumption currently reaches 415 terawatt-hours (TWh) annually, representing 1.5% of global electricity consumption, with projections indicating growth to 945-1,000 TWh by 2030 a 128% increase. In the United States alone, data center electricity consumption is projected to increase from 183 TWh in 2024 to 426 TWh by 2030, with a potential range of 325-580 TWh depending on adoption rates. This paper employs an IMRAD (Introduction, Methods, Results, Discussion) framework to synthesize comprehensive evidence from the International Energy Agency, U.S. Department of Energy, and peer-reviewed literature.

Results demonstrate that while AI infrastructure demands represent significant energy challenges, AI-enabled applications in renewable forecasting (15-30% accuracy improvements), grid optimization (9-12% efficiency gains), and predictive maintenance offer substantial benefits for energy system decarbonization. Regional disparities are pronounced: the United States faces potential electricity bill increases of $18-$25 monthly

in concentrated data center markets, while wholesale electricity prices have increased up to 267% in areas with significant data center activity. Strategic infrastructure investment, cybersecurity protocols, and coordinated policy frameworks are essential to maximize AI benefits while mitigating associated risks and ensuring equitable energy access.

The relationship between artificial intelligence and the energy sector represents one of the most significant technological intersections of the twenty-first century. Unlike many technology-energy relationships that operate independently, AI and energy are fundamentally interdependent [1]. As the International Energy Agency notes: "There is no AI without energy specifically electricity for data centres. At the same time, AI could transform how the energy industry operates if it is adopted at scale."

## 2. Materials and Methods

The rapid advancement of artificial intelligence technologies, particularly large language models and generative AI applications, has created unprecedented computational demands at precisely the moment when global energy systems are transitioning from fossil fuels to renewable sources [2]. This convergence creates both substantial challenges and significant opportunities requiring comprehensive analysis.

AI's impact on the energy sector operates along two distinct but interconnected dimensions. First, AI infrastructure itself is extraordinarily energy-intensive. Training modern large language models consumes vast quantities of electricity training OpenAI's GPT-4 required approximately 50 gigawatt-hours of energy, equivalent to powering San Francisco for three days. A single AI query consumes approximately ten times the electricity of a traditional Google search [3]. Second, AI technologies offer potentially transformative solutions to persistent energy sector challenges including renewable energy forecasting, grid optimization, predictive maintenance, and accelerated development of new energy technologies. Understanding both dimensions is critical for policy and business decisions [4].

This paper aims to comprehensively examine AI's effect on the energy sector through:

1. Documenting AI's current and emerging applications within energy systems
2. Quantifying energy demands imposed by AI infrastructure with regional analysis
3. Analyzing AI-enabled improvements in renewable integration, grid management, and energy efficiency
4. Assessing cybersecurity threats, infrastructure constraints, and supply chain vulnerabilities
5. Evaluating regulatory frameworks, policy requirements, and investment mechanisms

This comprehensive analysis synthesizes information from multiple authoritative sources using a narrative review methodology. Primary sources include:

- International Energy Agency (IEA) 2025 Energy and AI Report with comprehensive global energy modeling
- U.S. Department of Energy (DOE) assessments and cybersecurity analyses
- Peer-reviewed scientific literature from ScienceDirect, Nature, and academic journals
- Policy analyses from research institutions including Center on Global Energy Policy
- Industry analyses from Bloomberg NEF, World Economic Forum, and specialized energy consultancies

Data was organized across thematic categories: AI energy consumption with regional breakdowns, AI applications in energy systems, grid optimization capabilities, renewable energy integration, cybersecurity implications, and policy frameworks. Statistical data was extracted from authoritative sources and compiled into comparative tables and analytical summaries to facilitate evidence-based conclusions [5].

## 3. Results

AI's energy requirements are substantial and accelerating. Data centers currently consume 415 TWh of global electricity annually, representing 1.5% of total global electricity consumption in 2024. This growth has accelerated at 12% annually over the past five years, with AI-specific acceleration more pronounced (Table 1).

