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Research Article

Stranded Power From Data Centers And Possible Uses

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Abstract

Growing demand for data center services has heightened emphasis on electricity consumption, energy efficiency and underutilized available power resources. Stranded power, which can be defined as unutilized electrical capacity within data center infrastructure or excess renewable electricity that cannot be efficiently utilized by the modern electrical power system, can offer opportunities to improve energy management and computing efficiency. In this work a literature review was conducted to assess the sources, nature and potential applications of stranded power associated with data centers. The review pays particular attention to inefficient power provision, stranded renewable electricity, flexible scheduling of workloads and demand response. The assessment concludes with the potential applications of data centers' demand for stranded power, such as increased utilization of current IT infrastructure and computational processing, integration of renewable energy, and support to the electrical power grid. The economic, environmental and technical constraints of these proposed solutions are discussed, leading to the conclusion that demand side solutions improve power utilization provided they are applied under certain infrastructure and workload conditions and depending on local, renewable electricity generation levels. The piece ends with the point that stranded power can be harnessed for data centers, as long as optimization efforts are backed by fit for purpose technical, economic and environmental planning. evaluation.

Keywords: Stranded Power, Data Centers, Energy Efficiency, Renewable Energy, Power Utilization, Workload Management, Demand Response.

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Introduction

Background of the Study

Data centers have become essential infrastructure for modern digital economies, supporting cloud computing, artificial intelligence, telecommunications, and large-scale information processing. Their growing importance has been accompanied by increasing electricity demand, creating concerns about energy efficiency, operational costs, and environmental sustainability (Geng, 2014; Loesel & Smith, 2025). Despite improvements in computing technologies and power management systems, significant opportunities remain to optimize energy utilization within data center facilities (Kandlur & Keller, 2009; Takci et al., 2025).

One important challenge is stranded power, which can arise when installed electrical capacity remains underutilized because of conservative power provisioning, fluctuating workloads, and infrastructure limitations (Ganesh et al., 2009). Research has demonstrated that more efficient workload distribution

and power management can improve the utilization of existing data center infrastructure without necessarily increasing installed electrical capacity (Ganesh et al., 2009; Dvorkin, 2024). Consequently, understanding how stranded power can be identified and effectively utilized is increasingly relevant to sustainable data center operations (Yang & Chien, 2017; Takci et al., 2025).

Concept of Stranded Power in Data Centers

Stranded power in data centers primarily refers to electrical capacity that has been provisioned but remains unavailable for productive use because of operational, technical, or infrastructure constraints (Ganesh et al., 2009). This situation frequently occurs when server power allocations are determined using maximum rated consumption rather than actual operating demand, leaving portions of the available infrastructure capacity unused (Ganesh et al., 2009). Stranded renewable electricity represents a related but different concept, describing electricity that cannot be economically utilized or delivered because of transmission limitations, geographical constraints, or mismatches between generation and demand (Yang & Chien, 2016; Kim et al., 2016).

Although unused electrical capacity does not constitute electricity generated by a data center, improved power allocation can make that capacity available for additional computing activities, while flexible data center operations can support wider electricity system efficiency (Ganesh et al., 2009; Takci et al., 2025).

Causes of Stranded Power in Data Centers

Stranded power is associated with several operational factors, including overprovisioning of power infrastructure, uneven server utilization, fluctuating computing workloads, and limitations in rack-level power distribution (Ganesh et al., 2009; Geng, 2014). Traditional provisioning methods often reserve sufficient capacity for peak demand even when actual consumption remains considerably below those limits (Ganesh et al., 2009). Furthermore, restrictions on workload scheduling and the geographical distribution of computing resources can limit opportunities to match electricity consumption with available generation (Chien et al., 2015; Dvorkin, 2024).

