A SYNERGISTIC PARTNERSHIP: DECISION-MAKING FOR GREEN ENERGY ADOPTION IN CHINA DATA CENTERS FOR SUSTAINABLE BUSINESS DEVELOPMENT

by

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ABSTRACT

This thesis presents a critical analysis of strategic decision-making for green energy adoption in China's rapidly growing Internet Data Center (IDC) industry. The industry is grappling with pressing challenges around energy consumption, carbon emissions, and stringent regulatory pressures. This research bridges the fields of economics, business strategy, and environmental studies, providing a comprehensive view of the IDC industry's green transition within China's distinctive energy landscape.

The research offers a holistic examination of the economic, environmental, and regulatory drivers prompting Chinese IDCs to integrate green energy. It elucidates a range of green energy strategies, highlighting potential benefits, inherent challenges, and the complex decision-making processes IDCs face. The centerpiece of this thesis is a novel hierarchical decision-making framework comprising six stages: demand analysis, supply analysis, regulatory compliance, financial considerations, technical feasibility, and risk management. It offers a comprehensive approach to strategy formulation, integrating diverse factors that influence green energy decisions.

The utility and versatility of the proposed decision-making framework are illustrated through case studies of two companies in China, underscoring the flexibility of the framework in accommodating unique circumstances and strategic priorities, thereby illuminating the nuances of green energy decision-making.

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CHAPTER 1 INTRODUCTION

1.1 Motivation

1.1.1 Raising Sustainability Awareness in China

The global threat of climate change and the depletion of natural resources have ignited a pressing need for sustainable practices worldwide (National Oceanic and Atmospheric Administration, 2021). As the world's largest emitter of greenhouse gases (IEA, 2021b), China has noted this urgency and committed itself to an ambitious "dual carbon" goal: peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060. This commitment has been a catalyst for industries nationwide, pushing them to adopt innovative strategies to lessen their environmental impact.

1.1.2 The Imperative for a Market-Driven Green Power Production Industry

Simultaneously, China's green power production sector has seen unprecedented growth, driven by governmental efforts to promote renewable energy and lessen the dependence on fossil fuels. Despite this growth, the industry's reliance on government subsidies and external support raises questions about its long-term sustainability. Echoing the events in the electric vehicle industry where the government planned to phase out direct subsidies (IEA, 2021b), the green power production sector faces the possibility of dwindling external support (GlobalData, 2022), highlighting the need for a market-driven approach.

1.1.3 The Struggles of the Data Center Industry

Conversely, China's Internet Data Center (IDC) industry, while experiencing rapid growth due to demand from the Internet and high-tech companies (PW Consulting, 2021), is grappling with increased competition and stringent regulatory scrutiny. These challenges, coupled with the industry's high energy consumption and carbon emissions, have made it harder for IDC providers to find suitable opportunities for business expansion.

1.2 Research Scope

This thesis aims to bridge these two industries, exploring the potential for integrating green power production with data center facilities in China. By doing so, companies could not only contribute to China's dual carbon goals but also enhance their competitiveness, addressing pressing concerns in both sectors. The research will dive into the benefits, challenges, and strategies involved in such integration, providing valuable insights for stakeholders in both industries and contributing to the broader discourse on sustainable development.

The primary objective of this research is to explore the opportunities and challenges associated with integrating green power production and data center facilities in China. The study will be guided by a microeconomic perspective, focusing on the following areas:

1. Analysis of the current state of China's green power production industry, including growth trends, government policies, subsidies, and incentives, as well as potential risks and challenges such as diminishing government support and grid integration issues.
2. Examination of the IDC industry in China, focusing on its growth, challenges, and the role of government policies and regulations.

3. Identification and evaluation of the potential benefits of integrating green power production with data center business, such as improved energy efficiency, reduced carbon emissions, and enhanced competitiveness.
4. Exploration of the challenges and barriers to integrating green power production and data center business, including technical challenges, regulatory and policy-related barriers, and potential cultural and organizational challenges.
5. Development of strategies and recommendations for successful integration, offering a roadmap for stakeholders in both industries to capitalize on the opportunities presented by integrating green power production and data center facilities rental business models in China.

The goal is to comprehensively understand the potential benefits, challenges, and strategies associated with integrating green power production and data center facility rental in China, offering valuable insights for stakeholders and contributing to the broader discourse on sustainable development and the transition to a low-carbon economy.

1.3 Methodology

This research seeks to provide a holistic exploration of the integration of green power production and data center facilities in China, delving into the benefits, challenges, and strategies associated with such a union. To conduct a thorough analysis, the study will employ the following methodologies:

1.3.1 Literature Review and Policy Survey

A comprehensive literature review and policy survey will be carried out to build a solid theoretical foundation. This process will involve a review of academic articles, industry reports, policy documents, and case studies related to green power production, data center sustainability, and relevant Chinese government policies. This comprehensive survey will aid in identifying critical trends, opportunities, and challenges in both industries and the key success factors for effective integration.

1.3.2 Case Study Analysis

The research will also incorporate an analysis of select case studies to gain practical insights into the integration of green power production within data center facilities. These cases will encompass both domestic and international contexts, allowing the identification of best practices, lessons learned, and potential pitfalls. Case studies will be sourced from industry reports, news articles, and other publicly available resources.

1.3.3 Interviews with Industry Experts

To gather firsthand insights into the practical challenges and opportunities of integration, semi-structured interviews will be conducted with industry experts and stakeholders from China's green power production and data center sectors. Interviewees will be selected based on their expertise, experience, and willingness to participate. The data collected from these interviews will undergo qualitative analysis to identify common themes and insights, informing the research findings.

1.3.4 Recommendations and Conclusion

This research will culminate with actionable recommendations for businesses looking to integrate green power into data center facilities in China. These recommendations, based on the findings from the data analysis and synthesis, will address the identified benefits, challenges, and strategies, providing practical guidance for stakeholders in both sectors. Lastly, the research will conclude with a summary of the findings and their implications for the sustainable development of both industries in China.

CHAPTER 2 LITERATURE REVIEW

2.1 China's Commitment to Carbon Reduction

China has pledged to peak its carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060, marking a significant commitment to its environmental strategy as part of the Paris Agreement (UNFCCC, 2020). This pledge, affirmed by President Xi Jinping at the 75th session of the United Nations General Assembly, necessitates a transition towards renewable energy technologies from the historical reliance on fossil fuels (UN News, 2021).

This commitment is reflected in China's 14th Five-Year Plan (2021-2025) and its long-term strategy to 2035, emphasizing green and low-carbon circular economic development (UNDP China, 2021a). This policy direction reinforces the potential for sectors contributing to China's carbon neutrality goal, such as the integration of green power production and data center facilities.

2.2 Emergence and Evolution of China's Green Power Production Industry

2.2.1 From Inception to Advancements: Tracing the Green Energy Trajectory in China

The narrative of China's green power production industry is marked by rapid growth and significant achievements. Over the past two decades, China has positioned itself as a global leader in renewable energy production, with the largest installed capacity of wind, solar, and hydropower globally (Climate Action Tracker, 2022; Feffer, 2022; IEA, 2021b, 2021c, 2022). This progression owes much to the strategic policies and ambitious renewable targets set by the Chinese government, coupled with a keen focus on technological innovation. The establishment of a legal system for green production and consumption further encouraged the industry's robust development (Hu & Cheng, 2013; M. Yang et al., 2020). According to the data from IRENA, by the end of 2022, China's total renewable energy capacity reached 1,082 GW, with hydro, wind, solar, and biomass being the main contributors (IRENA, 2023).

The decreasing costs of renewable energy technologies have also significantly driven China's green electricity production growth. The global weighted average levelized cost of electricity (LCOE)[1] for solar photovoltaic (PV) and onshore wind projects commissioned in 2022 was $0.038 and $0.045 per kWh, respectively, representing a decrease of more than 80% for solar PV and 45% for onshore wind compared to 2010 (IRENA and CPI, 2023).

2.2.2 The Propelling Forces: Investment Opportunities and Government Facilitation

While the growth of China's green power industry is a multifaceted phenomenon, two critical factors have been instrumental - the feasibility of investment and the government's facilitating role. The industry has seen a surge in private investments, buoyed by favorable green finance policies and the promise of long-term returns (Hamrin, 2006; Hove, 2020; Huld, 2022; UNDP China, 2021b).