**Table 1.** Global Data Center Electricity Consumption - Current and Projected (TWh)

| Region | 2024 (TWh) | 2030 Proj. (TWh) | Growth % |
|---|---|---|---|
| **Global Total** | **415** | **945** | **127%** |
| United States | 183 | 426 | 133% |
| China | ~103 | ~278 | 170% |
| Europe | ~65 | ~110 | 70% |
| Japan | ~18 | ~33 | 80% |

*Source: International Energy Agency (IEA) 2025 Energy and AI Report*

Notably, AI-specific servers are the primary growth driver. GPU-accelerated servers increased from less than 2 TWh in 2017 to over 40 TWh in 2023, a twenty-fold expansion. By 2030, accelerated servers (primarily AI) are projected to grow at 30% annually, compared to 9% for conventional servers.

**Per-Capita Energy Intensity**

Regional disparities in data center electricity consumption per capita reveal significant structural differences in AI deployment [6]. The following table illustrates these variations (Table 2):

**Table 2. Per-Capita Data Center Electricity Consumption (kWh/person)**

| Region | 2024 (kWh/capita) | 2030 Proj. |
|---|---|---|
| **United States** | **540** | **>1,200** |
| South Africa | ~15 | >25 |
| Africa (average) | <1 | <2 |

Source: IEA Energy and AI Report. Note: US per-capita consumption is approximately 10 times higher than any other region, representing ~10% of average US household electricity consumption.

The United States dominates global data center electricity consumption. By 2030, the US economy is projected to consume more electricity for processing data than for manufacturing all energy-intensive goods combined, including aluminum, steel, cement, and chemicals (Table 3).

**Table 3.** US Data Center Electricity Consumption Scenarios (TWh)

| Scenario | 2028 (TWh) | % of US Total |
|---|---|---|
| Conservative | 325 | 6.7% |
| Midpoint | ~450 | ~9% |
| **High Growth** | **580** | **12%** |

Source: MIT Technology Review analysis; 2024 US Data Center Energy Usage Report

**AI-Specific Electricity Consumption**

Within data centers, AI-specific workloads consume disproportionately high amounts of electricity. In 2024, AI-specific servers accounted for 24% of all server electricity demand while representing only 15% of total data center energy demand. However, this proportion is expanding rapidly. By 2030, AI is projected to account for 35-50% of total data center electricity consumption (Table 4).

**Table 4.** Energy Intensity Comparison - AI vs Traditional Services

| Operation Type | Energy per Query | Multiple vs Google |
|---|---|---|
| Google Search (traditional) | ~0.0003 kWh | 1x |
| **ChatGPT Query (AI)** | **~0.003 kWh** | **10x** |
| GPT-4 Training (one-time) | 50 GWh total | ~167M times |

*Source: MIT Technology Review; International Energy Agency*

**Impact on Electricity Prices and Consumer Bills**

Data center expansion is driving significant wholesale electricity price increases in concentrated markets [7]. Bloomberg analysis reveals that wholesale electricity costs have increased up to 267% in areas with significant data center activity compared to 2020 levels. These wholesale price increases are being passed directly to residential consumers through higher electricity bills (Table 5).

**Table 5: Data Center Impact on Regional Electricity Prices (vs 2020)**

| Market Region | Price Increase | Monthly Bill Impact | DC Proximity |
|---|---|---|---|
| Near Major DC | ~100-267% | $20-$25 | <50 miles |
| **Ohio (Western MD)** | **~80%** | **$16-$18/mo** | **Moderate** |
| Baltimore Region | ~50-120% | $10-$15 | High |

*Source: Bloomberg News analysis of Grid Status and DC Byte data; PJM analysis*

A Carnegie Mellon University study projects that data centers and cryptocurrency mining could lead to an 8% increase in average US electricity bills by 2030, potentially exceeding 25% in highest-demand markets like central and northern Virginia. In the PJM electricity market (Illinois to North Carolina), data centers accounted for a $9.3 billion price increase in the 2025-26 capacity market, resulting in average residential bill increases of $18/month in western Maryland and $16/month in Ohio.