Possible Uses of Stranded Power

Improved utilization of stranded electrical capacity can support additional server deployment, increased computing workloads, and better use of existing power infrastructure (Ganesh et al., 2009). Flexible computing systems can also utilize otherwise curtailed renewable electricity for cloud computing and high-performance computing, potentially reducing operational costs and improving renewable energy integration (Yang & Chien, 2016, 2017). Through demand response, workload shifting, and coordinated energy management, data centers can provide flexibility to electricity networks and support more efficient grid operations (Kim et al., 2016; Dvorkin, 2024; Takci et al., 2025).

However, these benefits depend on operational conditions and the electricity generation mix, since greater data center flexibility does not automatically translate into lower carbon emissions (Knittel et al., 2025).

Statement of the Problem

Despite advances in data center energy management, inefficient power provisioning and limited operational flexibility continue to restrict the productive utilization of available electrical resources (Ganesh et al., 2009; Takci et al., 2025). Although previous studies have explored stranded renewable energy, workload optimization, and flexible computing systems, these approaches address different aspects of energy utilization and require careful consideration when evaluating their practical applications (Yang & Chien, 2017; Dvorkin, 2024). Furthermore, the

economic and environmental benefits of recovering underutilized capacity depend on infrastructure requirements, workload characteristics, electricity prices, and regional energy conditions (Yang & Chien, 2016; Knittel et al., 2025).

Aim and Significance of the Study

This article examines stranded power associated with data center operations, focusing on its causes, characteristics, possible uses, and implications for energy efficiency. Drawing on existing research, it evaluates how improved power allocation, flexible workload management, and renewable energy integration can enhance the utilization of electrical resources (Ganesh et al., 2009; Kim et al., 2016; Takci et al., 2025). The discussion provides a foundation for understanding the technical, economic, and environmental considerations involved in reducing stranded capacity and improving the sustainability of data center infrastructure (Yang & Chien, 2017; Knittel et al., 2025).

Literature Review

Conceptual Overview of Stranded Power

The literature on stranded power in relation to data centers can be grouped into two closely related but distinct areas. The first concerns unused electrical capacity inside data centers, where installed power infrastructure is not fully utilized because provisioning decisions are based on peak or nameplate power ratings rather than actual operating demand. The second concerns stranded renewable electricity outside the data center, where available energy cannot be fully absorbed by the grid because of transmission constraints, temporal mismatch between generation and demand, or location-specific limitations. This distinction is important because several studies discuss stranded energy as a grid-level phenomenon, whereas others focus on underused capacity within computing facilities (Ganesh et al., 2009; Kim et al., 2016; Yang & Chien, 2016; Yang & Chien, 2017).

Early discussions of energy efficiency in data centers emphasized that computing facilities are often designed with conservative safety margins for power and cooling, which can lead to substantial underutilization of installed infrastructure (Kandlur & Keller, 2009; Geng, 2014). As data centers expanded in scale and strategic importance, attention shifted from simple efficiency improvements to more advanced methods of matching energy supply, workload demand, and infrastructure capability (Geng, 2014; Loesel & Smith, 2025). Within this broader context, stranded power has become an important topic because it represents both a technical inefficiency and a potential opportunity for improving computational productivity and power system performance (Takci et al., 2025; Dvorkin, 2024).

Stranded Power Within Data Center Infrastructure

A major contribution to this discussion was provided by Ganesh et al. (2009), who showed that the common practice of allocating rack power according to the maximum rated consumption of servers leads to stranded capacity. In practice, servers rarely operate continuously at their peak power, meaning that power distribution units and rack circuits may have additional usable capacity that remains inaccessible under static provisioning methods. This creates a situation in which data centers appear fully allocated on paper while significant electrical headroom still exists in operation (Ganesh et al., 2009).

This internal form of stranded power is influenced by workload diversity, server utilization patterns, and infrastructure management policies. Facilities that provision for worst-case scenarios may protect reliability, but they also risk leaving valuable electrical and computational capacity idle. Geng (2014) explained that

data center planning involves balancing reliability, redundancy, and operational efficiency, and this balance often encourages overprovisioning. Kandlur and Keller (2009) similarly argued that green data center strategies must address not only energy-efficient components but also the broader design and management practices that shape real power use. These observations support the view that stranded power is not only a supply issue but also a consequence of conservative infrastructure planning and incomplete visibility into actual demand behavior (Kandlur & Keller, 2009; Geng, 2014).