Yet, the government's role has indeed catalyzed the sector's growth. Through supportive policies, mandatory renewable targets, and subsidies, the government has fostered a favorable

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[1] The levelized cost of electricity (LCOE) is a measure of the average net present cost of electricity generation for a generator over its lifetime. It is used for investment planning and to compare different methods of electricity generation on a consistent basis. The LCOE is defined as the price at which the generated electricity should be sold for the system to break even at the end of its lifetime (Salinity Gradient Heat Engines, 2022).

environment for the industry's expansion (J. Li et al., 2022; Stauffer, 2021; Tu et al., 2021; C. Wang et al., 2022; S. Zhang et al., 2021).

2.2.3 Forging Ahead: Challenges and the Imperative of Cross-Sector Partnerships

Despite its considerable progress, China's green power production industry faces challenges that underscore the need for strategic partnerships with other sectors. The industry's heavy reliance on government support has raised concerns about its long-term sustainability, with potential issues such as reduced competition, corruption, and favoritism (Hu & Cheng, 2013; Jin & Ruan, 2020a).

Moreover, the potential reduction or eventual disappearance of government subsidies as the industry matures highlights the need for the industry to become more market-oriented and independent (Jiao et al., 2018; C. Li, 2014). Partnerships with other sectors, both domestically and internationally, could prove pivotal in addressing these challenges. Such collaborations can not only help diversify revenue streams and increase economies of scale but also facilitate knowledge exchange, technological advancements, and more significant policy influence (Casey, 2019; IEA, 2021a; Stiffler, 2022).

In essence, the Chinese green power production industry has reached a critical juncture in its development trajectory. While it has made substantial strides, its future growth and sustainability hinge on its ability to forge strategic partnerships and navigate a shifting policy landscape. The industry's evolution will undoubtedly be a key determinant of China's broader goal of transitioning to a low-carbon economy.

2.3 China's Internet Data Center (IDC) industry

2.3.1 Tracing the Growth Trajectory: An Overview of IDC Development in China Market

The development of China's IDC industry has been nothing short of phenomenal. Over the past decade, the sector has experienced rapid growth, driven by increasing digitization, evolving data needs, and a supportive policy environment. As of 2020, China was home to the second-largest data center market globally, accounting for approximately 23% of the world's total data center capacity (Knight Frank, 2020). The IDC industry in China has grown at an impressive rate, with the compound annual growth rate (CAGR) for the five years estimated at 2.7% between 2022 and 2028, with a forecast market size reaching USD$ 34.03 billion in 2028, a significant increase from USD$ 29.02 billion in 2022 (PR Newswire, 2023). The development trajectory of China's IDC industry is a testament to the country's digital revolution and data's central role in its economy.

Key competitors in the market are making significant investments to capitalize on this growth. Major players include domestic companies such as GDS, VNET, and ChinData and international companies like Equinix and Digital Realty (CBRE, 2022). The increasing demand for data storage and processing has driven these companies to expand their data center facilities across the country, as can be seen in Figure 1, particularly in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Pearl River Delta region, which continue to maintain strong data center construction impetus (Cushman & Wakefield, 2022).

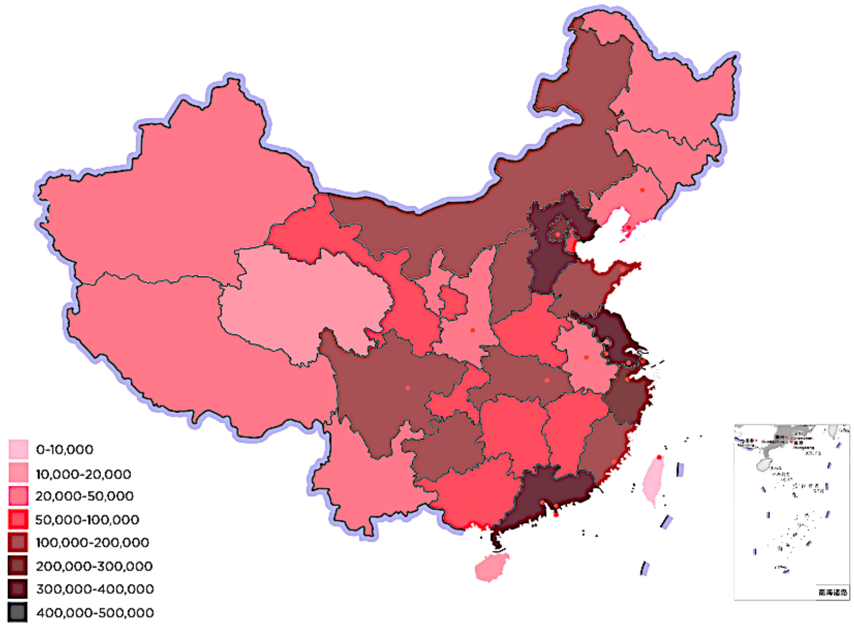

Figure 1. Cabinet stock in Mainland China – Distribution heatmap (May 2021)

(Source: Cushman & Wakefield, 2022)

2.3.2 Demand Catalysts: Key Drivers of the IDC Market in China

Several factors have propelled the growth of the IDC market in China. Firstly, the widespread adoption of cloud computing services by businesses across a range of sectors has been a significant driver of demand. In 2021, the Chinese cloud services market was valued at $19 billion, growing at a CAGR of 33.9% from 2016 (Canalys, 2022). Secondly, the proliferation of data-intensive technologies such as artificial intelligence (AI), machine learning, and the Internet of Things (IoT) has spurred the need for robust data storage and processing capabilities (Qianzhan, 2023). The rise of online services, particularly during the COVID-19 pandemic, has further fueled demand for IDC services. Industries such as e-commerce, online entertainment, and remote working tools have seen an upsurge, thereby driving data center growth (Knight Frank, 2020).

2.3.3 The Environmental Conundrum: Energy Intensity and Implications for IDCs

While central to China's digital economy, the IDC industry has significant environmental implications due to its energy-intensive nature. In 2018, China's IDC industry consumed approximately 161 billion kWh of electricity, accounting for about 2% of the country's total electricity consumption (H. Wang & Ye, 2020). By 2035, China's digital infrastructure's total power consumption is forecasted to reach 782 billion kWh, accounting for 5-7% of the total national consumption (Greenpeace, 2020).

This high energy demand has implications for the environment, primarily through increased carbon emissions. Moreover, the reliance on coal-powered electricity exacerbates the environmental impact of IDC operations, leading to significant carbon emissions. Approximately 73% of the electricity consumed by data centers in China was generated from coal-fired power plants in 2018 (versus 23% from renewable sources and 4% from nuclear), significantly higher than the global average of around 39% (Judge, 2021). These environmental concerns have brought the IDC industry under increased scrutiny, necessitating a more sustainable approach to data center operations. The Chinese government has recognized this, introducing regulatory measures to promote energy efficiency and the use of renewable energy sources in the IDC industry (MIIT & NDRC, 2021).

2.3.4 Navigating the Regulatory Landscape: Challenges and Opportunities for IDC Expansion

Navigating the complex regulatory landscape for IDCs in China is a challenging yet critical task, governed by various policies and regulations encompassing planning approval, data security, energy use, power supply, and compliance with both local and national policies (CoE, n.d.; King & Wood Mallesons, 2020). The planning approval process involves intricate coordination with several government departments, including the NDRC, the MIIT, and local governments. These bodies assess project proposals based on numerous factors like land availability, infrastructure, resource availability, and alignment with local development plans(China Commercial Law Firm, 2020; King & Wood Mallesons, 2020).

The increasing importance of energy-saving and carbon-reduction policies in China's IDC development landscape introduces an additional layer of regulatory complexity. These policies have led to the introduction of energy-saving assessments (ESAs), a prerequisite for obtaining planning approval for new IDCs (China Commercial Law Firm, 2020; King & Wood Mallesons, 2020). IDCs failing to meet ESA requirements may face denial of approval, operational suspension, or fines (China Commercial Law Firm, 2020).

Energy quotas present another significant policy instrument in China's toolbox for managing energy consumption. These quotas, determined at the provincial level, allow individual provinces to address their unique energy needs and constraints while working towards the nation's overall clean energy objectives (Hove & Wetzel, 2018). Compliance with these allocated energy quotas is crucial for IDCs' establishment and operation (China Commercial Law Firm, 2020; King & Wood Mallesons, 2020).

However, IDCs, being energy-intensive entities, often grapple with securing sufficient energy quotas. Given their relatively low contribution to local GDP and employment, IDCs may find themselves lower on the priority list when local governments allocate these quotas (Yu, 2021). Provinces tend to favor industries with higher output when allocating energy quotas due to IDC's relatively high energy consumption per unit of GDP. IDCs powered by renewable energy sources may still face challenges related to energy quotas. However, their use of clean energy makes them more appealing to provincial governments due to their alignment with China's broader goals of increasing the renewable energy share in its power mix (Z. Wang, n.d.). As a result, these 'greener' IDCs are more likely to receive favorable energy quota allocations compared to those relying solely on traditional energy sources.