**AI Applications Enhancing Energy Systems**

Despite substantial energy demands, AI offers transformative capabilities for improving energy system efficiency [8]. The following table summarizes key AI applications and their documented improvements (Table 6):

**Table 6. AI Applications in Energy Systems - Documented Improvements**

| Application | Technology/Method | Documented Impact |
|---|---|---|
| Renewable Forecasting | GAN/LSTM neural networks | 15-30% accuracy improvement |
| **Energy Storage Optimization** | VAE dispatch models | 9-12% efficiency gains |

| Application | Technology/Method | Documented Impact |
|---|---|---|
| Demand Forecasting | Machine learning time-series | 20-30% error reduction |
| Predictive Maintenance | Anomaly detection algorithms | 70% reduction in downtime |
| **Grid Optimization** | Real-time control systems | 15-20% cost reduction |
| Building Energy Management | Smart building AI systems | 20% energy cost reduction |

*Source: ScienceDirect peer-reviewed research; IEA reports; DOE assessments*

### Cybersecurity and Infrastructure Challenges

AI introduces both cybersecurity risks and defense capabilities. The energy sector faces escalating threats while AI enables advanced defense mechanisms [9]. Statistics reveal concerning trends and promising protective measures (Table 7).

**Table 7. Cybersecurity Threats and AI-Enabled Defenses in Energy Sector**

| Metric | Threat/Risk Value | Time Period/Source |
|---|---|---|
| Cyberattacks on utilities | Tripled in 4 years | 2020-2024 |
| **Weekly attacks per org** | **1,514 attacks/week** | **2024 (+37% YoY)** |
| Cybersecurity skills gap | 42% shortfall | 2024 Boston Consulting Group |
| AI threat detection rate | 98% accuracy | Implemented AI systems |
| **Response time reduction** | **>70% faster** | **AI-enabled defense systems** |

*Source: Check Point Research; Boston Consulting Group; DOE cybersecurity assessments; MDPI security studies*

The electricity sources powering data centers reveal energy transition challenges. As of 2024, the energy mix for US data centers remains fossil-fuel dependent, though with growing renewable and nuclear components (Table 8):

**Table 8. US Data Center Electricity Sources - 2024 Composition**

| Energy Source | % of DC Electricity | 2030 Projection |
|---|---|---|
| Natural Gas | 40%+ | Largest share |
| **Renewables (Wind/Solar)** | **24%** | **Increasing** |
| Nuclear Power | 20% | Could increase |
| Coal | ~15% | Declining |

*Source: International Energy Agency 2025; PEW Research Center*

## 4. Discussion

### The AI Energy Paradox

The relationship between AI and energy presents a fundamental paradox that requires careful navigation [10]. AI systems demand unprecedented amounts of electricity global data center consumption is projected to reach 945-1,000 TWh by 2030, more than doubling from 415 TWh in 2024. Yet this same technology offers solutions to the energy sector's most

pressing challenges. This paradox demands understanding both dimensions comprehensively to maximize benefits while minimizing harms.

Data center concentration creates significant regional disparities. The United States dominates with 183 TWh consumed in 2024 and projected 426 TWh by 2030, representing per-capita consumption exceeding 1,200 kWh annually by 2030. In contrast, Africa currently consumes less than 1 kWh per capita. This concentration raises equity concerns, as electricity generated for data centers benefits primarily developed economies while potentially constraining electricity access in developing regions facing competing demands for energy infrastructure investment [11].

**Consumer Impact and Energy Affordability**

Data center electricity demand is directly driving residential electricity bill increases of $18-$25 monthly in concentrated markets. In the PJM region alone, data centers accounted for a $9.3 billion capacity market price increase, affecting millions of households. Carnegie Mellon projections suggest 8% average US bill increases by 2030, with concentrated markets potentially exceeding 25%. These impacts disproportionately affect low-income households with less capacity to absorb cost increases, raising environmental justice concerns that require policy attention [12].