Stranded Renewable Power and Computing Opportunities

A second stream of literature examines stranded power as surplus renewable electricity that cannot be fully utilized by the grid. Yang and Chien (2016) and Yang and Chien (2017) explored how large-scale and extreme-scale computing could be located with stranded green power resources, especially wind energy that would otherwise be curtailed or remain economically unusable. Their work showed that volatile and location-dependent renewable resources may still support valuable computational activities if workloads are sufficiently flexible and system design accounts for intermittency. In this context, stranded power is treated as an energy opportunity rather than simply an infrastructure inefficiency (Yang & Chien, 2016; Yang & Chien, 2017).

Chien, Wolski, and Yang (2015) advanced this line of thinking through the concept of the Zero-Carbon Cloud, which proposed using volatile renewable resources for high-performance computing. Their argument was that certain computational tasks can tolerate interruptions, migration, or temporal adjustment, making them suitable for execution on variable renewable energy. Kim et al. (2016) further strengthened this perspective by presenting data centers as dispatchable loads capable of adjusting demand in response to power system conditions. Their work demonstrated that data centers can play an active role in absorbing surplus electricity and supporting renewable integration when computing demand becomes flexible rather than fixed. Together, these studies broaden the meaning of stranded power by showing that unused or curtailed renewable electricity can be converted into productive computational output under appropriate operating models (Chien et al., 2015; Kim et al., 2016; Yang & Chien, 2017).

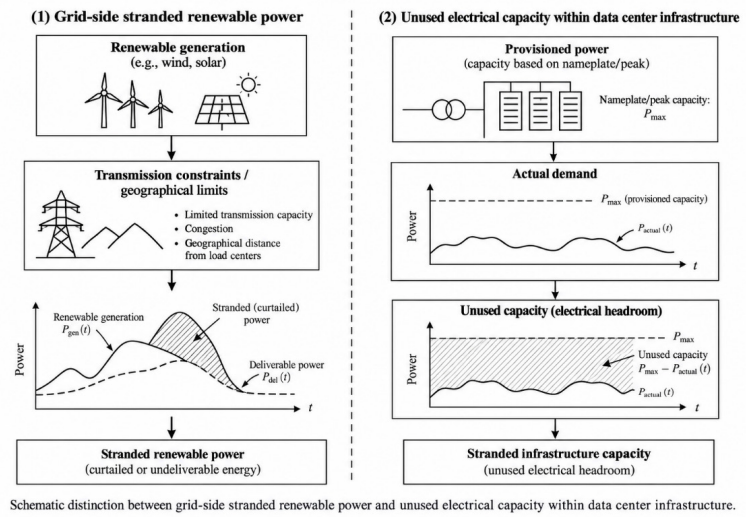


Figure 1: Schematic distinction between grid-side stranded renewable power and unused electrical capacity within data center infrastructure. The hatched regions represent potentially recoverable resources. Source: Conceptual synthesis based on Ganesh et al. (2009), Kim et al. (2016), and Yang and Chien (2017).

Data Centers as Flexible Energy Assets

Recent literature extends the discussion of stranded power by considering data centers as flexible resources within electricity systems. Takci et al. (2025) reviewed the ability of data centers to provide power system flexibility through demand response, workload shifting, and integration with storage or on-site energy resources. Their analysis suggests that data centers can move beyond being passive electricity consumers and become active participants in balancing supply and demand. This flexibility is especially valuable in power systems with high shares of renewable generation, where variability and curtailment create opportunities for responsive loads (Takci et al., 2025).