PUE, a widely recognized metric for assessing data center energy efficiency, is another regulatory element in China's IDC landscape. The Chinese government has established PUE limitations for IDCs, requiring them to operate below certain thresholds. This policy stimulates the adoption of more energy-efficient technologies and practices, consequently reducing overall energy consumption and carbon emissions (China Commercial Law Firm, 2020; CoE, n.d.).

This intricate tapestry of governmental policies and regulations plays a pivotal role in shaping the trajectory of IDC development in China. The varied attitudes of local governments towards IDC development, combined with regional disparities in infrastructure, economic conditions, and policy support, contribute to a diverse landscape of data center growth across the country.

2.3.5 Towards a Sustainable Future: Strategies for Improving IDC Energy Performance

The rapid expansion of data centers in China, fueled by escalating demand for cloud services and digitalization, leads to high energy consumption and carbon emissions, posing significant environmental challenges (Liu, 2023; Zheng, 2023). The response has been a strategic shift towards prioritizing green energy solutions, aiming to foster sustainable practices within the industry and align with strict government regulations and a growing global emphasis on sustainability (McKinsey, 2022).

China's abundant green energy resources, including solar, wind, hydro, biomass, and geothermal energy, offer significant opportunities for IDCs (IRENA, 2014; R. Lin et al., 2019; W. Lin, 2004; Q. Wang et al., 2019). The integration of these renewable energy sources into data center operations seems to be a strategic approach to mitigate environmental impacts and enhance industry competitiveness (Environment+Energy Leader, 2022; Gillin, 2022; Huang et al., 2021).

However, transitioning to greener data centers necessitates a multifaceted approach. Infrastructure upgrades to incorporate energy-efficient hardware and software, coupled with the integration of renewable energy sources, are crucial first steps (Environment+Energy Leader, 2022; Gillin, 2022; Huang et al., 2021; Liu, 2023; McKinsey, 2022; Mytton, 2021). It is equally important to develop tailored adoption models and strategies that consider China's unique context, addressing potential risks and challenges (Bai, 2021; Gao et al., 2020; Y. Li et al., 2017; C.-Y. Yang & Masron, 2022).

Notwithstanding the growing interest in greener facilities among data center providers, several challenges persist. These include the lack of specific government policies and incentives encouraging green technology adoption, the volatility of renewable energy sources, and the high upfront costs of implementing green technologies (Dikaiakos et al., 2023; Liu, 2023).

When contemplating the most appropriate approach, investors should consider scalability, resilience, and adaptability to accommodate growth and future changes in the energy landscape (Liu, 2023), align each strategy with China's unique energy landscape, regulatory framework(C.-Y. Yang & Masron, 2022), and understand the technological advancements for long-term cost savings and return on investment (Liu, 2023).

Emerging technologies, such as energy storage, play a fundamental role in enhancing energy performance. A holistic approach, combining on-site generation, off-site power purchase agreements (PPAs), and renewable energy certificates (RECs), can yield optimal results (C.-Y. Yang & Masron, 2022). Public-private partnerships can accelerate the implementation of green initiatives, contributing to China's sustainability goals (Bai, 2021).

2.4 Research Questions

In light of the pressing need for the green power generation industry to diversify alliances and adapt to market changes, it is crucial to identify potential partners that can mutually benefit from green power advancements. Concurrently, as high-energy consumers contribute significantly to carbon emissions, data centers are increasingly under scrutiny. China's government, concerned about environmental impact, has imposed stricter regulations, which have influenced the industry's growth and geographical distribution.

Despite these challenges, China's abundant renewable energy resources present a promising opportunity for IDCs to both mitigate their environmental impact and comply with regulatory requirements. While some IDCs have initiated green energy solutions, the literature suggests ample scope for further expansion in this area. Comprehensive research is needed to understand the unique characteristics of the Chinese market, justify the rationales of integrating renewable energy into IDC operations, and guide the decision making process with the economic circumstances, potential benefits and challenges of such an endeavor.

In this context, two primary research questions arise:

1. What are the unique characteristics of the Chinese market make it conducive for a collaboration between the IDC and renewable energy industries? This question aims to explore the specific economic, regulatory, and technological factors in China that may influence the integration of renewable energy into IDC operations. It also seeks to understand how these factors can be leveraged to facilitate such collaboration.
2. What is the pattern and process of integrating green energy sources into IDC operations in China, and how can decision-makers identify the most suitable collaboration mode? This question aims to identify the best practices, strategies, and models for integrating renewable energy into IDC operations. It also seeks to understand potential challenges in this process and how they can be mitigated.

Answering these questions will offer valuable insights for IDC operators, renewable energy providers, policymakers, and other stakeholders, assisting them in making informed decisions about adopting green energy solutions in IDC operations. Furthermore, this research will contribute significantly to the broader discourse on sustainable development in the digital era.

CHAPTER 3 REDEFINING CHINA'S IDC INDUSTRY: THE SHIFT TO GREENER DATA CENTERS FROM AN URBAN ECONOMIC PERSPECTIVE

The growth of the digital economy in China and the associated demand for data storage and processing has led to a significant expansion in the country's data center infrastructure. However, the distribution of these facilities is not evenly spread across the country. This Chapter will dive into the geographical disparities in data center distribution across the country, the rationales behind them, and the energy supply as a game-changer involved.

3.1 Spatial Arrangements of Data Center Clusters

3.1.1 Regional Disparities

China's data center market is predominantly concentrated in the eastern and coastal regions. This distribution pattern reflects the concentration of the economy and population in these areas, which drives higher demand for data center services (Knight Frank, 2020). As seen in Figure 2, per data from the China Association for Engineering Construction Standardization (CAECS), nearly 80% of the 4.15 million data center racks installed in China by the end of 2021 were situated in these eastern provinces (E. Zhang & Chen, 2022).

Major areas of concentration include the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Guangdong-Hong Kong-Macao Greater Bay Area. These regions, along with the Chengdu-Chongqing economic circle, have been designated as national computing hubs by the NDRC as part of the Eastern Data and Western Computing project (Z. Zhang & Chen, 2021). In stark contrast, China's central and western regions have a notably lower concentration of data centers.

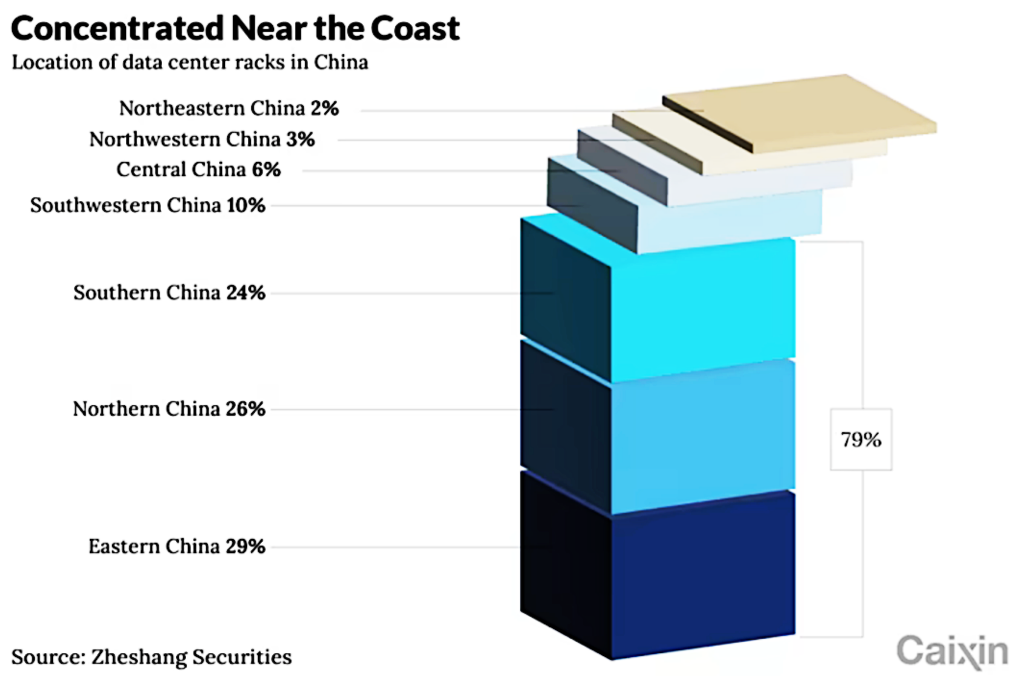

Figure 2. Data Center Racks Concentrated Near the Coast

(Source: E. Zhang & Chen. Caixin. 2022)

3.1.2 Advantages and Disadvantages of This Imbalance

The current geographical imbalance in China's data center distribution, being primarily concentrated in the eastern and coastal regions, has multifaceted implications from a microeconomic perspective.