**AI-Enabled Energy Efficiency Benefits**

Despite substantial energy demands, AI's contributions to renewable energy integration, grid optimization, and predictive maintenance are substantial and documented [13]. Forecasting improvements of 15-30% enable better planning for variable renewable resources. Energy storage optimization achieves 9-12% efficiency gains. Demand response optimization reduces peak loads, lowering system costs. Predictive maintenance extends infrastructure lifespan and reduces operational expenses. These applications collectively support accelerated decarbonization, though their benefits require proper implementation and measurement.

**Cybersecurity - Double-Edged Technology**

AI's cybersecurity role exemplifies the paradox. Cyberattacks on energy utilities have tripled in four years, with AI enabling sophisticated attack vectors including phishing automation, code obfuscation, and network reconnaissance [14]. Simultaneously, AI-enabled defense systems demonstrate 98% threat detection accuracy with 70% faster response times. The energy sector faces a cybersecurity skills gap with 42% shortfall in expertise. Effective responses require substantial investment in workforce development, cybersecurity infrastructure, and federal-industry coordination.

**Infrastructure and Supply Chain Constraints**

Data center expansion is placing unprecedented pressure on electricity infrastructure. Approximately 70% of US transmission lines exceed their design lifespan. Grid connection queue times are extending substantially, with some utilities reporting connection wait times of multiple years. Critical mineral supply chains face concentration risks, with supplies of materials needed for both data centers and renewable energy infrastructure heavily concentrated geographically [15]. These constraints require coordinated long-term infrastructure investment and strategic supply chain resilience planning.

**Policy and Regulatory Framework Requirements**

Effective policy responses require multi-dimensional approaches. Executive Order 14110 establishes a framework for federal agencies to develop AI standards for critical infrastructure. The DOE's risk assessment identifies four categories of risk: unintentional failure modes, adversarial attacks, hostile applications, and supply chain compromise. Regulatory approaches should build cybersecurity into AI system design rather than relying on add-on protections. Financial mechanisms including the Inflation Reduction Act create opportunities for scaling AI and renewable energy investments, though additional capital mobilization is necessary.

Artificial intelligence is reshaping the energy sector through simultaneous mechanisms that require careful management. AI infrastructure demands are substantial and

growing—global data center electricity consumption is projected to reach 945-1,000 TWh by 2030, more than doubling from 415 TWh in 2024. In the United States, consumption is projected to increase from 183 TWh in 2024 to 426 TWh by 2030, potentially consuming 12% of total national electricity by 2028 under high-growth scenarios.

Simultaneously, AI technologies offer transformative solutions for energy decarbonization [16]. Renewable energy forecasting improvements of 15-30% enhance grid stability and enable higher renewable penetration. Energy storage optimization achieves 9-12% efficiency gains. Demand response capabilities reduce system costs and peak loads. Predictive maintenance extends infrastructure lifespan and reduces operational expenses. Accelerated materials science and battery development support rapid scaling of clean energy technologies.

## 5. Conclusion

However, realizing these benefits requires careful attention to associated challenges. Cybersecurity threats are escalating, with AI both enabling sophisticated attacks and providing defense capabilities—threat detection rates have improved to 98% with response times reduced by over 70%. Infrastructure constraints are substantial, with over 70% of US transmission lines exceeding design lifespan. Regional electricity concentration creates potential supply chain vulnerabilities. The energy sector faces a 42% cybersecurity skills gap requiring urgent workforce development.

Consumer impacts are significant and growing. Data center electricity demand is driving residential electricity bill increases of $18-$25 monthly in concentrated markets, with regional wholesale prices up to 267% higher than 2020. These impacts disproportionately affect low-income households, raising environmental justice concerns requiring policy attention.

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