Dvorkin (2024) contributed to this area by investigating coordinated operation across geographically distributed data centers. Using contextual regression for agent coordination, the study showed that operational decisions can be optimized to improve flexibility and economic performance. This perspective is important for stranded power studies because it links local infrastructure conditions with system-wide decision making. Rather than treating each data center as an isolated facility, newer work increasingly frames them as networked assets whose computing loads can be shifted in time and place to exploit energy availability more efficiently (Dvorkin, 2024; Takci et al., 2025).

Economic and Environmental Implications

The literature generally agrees that better use of stranded power can improve utilization and reduce some operational costs, but it also shows that outcomes depend strongly on context. Ganesh et al. (2009) demonstrated that recovering stranded rack-level capacity allows more computing work to be performed with existing infrastructure, which can delay capital expansion and improve asset productivity. Yang and Chien (2016, 2017) likewise found that stranded renewable power can support cost-effective large-scale computing when system design is adapted to the temporal and spatial characteristics of the resource.

However, economic gains do not always guarantee environmental gains. Knittel, Senga, and Wang (2025) showed that flexible data centers may lower grid costs while potentially increasing total emissions, depending on the underlying generation mix and operational response. This is a critical finding because it challenges the assumption that flexibility is automatically sustainable. A similar caution applies to the broader energy sourcing debate. Warden and Koenig (2025) discussed the growing interest in nuclear energy as a dependable power source for data centers, arguing that future demand growth may require more stable low-carbon electricity supply. Although this perspective does not deal directly with stranded power recovery, it highlights the larger energy context within which data center power strategies must be evaluated. Therefore, the possible uses of stranded power should be assessed not only in terms of technical feasibility and cost, but also with respect to environmental outcomes and long-term energy planning (Knittel et al., 2025; Warden & Koenig, 2025).

Emerging Research Gap

Although the literature provides valuable insights, it remains fragmented. Some studies focus on stranded capacity inside data center infrastructure, others examine stranded renewable electricity, and still others analyze data center flexibility in broader power systems. These are related issues, but they are not identical. Without careful distinction, the concept of stranded power can become overly broad and analytically unclear. The reviewed studies collectively show that stranded power may refer to unused rack-level electrical capacity, curtailed or geographically isolated renewable energy, or flexible demand opportunities that improve grid balancing (Ganesh et al., 2009; Kim et al., 2016; Yang & Chien, 2017; Takci et al., 2025).

The main gap, therefore, is the lack of an integrated and concise discussion that clearly separates these forms of stranded power while also explaining their possible uses in data center operations. Existing studies provide strong technical foundations, but they are often specialized in scope. A focused synthesis is needed to explain how stranded power arises, what forms it takes, how it can be utilized, and what technical, economic, and environmental limitations shape its practical value. This article addresses that gap by bringing together infrastructure-level, renewable energy, and power-system perspectives into a unified discussion of stranded power from data centers and its possible uses.

Technical Assessment of Stranded Power and Its Possible Uses

Recovery of Underutilized Data Center Power Capacity

One practical approach to addressing stranded power involves improving the utilization of electrical capacity already installed within data centers. Ganesh et al. (2009) investigated this problem through RackPacker, a workload-aware server placement approach that considers variations in server power consumption rather than relying exclusively on peak power ratings. By grouping servers with complementary demand patterns, the approach seeks to increase rack utilization without exceeding established electrical limits.

The significance of this approach is that additional computing activities may be accommodated within existing infrastructure, reducing the need for immediate expansion of power distribution capacity. However, the unused capacity represents electrical headroom rather than electricity that has already been generated and can be recovered or exported (Ganesh et al., 2009; Geng, 2014).