On the one hand, the clustering of data centers in these regions brings about considerable economic benefits. Economies of scale and scope become evident as the concentration of data centers facilitates cost reductions per unit of output due to increased production levels and shared resources. The concentration also catalyzes network effects, a phenomenon whereby the value of a service enhances with an increase in its users. In the context of data centers, a robust network can bolster service reliability and decrease latency, thereby attracting more users and further fortifying the network. Furthermore, the proximity of data centers to each other and related industries encourages the emergence of agglomeration economies. These economies foster knowledge spillovers, collaborations, and innovation, thereby driving further growth and development.

Despite the benefits, the geographical imbalance of data centers presents several challenges. The concentration of data centers in specific regions can put substantial strain on local resources, particularly energy and water supplies required for cooling. This strain escalates costs and can adversely impact the environment. Over-concentration may also lead to market saturation, creating a limiting factor for future growth. An increased level of competition in saturated markets could drive down prices, subsequently reducing profits. Furthermore, the geographical risk intensifies when data centers are concentrated in a single region, which could expose services to disruption due to regional events such as natural disasters. Lastly, the current distribution pattern may exacerbate regional disparities in economic development, potentially leading to a 'digital divide' where regions with fewer data centers lag in the digital economy.

In conclusion, while China's current geographical distribution of data centers leverages economies of scale, network effects, and agglomeration economies, it simultaneously risks resource strain, market saturation, geographical risk, and uneven development. Therefore, policymakers and stakeholders must consider these implications carefully in their future planning and policy design to strike an effective balance between these benefits and drawbacks.

3.2 Rationale behind Data Center Spatial Arrangement

3.2.1 Driving Factors on the Macroeconomic Level

Demand-Induced Regional Growth

China's uneven economic activity and population distribution largely dictate the spatial disparity in the demand for data center services. The eastern and coastal regions, characterized by higher economic activity and population density, consequently register higher demand for data center services. This is evidenced by the three primary data center clusters in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Pearl River Delta region. These clusters represent China's three most economically developed regions, with Beijing, Shanghai, and Guangzhou + Shenzhen at their respective cores.

Contrastingly, the demand for data center services in China's central and western regions is relatively lower, mirroring their lesser economic activity and population density. Consequently, fewer data centers are established in these areas. This pattern aligns with the demand-induced regional growth theory in urban economics (DiPasquale & Wheaton, 1992), which postulates that areas with higher demand for a service or product will experience more growth in that sector.

Supply-Induced Regional Growth

According to urban economics, the availability of key inputs can induce growth in certain regions (DiPasquale & William, 1996). The distribution of data centers is also guided by the availability of infrastructure and labor, both key inputs for data center operations. The cities in eastern and coastal China often boast better network connectivity due to more advanced telecommunication infrastructure, which is crucial for efficient data center operations. Similarly, the presence of a skilled talent pool in these cities makes them attractive for data center operations.

The Impact of Local Governments

Local governments significantly shape the data center landscape through public policies. Historically, the Chinese government has encouraged data center development, especially in tier 1 cities with relatively higher fiscal revenue. Incentives and benefits provided by these city governments have catalyzed the growth of data centers.

The establishment of data centers brings benefits such as technology development and digital economic growth, aligning with the government's broader objectives. However, this is not uniformly the case across the country. In less-developed regions, local governments often prioritize other development projects due to less direct GDP contributions from data centers, further exacerbating the regional disparity in data center distribution.

As the digital economy continues to evolve, these factors will likely continue to shape the data center landscape in China.

3.2.2 Driving Factors on Microeconomic Level

The location decisions of data center operators at the microeconomic level can be largely understood within the framework of the monocentric city model (DiPasquale & William, 1996), which captures the spatial equilibrium of firms within a city. This model implies that the clustering of data centers around major cities like Beijing, Shanghai, and Guangzhou results from firms seeking to maximize profits.

The equilibrium condition for firms, as presented in the monocentric city model, is represented by the equation:

$\pi = Q[P-C-s*t]-rf(t)$,

where π is the firm's profit per unit of land, P represents the sale price per unit, C is the product cost per unit, s*t is the unit shipping cost per mile times distance, and rf(t) represents the firm's rent per acre, and Q is the units of output per acre.

In the case of data centers, the term s*t becomes less significant, given the use of fiber optics for communication, little physical shipment activity for goods. The location of a data center has no impact on its revenue as services-exported properties, rendering the unit shipping cost inconsequential. Instead, the equation can be modified to cater specifically to the data center context:

$\pi\_dc = Q[P-C]-rf(t)$,

where π_dc represents the profit per unit of land for a data center.

The maximization of π_dc thus governs the spatial equilibrium of data centers within a city, with profits needing to be equal across different locations. This often results in a "flat" rent gradient (Figure 3), pushing data centers towards the outskirts of the city, where rents are typically lower. This is similar to what is observed for industrial properties.

However, additional factors need to be considered for data centers. The labor costs for data centers are significant, given the requirement for highly skilled talent. Thus, wages need to consider the commuting costs of these talents, suggesting a steeper slope in the rent gradient, similar to what is observed for office properties.

Furthermore, energy cost is another significant consideration for data centers, given their energy-intensive nature. This introduces another variable to the profit equation, further complicating the site selection process.

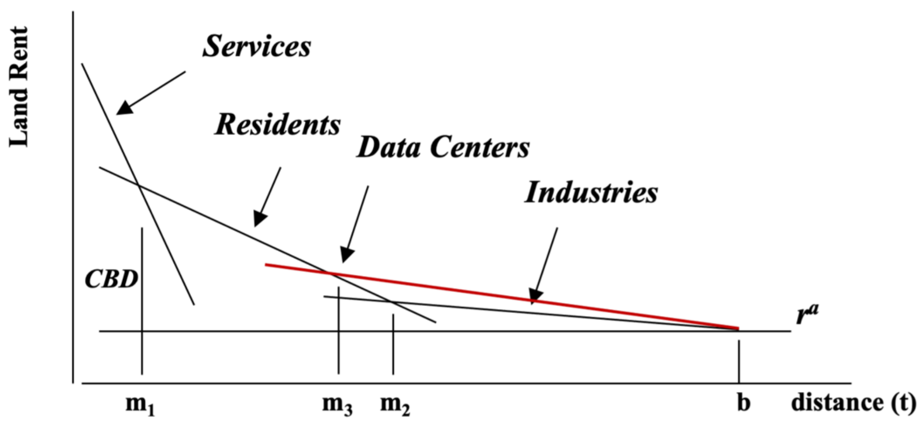

Figure 3. Spatial separation and land rents: land rents for various uses

Data centers with a slightly steeper slope (Based on DiPasquale & William's Theory)

Lastly, the agglomeration effect comes into play. As per Wheaton's theory, the higher concentration of businesses and industries in these cities leads to a higher demand for data center services, thus encouraging the establishment of data centers in these locations. This creates a virtuous cycle, further amplifying the spatial concentration of data centers.

In conclusion, the microeconomic factors influencing the location decisions of data centers are a complex interplay of spatial economics, labor costs, energy costs, and the agglomeration effect.

These factors collectively shape the spatial distribution of data centers within cities, driving the observed clustering around major urban centers

3.2.3 Examining Economic Factors in China's Specific Circumstances

Applying economic principles to the site selection of data centers must be nuanced by China's specific circumstances. Two key factors – land cost and product cost – serve as illustrations of this point.

Firstly, the cost of land, especially in China's top-tier cities, is a critical consideration in the location decisions of data centers. There is a trade-off between the high land price and the need for proximity to city centers, where the demand for data center services is highest. Consequently, many data centers choose to locate in the suburban areas of tier-1 cities or in non-tier-1 cities that are in close proximity to major urban centers.

Secondly, product cost, primarily labor and energy costs for data centers, also plays a significant role in location decisions. Labor costs in more developed cities are generally higher due to the cost of living and the higher skill level of the workforce. However, the higher wages are often justified by the greater productivity and skill level of the workers and the fact that they are already located in the city, thus reducing commuting costs.

Regarding energy costs, data centers are highly energy-intensive; thus, energy supply cost and reliability are important considerations. Despite the higher overall cost of living in more developed areas, energy costs in these regions are not significantly higher than in the central and western regions. This is largely due to China's historically fixed electricity tariff (Z. Zhang & Chen, 2021), which has kept energy costs relatively stable across regions.

In conclusion, an examination of the economic factors unique to China reveals that the clustering of data centers in the eastern and coastal regions, specifically in suburban areas and non-tier-1 cities close to major urban centers, is largely driven by the trade-off between land cost and proximity to city centers, and the relative stability of labor and energy costs across regions.

3.3 Economic Shifts in China and their Implications

3.3.1 Demand

The ongoing digital transformation has significantly increased the demand for data center services. With the advent of cloud computing, edge computing, and 5G technologies, businesses increasingly rely on data centers to manage their digital workloads. According to the China Internet Network Information Center (CNNIC), the number of internet users in China reached 1,067 million by the end of 2022, an increase of 212.51 million from 2019 (CNNIC, 2023). This massive surge in internet usage, driven by e-commerce transactions, online gaming, and other digital services, has fueled the demand for data centers, particularly in major cities where latency is a critical factor.

Moreover, the shift towards a knowledge-based economy has further amplified the demand for data centers. Industries such as finance, healthcare, and education increasingly rely on data centers to store, process, and analyze large volumes of data. This has led to a more fine-grained segmentation of data center needs. On the one hand, computing-intensive services requiring fast response times, such as e-commerce transactions and online gaming, must be located close to urban centers to minimize latency. On the other hand, services like data storage and backup, which are less sensitive to latency, can be located farther away from end-users.

3.3.2 Supply

On the supply side, China's data center industry has benefited from the country's rapidly developing infrastructure and technological advancements. The nationwide rollout of 5G networks and the expansion of fiber optic networks have made it possible to establish data centers in locations that were previously inaccessible. Furthermore, advances in artificial intelligence (AI) have transformed data center management and operations. AI technologies have significantly improved the efficiency of data centers by automating routine tasks and optimizing resource allocation. According to a report by McKinsey, AI could reduce data center operating costs by up to 20%, primarily by reducing the need for human labor (McKinsey, 2022). This offsets the traditionally high labor costs associated with data center operations and expands the potential locations for data centers.

However, despite these positive developments, there are also growing challenges, primarily associated with the dramatic increase in urban land prices. As economic development and urbanization accelerate in Chinese cities, the demand for land has skyrocketed, resulting in a sharp increase in land costs. This is especially true in tier-1[2] cities, where land prices can be prohibitively high.

This situation significantly impacts the data center industry, given that data centers require substantial amounts of land for their facilities. The increasing land costs in urban areas have made it more difficult for data center operators to find affordable sites for new data centers. High

[2] Tier-1 cities in China typically refer to the most developed and economically significant cities, including Beijing, Shanghai, Guangzhou, and Shenzhen.

land prices can also increase the total cost of establishing a data center, potentially eroding these operations' profitability.

3.3.3 Government Policy

The Chinese government, recognizing the strategic importance of data centers, has included them as one of the Six Innovative Industries[3] for accelerated development. The Three-year Action Plan for New Data Centre Development (2021-2023) is a prime example of this commitment. The plan aims to optimize the industry's layout, upgrade network quality, enhance computing power, strengthen the industrial chain, promote 'green' and low-carbon development, and ensure safety and reliability. By 2023, the plan aims to increase the national average utilization rate for data centers to over 60% (Cushman & Wakefield, 2022). The government's supportive stance fosters a conducive environment for expanding the data center industry in China.

3.3.4 Interpretation of the Trends

To interpret the dynamics of China's data center industry, we revisit our theoretical framework grounded in urban economics – the negative Density gradient model (Figure 4) and the equation, $\pi\_dc = Q[P-C]-rf(t)$. This allows us to extrapolate meaningful insights from the interplay of demand, supply, and government policy influences.

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[3] Six Innovative Industry: The direction of key development industries set out by Chinese president Xi, including new infrastructure, new material, new technologies, new equipment, innovative products, innovative models.

On the demand front, the necessity for proximity to city centers varies across data centers, depending on their specific functions. Data centers with latency-sensitive operations prioritize urban proximity, while those with less latency-sensitive functions, such as data storage and backup, can afford to be situated further afield. The implication of this is a less steep gradient for the data center property rent line, indicating the possibility of data centers being located further from city centers without substantially affecting operational efficiency.

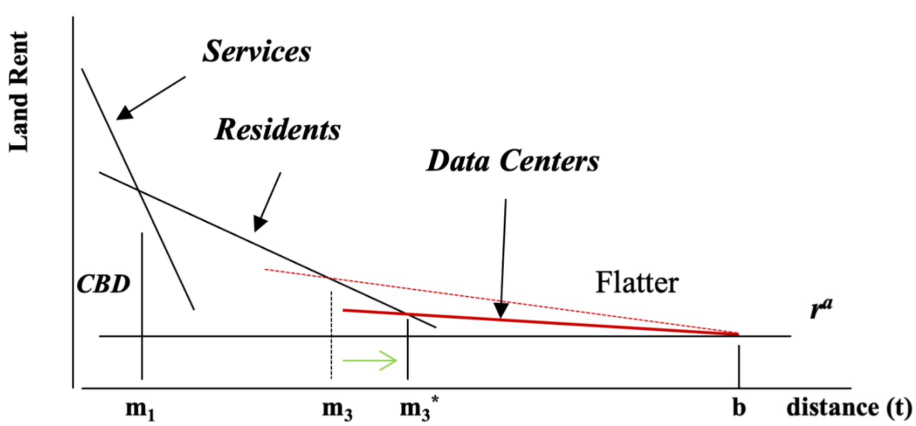

Figure 4. Spatial separation and land rents: economic trends flat the gradient model of IDC

Turning our attention to supply-side factors, the persisting policy support coupled with nationwide infrastructure development has reduced the Industry's dependence on more developed urban areas. In tandem with this, AI advancements have mitigated the traditionally high labor costs associated with data center operations, enabling a longer commuting distance for labor. This has led to a further flattening of the data center property rent line.

The significant surge in urban land prices presents a formidable challenge in acquiring sites close to city centers. According to the model (Figure 5), it has the effect of pushing the 'b' point – the location with only residual agricultural value – further out, indicative of urban expansion. This results in an outward shift of both the residential and data center rent gradient lines, reflecting an increased cost of urban land for data center operations.

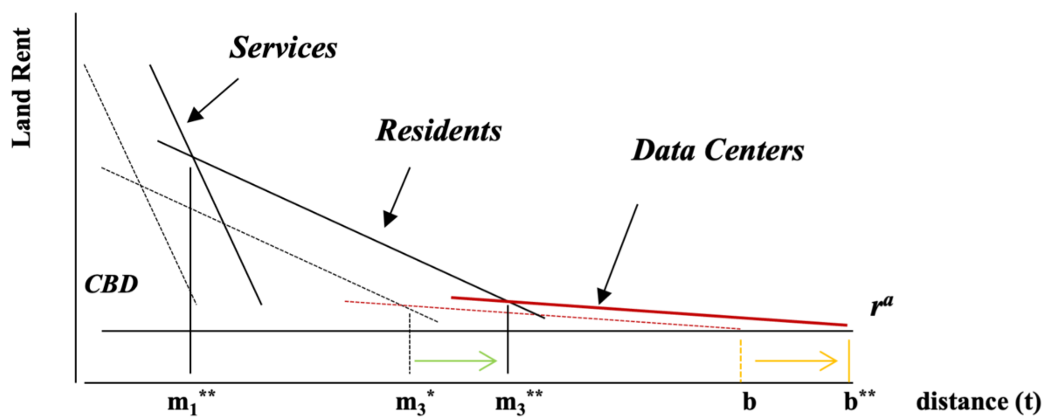

Figure 5. Spatial separation and land rents: economic trends push the edge of the city

Given these dynamics, it can be inferred that the location of data centers can extend further from city centers, covering not just more developed cities, but also surrounding less-developed regions. In some instances, data centers could even be unbundled from cities if other significant benefits are present. This trend is observable in the heatmap of new cabinet supply distribution across Mainland China (Figure 6), where regions like Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta show vigorous data center construction momentum beyond only Tier-1 cities. For example, Langfang, a city located between Beijing and Tianjin, is home to numerous data centers due to its strategic location and relatively lower land cost compared to

Beijing and Tianjin (Knight Frank, 2020). Additionally, large amount data of data center development activities can be observed in the western China such as Shanxi Province (Cushman & Wakefield, 2022).