Utilization of Stranded Renewable Electricity

Stranded renewable electricity offers a different opportunity for data center operations. Yang and Chien (2016, 2017) investigated the use of otherwise uneconomic renewable power to support large-scale computing. Their research considered the geographical availability, intermittency, and economic implications

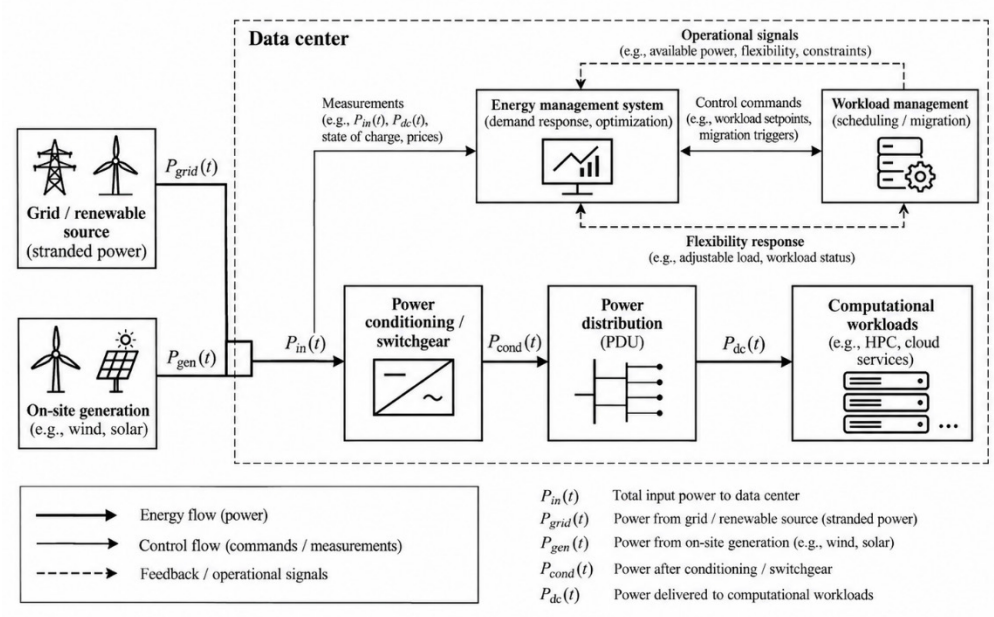


Figure 2. Technical Pathways for Stranded Power Utilization. Engineering schematic illustrating pathways for utilizing stranded power through power conditioning, energy management, and flexible workload coordination.

of operating computing systems using electricity that might otherwise remain unused.

This approach is particularly relevant to computational tasks that can tolerate interruptions or changes in operating schedules. Chien et al. (2015) explored this possibility through the Zero-Carbon Cloud concept, demonstrating how flexible high-performance computing could be associated with variable renewable electricity availability.

Flexible Computing and Grid Support

Data centers can also contribute to electricity system flexibility by modifying their demand in response to available generation. Kim et al. (2016) found that appropriately located dispatchable data centers could reduce stranded renewable electricity and improve power system efficiency. Importantly, their findings also indicated that simply locating inflexible computing loads near renewable generation facilities does not necessarily improve overall grid performance.

Dvorkin (2024) examined the coordination of geographically distributed data centers, showing how computing tasks can be reassigned among facilities to improve operational flexibility. Takci et al. (2025) further identified workload shifting, uninterruptible power supply systems, and demand response as mechanisms through which data centers can provide electricity system services.

Technical and Environmental Limitations

The practical utilization of stranded power depends on electrical infrastructure limits, computational workload requirements, power availability, and operational reliability. Although flexible computing can improve energy utilization, not all applications can tolerate interruptions or relocation without affecting service quality (Yang & Chien, 2017; Takci et al., 2025).

Environmental outcomes also require careful assessment. Knittel et al. (2025) demonstrated that flexible data center operations can reduce electricity system costs while producing different emissions outcomes depending on regional generation characteristics. Therefore, improved energy utilization should not automatically be interpreted as a reduction in carbon emissions.

Discussion

Practical Feasibility of Stranded Power Utilization

The reviewed literature indicates that stranded power presents opportunities for improving data center energy utilization, although its practical value depends on the source of the unused capacity and the operational conditions of the facility. Ganesh et al. (2009) demonstrated that stranded capacity within data centers can be addressed through improved server placement and power allocation. In contrast, Yang and Chien (2017) investigated the possibility of using stranded renewable electricity for large-scale computing, emphasizing the importance of adapting computational activities to variable electricity availability.