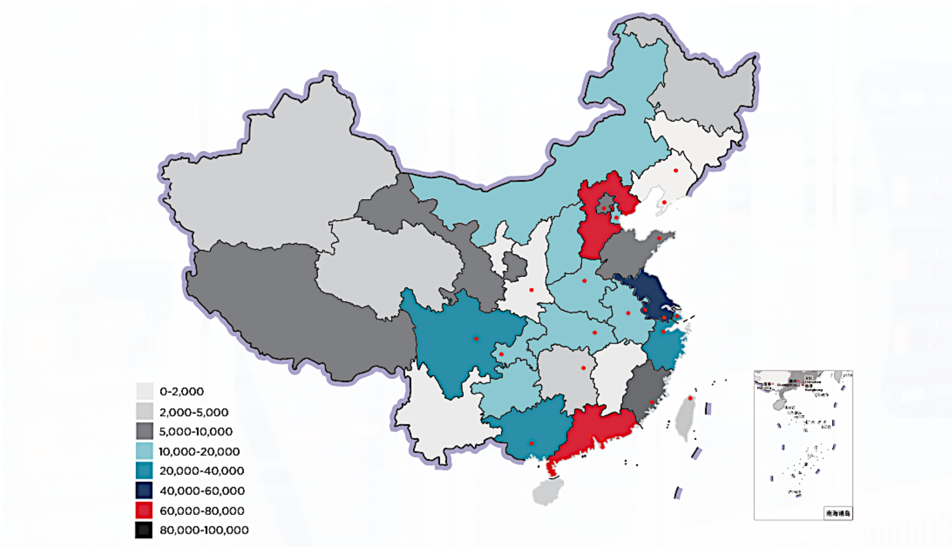

Figure 6. New cabinet supply in Mainland China – Distribution heatmap (Jan-May2021)

(Source: Cushman & Wakefield, 2022)

In conclusion, the interplay of demand, supply, and government policy trends points to a geographic diversification of data center locations in China. The theoretical model and equation provide valuable insights into interpreting these trends and their implications for the data center industry, highlighting the importance of continuously reevaluating location strategies by data center operators in response to evolving economic and policy landscapes.

3.4 Game-Changer: Energy Consumption and Carbon Emission in Shaping the IDC Industry

As China rapidly digitalizes, the Internet Data Center (IDC) industry's growth trajectory has increasingly intersected with the nation's environmental concerns. The rising significance of energy efficiency and carbon reduction in the IDC industry is not just a consequence of ethical responsibility or reputational management; it is becoming a game-changer that could redefine industry dynamics and competitive advantages.

3.4.1 Regulations: Better Environmental Performance

Challenges in Acquiring ESAs and Energy Quotas

ESAs act as an essential regulatory instrument that assesses proposed data center projects' energy efficiency and environmental impact to ensure that proposed projects align with the government's energy-saving and carbon-reduction targets. Failure to meet ESA requirements could lead to the denial of planning approval, operational suspension, or even financial penalties.

Energy quotas are crucial in managing energy consumption within the IDC industry. Acquiring sufficient energy quotas is often a significant hurdle due to the IDC industry's high energy consumption and low direct contribution to local GDP and employment.

Thus, the interplay of ESA requirements and energy quotas is shaping the IDC industry, pushing it towards more energy-efficient and environmentally-friendly practices. However, there is a silver lining for IDCs that pivot toward renewable energy sources. While they may still face challenges in securing energy quotas, their alignment with China's broader goals of increasing renewable energy in its power mix could potentially make them more appealing to provincial governments. As such, these 'greener' IDCs are more likely to receive favorable energy quota allocations.

Stricter PUE Requirements

Power Usage Effectiveness (PUE) has become a critical measure of energy efficiency of data center operations. As regulatory requirements around PUE become stricter, data center operators are incentivized to enhance energy efficiency, thus contributing to the government's environmental goals. These stricter regulations might impact the design and operation of data centers to make more effort to achieve a higher energy efficiency level or force relocations of data center clusters to where with loose PUE requirements.

3.4.2 Policy - "East Compute, West Store" Plan

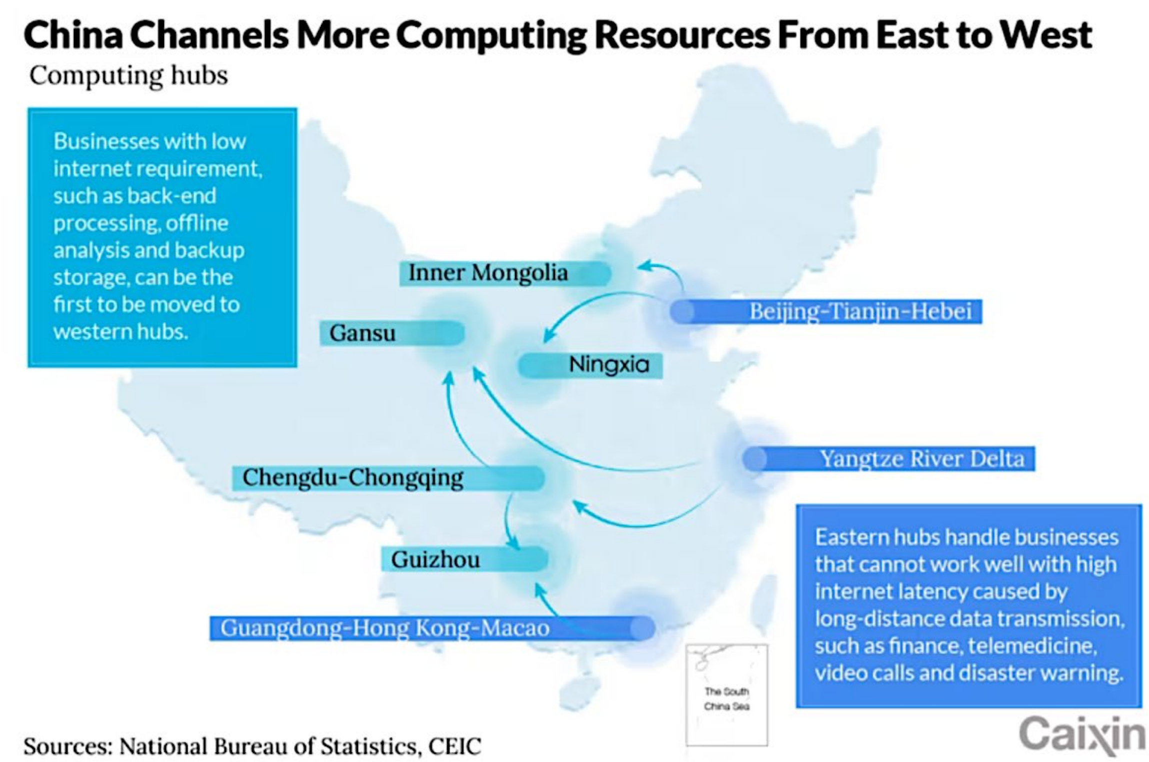

Figure 7. Layout for the Data Center Nodes of "East Compute, West Store"

(Source: E. Zhang & Chen. Caixin. 2022)

China's strategic approach of situating computing centers in the eastern provinces, where the demand for computing resources is high, and data storage centers in the western regions, where renewable energy resources are abundant and natural cooling conditions are more favorable, is an innovative national plan (Figure 7). This strategy reduces reliance on fossil fuels, maximizes green energy use, and contributes to a more sustainable data center industry. Additionally, it could trigger the formation of new data center clusters, encouraged by local government initiatives.

3.4.3 Capital Market: ESG Disclosure Requirements

The growing importance of environmental performance and corporate reputation is another key factor. As Environmental, Social, and Governance (ESG) disclosure requirements become increasingly stringent, data center owners and operators need to improve their environmental performance to earn favor from regulators and investors. Compliance with these standards can be challenging and costly, requiring significant investments in sustainable infrastructure, technology, and practices. However, major internet and technology companies in China, such as Apple, Tencent, and Alibaba, have recognized the importance of incorporating ESG standards into their operations to demonstrate their commitment to environmental stewardship, indicating a possible shift in industry standards and expectations.

3.4.4 Economic Performance: Increasing Energy Costs

Power costs typically account for a significant portion of data center operating expenses, but the exact percentage may vary depending on the specific data center and its energy-saving mechanisms. As energy prices rise, they contribute to the overall operating cost (C) in the equation of $\pi\_dc = Q[P-C]-rf(t)$, impacting the profitability of data center operations. This increase in energy costs adds pressure on IDC operators to pursue more energy-efficient practices, both to lower operating costs and maintain competitive profit margins. Taking Beijing as an example, in addition to the restrictions on new data center development, Beijing has levied an extra power price of RMB 0.50/kWh and RMB 0.20/kWh on the facilities with a PUE higher than 1.8 and PUE between 1.4 to 1.8 respectively (Kang et al., 2021). This policy not only increases the cost of inefficient energy use but also incentivizes the adoption of more energy-efficient technologies and practices or a shift to regions with a lower unit power cost.

3.5 Potential Green Pathways and Associated Economic Advantages

Given the discussed challenges, the IDC industry could benefit from two primary strategies: enhancing energy efficiency and incorporating renewable energy resources. These strategies offer several advantages, namely regulatory compliance and an array of financial benefits.

3.5.1 Enhancing Energy Efficiency

Continuous strides toward enhancing energy efficiency across all facets of data center operations are not only essential for regulatory compliance but also for reducing operational costs, thus augmenting the economic viability of data centers. This directly impacts 'C,' the operational cost variable in the profitability equation $\pi\_dc = Q[P-C]-rf(t)$.

Globally, data center electricity usage comprises 1.3% to 2% of total electricity consumption , underlining the fiscal and environmental necessity of decreasing energy usage (IEA, 2020). Beijing has levied an extra power price of RMB 0.50/kWh and RMB 0.20/kWh on the facilities with a PUE higher than 1.8 and PUE between 1.4 to 1.8 respectively (Kang et al., 2021).

According to the U.S. Department of Energy (DOE), IT equipment contributes 50-60% of a data center's total energy consumption, with cooling and power infrastructure accounting for the remaining 40-50% (DOE, n.d.). Implementing advanced cooling systems or capitalizing on colder climates can significantly mitigate energy consumption, reducing overall operational costs and boosting profitability.

3.5.2 Incorporating Renewable Energy Resources

The integration of renewable energy sources and green power solutions can be instrumental in shrinking carbon emissions and reliance on fossil fuels. This strategy aligns with China's overarching environmental objectives and could engender substantial economic benefits for a variety of stakeholders.

Regulatory Compliance and Local Government Support: Regulatory adherence and alignment with local government goals can ensure the operation and expedite IDC expansion. Green data centers are likely to attract support from local governments due to their diminished environmental impact and potential economic contributions. This translates into fewer regulatory hurdles and amplified ease in establishing such facilities. Moreover, the expansion of the green energy and IDC sector align with the development priorities of various provinces and cities, leading to GDP growth, job creation, and contributions to the prosperity of local economies. According to the NDRC, for every million yuan invested in the data center industry, an additional RMB 888K yuan is indirectly contributed to the value of digital industrialization, yielding a digital market worth 3.605 million yuan (Yu, 2021).

Financial Benefits: Minimizing 'C' and 'rf(t)' in the profitability equation could offer substantial financial advantages. In addition to energy efficiency and carbon reduction strategies, self-production power or fixed Power Purchase Agreements (PPAs) to hedge power price fluctuation risks can contribute to cost savings, considering that power costs make up a significant portion of operational expenses. Furthermore, situating data centers in less developed regions with lower land residual values can decrease 'rf(t),' thereby boosting profitability.

Power Arbitrage and Premium Pricing Opportunities: The integration of green power solutions could also yield power arbitrage opportunities and premium pricing prospects. As consumers increasingly express willingness to pay more for services from environmentally friendly data centers, operators have the opportunity to charge a green premium, which increases 'P' in the profitability equation. Moreover, diversifying the investment portfolio by incorporating green energy solutions can mitigate risks on returns, adding another layer of financial benefits.

3.6 Synthesizing the Justifications for Green Transition in China's IDC Industry

As this chapter has explored, the rapid digitalization in China has resulted in significant growth for the Internet Data Center (IDC) industry, creating new opportunities but also presenting pressing challenges—particularly in relation to energy consumption, carbon emissions, and regulatory compliance. The intersection of these factors has necessitated a shift in IDC operational strategies, with energy efficiency and renewable energy integration becoming essential aspects of industry dynamics.

The chapter's exploration of the economic model $\pi\_dc = Q[P-C]-rf(t)$ provided a framework to understand the financial implications of these changes. In particular, it highlighted how improving energy efficiency and incorporating renewable energy resources can reduce operational costs ('C') and land residual value ('rf(t)') while also providing an opportunity for power arbitrage and premium pricing, thereby increasing the price ('P').

Notably, the alignment of IDC operations with China's broader environmental and economic objectives is not merely a means for regulatory compliance—it also unlocks opportunities for business expansion and financial growth. Adopting green energy solutions and enhancing energy efficiency can render data centers more appealing to provincial governments, which could result in favorable policy support and potential financial benefits.

However, the transition towards a greener and more efficient IDC industry is not without challenges. It will require substantial investments in innovative technology and infrastructure and a comprehensive understanding of the regulatory landscape and market dynamics. As this chapter underscored, meeting these challenges will be instrumental in defining the future trajectory of the IDC industry.

In sum, China's rapidly digitizing economy's environmental concerns and regulatory landscape are redefining the IDC industry. Embracing these changes and adapting strategies accordingly will be key for IDC operators seeking to maintain competitiveness, achieve sustainable growth, and contribute to the broader societal goals of energy efficiency and carbon reduction.

CHAPTER 4 ANALYZING SUSTAINABLE APPROACHES FOR IDC REAL ESTATE: COMPARATIVE CASE STUDIES

4.1 Setting the Analytical Framework: Objectives and Overview

This Chapter aims to delve into a more nuanced understanding to explore and dissect green data center practices in China. Building on the solutions and benefits identified in the preceding chapters, the green transformation process - the decision-making process that underpins the selection of the most appropriate and effective green strategies is turning out to be focused as a crucial aspect. In order to facilitate a thorough and critical examination of this process, two international technology giants that have been pioneers in this field - Apple and Google - will be discussed. These corporations, with their successful and diverse implementations of green data center strategies, provide valuable insights into the factors that should be considered when making the transition to more sustainable practices.

The green strategies we will be considering can broadly be categorized into four main types: energy efficiency enhancement, self-generated power, power purchase agreements (PPAs), and renewable energy certificates (RECs) purchase. Each of these strategies presents distinct advantages and challenges, and their suitability varies depending on a multitude of factors, including but not limited to the nature of the demand, regulatory landscape, and specific operational circumstances.

The following sections will dissect the applications of these strategies in the operations of Apple and Google. The comparative case study analysis provides a comprehensive understanding of the considerations and decisions involved in adopting green strategies. It serves as a foundation for developing a decision-making model to guide IDC operators in choosing the right strategies to leverage benefits, overcome challenges, and avoid risks.

4.2 Case Study: Apple's Green Data Centers - Powering Growth through Renewable Energy

Apple Inc., as one of the world's largest tech companies, its data center operations have become a focal point for understanding the impact of technology on our economic and environmental landscapes. The company's strategic approach to energy use in its data centers represents a significant contribution to the ongoing discourse on sustainable economic growth. This section examines Apple's approach to data center operations, emphasizing its commitment to renewable energy and the economic implications of its strategy.

4.2.1 Overview of Apple's Data Center Operations

Apple's data centers are the backbone of its extensive services, including iCloud, App Store, Apple Maps, Apple Music, Apple Pay, Apple TV+, iMessage, and Siri. These facilities primarily serve for data storage and backup, ensuring the smooth functioning of Apple's service ecosystem with minimal latency.

Geographically, Apple's data center operations are strategically distributed across various locations. In the United States, data centers are established in Arizona, North Carolina, Oregon, Nevada, and California. Internationally, they have facilities in Denmark and China (M. Zhang, 2022). This geographical distribution not only ensures optimal service delivery but also enables the company to tap into diverse renewable energy sources.

Apple's commitment to expanding its data center facilities is evident in its investment plan. The tech giant has pledged $430 billion over the next five years for data center expansion and chip manufacturing (Shapiro, 2023). This substantial investment indicates Apple's strategic focus on enhancing its data center capabilities to support its growing services portfolio.

4.2.2 Embracing Renewable Energy: Apple's Commitment

Apple's commitment to renewable energy is central to its corporate sustainability initiative. All of Apple's facilities, including its data centers in over 40 countries, have been powered by 100% renewable energy since 2014 (Apple, 2018), reflecting the company's dedication to minimizing its carbon footprint. The company has undertaken several major renewable energy projects and collaborations such as the data center in North Carolina, US powered by solar farm, data center in Denmark synergized with onshore wind turbines and a nearby solar farm (M. Zhang, 2022).