A critical distinction is that unused electrical capacity within a data center cannot automatically be treated as surplus electricity available for external consumption. Rather, it represents infrastructure capacity that may accommodate additional workloads without exceeding operational limits. Stranded renewable electricity, however, represents potentially usable energy that may otherwise be curtailed because of grid limitations or insufficient demand (Kim et al., 2016; Yang & Chien, 2017).

Potential Applications and Implementation Requirements

The possible uses of stranded power vary according to its origin, availability, and technical characteristics. Unused infrastructure capacity may support additional

Table 1: Potential applications of stranded power and associated technical considerations

Source of stranded power	*Possible application*	*Technical considerations*
Unused rack-level power capacity	Additional server workloads	Power distribution limits and workload variability
Curtailed renewable electricity	Flexible computing and batch processing	Intermittency and workload scheduling
Underutilized facility electrical capacity	Expansion of computing operations	Cooling capacity and infrastructure reliability
Flexible data center electricity demand	Grid balancing and demand response	Coordination with grid signals and service requirements
Geographically distributed computing capacity	Workload migration between facilities	Network connectivity, data transfer, and operational constraints

Source: Synthesized from Ganesh et al. (2009), Kim et al. (2016), Yang and Chien (2017), Dvorkin (2024), and Takci et al. (2025).

computing workloads, while stranded renewable electricity can be directed toward flexible computing operations. Data centers may also provide demand response services by adjusting electricity consumption according to grid conditions (Ganesh et al., 2009; Chien et al., 2015; Takci et al., 2025).

Economic and Environmental Considerations

The economic value of stranded power utilization depends on whether improvements in computing productivity or electricity costs outweigh the investments required for infrastructure modification and operational coordination. Yang and Chien (2016, 2017) showed that stranded renewable electricity could support economically attractive computing operations under appropriate conditions, while Ganesh et al. (2009) identified opportunities to increase computing capacity through improved rack-level power management.

Nevertheless, economic efficiency and environmental sustainability must be evaluated separately. Knittel et al. (2025) found that greater data center flexibility could reduce electricity system costs while producing different emissions outcomes depending on the generation resources used. Consequently, the environmental benefits of stranded power utilization depend not only on the amount of electricity consumed but also on when, where, and how that electricity is generated (Knittel et al., 2025).

Implications for Future Data Center Operations

The findings suggest that future data center energy management should increasingly emphasize dynamic power allocation, flexible computing workloads, and improved coordination with electricity systems. The shift from fixed power provisioning toward more responsive operational strategies could improve the use of existing infrastructure while creating opportunities for renewable energy integration (Ganesh et al., 2009; Kim et al., 2016; Dvorkin, 2024).

However, implementation must account for power availability, computing reliability, economic feasibility, and environmental performance. These considerations indicate that stranded power utilization should be approached as an integrated infrastructure and energy management challenge rather than a single technological solution (Geng, 2014; Takci et al., 2025; Knittel et al., 2025).

Conclusion

Stranded power represents an important opportunity to improve energy utilization and operational efficiency in data centers. The reviewed literature establishes that stranded power can occur as unused electrical capacity within data center infrastructure or as surplus renewable electricity that cannot be effectively absorbed by existing power systems. Although these forms of stranded power

have different characteristics, both present opportunities for improving resource utilization through appropriate technological and operational strategies.

The findings indicate that dynamic power allocation, workload scheduling, and flexible computing can improve the utilization of available electrical resources. Stranded renewable electricity can also support computational activities, particularly those capable of accommodating fluctuations in electricity availability. However, the practical benefits depend on infrastructure capability, workload requirements, economic feasibility, and electricity generation characteristics.

Overall, stranded power should not be regarded simply as wasted electricity but as an underutilized resource whose value depends on how effectively it can be converted into productive computing capacity or power system flexibility. Its utilization requires coordinated energy management strategies that maintain operational reliability while improving economic and environmental performance.

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