In China, Apple's approach to renewable energy is marked by collaborations with local partners. The data center in Guizhou, operated in partnership with a local firm, is an example of this collaborative approach (Shapiro, 2023). This strategy not only ensures access to renewable energy but also fosters local economic development, underlining the economic significance of Apple's renewable energy commitment.

4.2.3 Innovations in Energy Efficiency and Sustainability

The company consistently integrates energy efficiency measures into its operations, exemplifying a model of sustainable technological growth.

Key energy-saving strategies include natural and plant-based treatment methods for cooling water, reducing energy consumption, increasing energy and water efficiency, reducing waste, and contributing to the data centers' overall efficiency (Apple, 2021; Shapiro, 2023). Additionally, the company distributes power at higher voltages in its data centers to reduce power losses.

These energy efficiency and sustainability innovations highlight Apple's strategic approach to green data center management. By implementing these measures, the company demonstrates the feasibility of sustainable practices in large-scale data center operations, contributing to a broader discourse on sustainable economic growth in the technology sector.

4.2.4 The Maiden Data Center, North Carolina

The Maiden Data Center in North Carolina vividly illustrates Apple's commitment to green energy and innovative sustainability. The 183-acre facility, situated in an area with abundant renewable energy resources, employs a range of energy efficiency measures. It showcases Apple's commitment to integrating renewable energy into its operations, highlighting the strategic role of site selection in achieving energy goals. The solar farm is strategically located near the data center, reducing transmission losses and ensuring efficient power management (Bidinger, 2022). The geographical advantage of Maiden, North Carolina, allows for the effective use of an on-site 100-acre, 20 MW solar farm.

With a tailoring strategy to the data center size and type, Apple has demonstrated the scalability of its data center design (Walbank, 2022). This scalability ensures that as the demand for data services grows, the data center's energy provision can keep pace without reliance on non-renewable energy sources.

To ensure energy security, Apple has installed energy storage systems and alternative energy sources, including a 10 MW fuel cell installation powered by biogas (Apple, 2019). This system offers an additional layer of energy security, demonstrating Apple's comprehensive approach to maintaining operational stability.

Navigating regulatory hurdles is another crucial aspect of Apple's strategy. Apple Energy LLC, a separate entity established by Apple (Sverdlik, n.d.), is a testament to the company's proactive approach toward regulatory compliance. By creating its own energy company, Apple can sell the energy generated by its renewable-energy plants directly to its data centers and the grid. In addition, while the capital expenditure for the Maiden Data Center was significant, the long-term operational cost savings and revenue from selling excess power more than offset the initial outlay. The ability to generate and sell its own power also insulates Apple from fluctuations in energy prices, providing financial stability.

The Maiden Data Center's success story, being 100% powered by renewable energy since 2012, embodies Apple's commitment to sustainability (Lahoud, 2020). Despite the considerable initial investment and the complexities of integrating renewable energy into data center operations, Apple has managed to create a facility that is not only sustainable but also highly efficient.

In summary, the Maiden Data Center case provides valuable insights into the considerations, benefits, challenges, and risks associated with creating a green data center. It underscores the importance of strategic site selection, scalable design, energy security, regulatory compliance, and cost considerations in the successful implementation of on-site self-generation of green power solutions for green data centers. The insights can inform other companies and policymakers interested in pursuing similar green data center initiatives.

4.2.5 Overcoming Challenges and Mitigating Risks: Future Plans and Innovation

Apple's expansion plans for its data centers, both domestically and internationally, have consistently emphasized energy efficiency. The tech giant aims to maintain a balance between the growing need for data processing power and the demand for renewable energy. Its data centers are planned to be highly resilient, adaptive, and agile, with a commitment to continuous innovation in energy efficiency measures.

Innovation in data center technology and processes is a vital part of Apple's strategy. For instance, the company has been re-engineering its substations for higher resiliency and developing energy-tracking systems to detect performance issues promptly. Moreover, Apple has innovated processes to test backup generators less frequently, reducing fuel consumption and emissions without compromising reliability (M. Zhang, 2022).

In addition to these initiatives, Apple has made significant investments in community development in the regions where its data centers are located. For instance, Apple committed $100 million to a Public Improvement Fund in Waukee, Iowa (M. Zhang, 2022). These community engagement initiatives, ranging from workforce development to environmental projects, serve a dual purpose - they help in regulatory compliance and foster goodwill in local communities, thereby enabling smoother operations and expansions.

4.2.6 The Impact and Implications of Apple's Green Data Center Strategy

The key elements of Apple's green data center strategy revolve around a robust commitment to renewable energy, relentless pursuit of energy efficiency, continuous innovation, and meaningful community engagement. Each of these elements not only contributes to the company's sustainability goals but also adds value to its operations in terms of cost savings, resilience, and public relations.

Apple's strategy has far-reaching implications for the data center industry and the broader push toward environmental sustainability. Firstly, it underscores the importance of energy efficiency in data centers, pushing the industry towards exploring more innovative ways to minimize energy usage. Secondly, it shows that renewable energy can be accessed through a variety of means, including on-site generation and power purchase agreements. Apple's use of renewable energy in China, where they collaborate with local partners, demonstrates the adaptability of this strategy in different regulatory environments.

Apple's approach also illustrates the critical considerations for the self-production of renewable energy, including site selection, the proximity of power generation to data centers, scalability of design, and navigating regulatory hurdles.

Lastly, Apple's green data center strategy brings to the fore the potential for significant alignment between business objectives, community development, and environmental sustainability. It is a compelling example of how corporations can actively contribute to global sustainability goals while simultaneously enhancing their operational efficiency and resilience.

4.3 Case Study: Google's Green Data Center Strategies in Diverse Circumstances

As a global leader in digital services, Google is at the forefront of the trend, striving to pioneer sustainable practices in its data centers. This section critically examines Google's green data center strategies and decision-making process.

4.3.1 Business Background and Data Center Demand

As one of the world's largest technology companies, Google's core businesses span search engines, cloud computing, digital advertising, and various other internet-related services and products. Each of these services generates considerable demand for data processing and storage, necessitating a vast network of data centers. It operates numerous data centers across North America, Europe, and Asia (Google Cloud, 2021). These facilities play a crucial role in supporting Google's global operations, processing and storing data for billions of users daily.

4.3.2 Commitment to Renewable Energy and Transparency in Reporting

Google has a long-standing commitment to renewable energy. In 2007, it became the first major company to commit to carbon neutrality, and by 2017, it achieved its goal of purchasing enough renewable energy to match 100% of its global operations (Google, 2018). In its environmental reports, Google has consistently demonstrated transparency in reporting its energy usage and carbon emissions. This commitment to renewable energy and transparency in reporting represents a key component of Google's green energy strategy, setting a benchmark for other businesses in the digital economy. Google uses on-site renewable electricity, Power Purchase Agreements (PPAs), and Renewable Energy Certificates (RECs) to ensure that its energy consumption is matched with renewable energy.

4.3.3 Regional Variations in Green Energy Supply

The regional variation in the proportion of carbon-free energy supplying Google's data centers is significantly influenced by the unique renewable energy markets and policy environments in different locations. Regional discrepancies in renewable energy availability, the structural organization of energy markets, and the governing policy frameworks are key determinants of this variation.

Google's data centers, spread across varied geographical locales, interact with energy markets with distinct characteristics. For instance, regions blessed with abundant sunlight or wind offer greater potential for harnessing solar and wind energy. Conversely, data centers in regions with limited renewable resources or underdeveloped renewable energy infrastructure may rely more heavily on conventional energy sources.

Real-world data support these observations. In 2019, Google's data center in Hamina, Finland, a region with a well-developed renewable energy infrastructure and supportive policy environment, was supplied with 97% carbon-free energy. Meanwhile, its data center in Council Bluffs, Iowa, a region with different market and policy conditions, only achieved 34% (Sverdlik, 2021).

The structure of regional energy markets also significantly impacts the proportion of green energy used. In deregulated energy markets, Google can directly negotiate PPAs with renewable energy providers, thereby ensuring a higher proportion of green energy for its data centers. However, in regulated markets, where utilities monopolize energy supply, Google's options are restricted, making reaching its green energy objectives more difficult.

Policy environments, too, exacerbate these regional variations. Supportive policies, such as feed-in tariffs, renewable portfolio standards, and tax incentives, can ease Google's transition to green energy. In contrast, regions without such policy support may present additional obstacles to accessing renewable energy.

4.3.4 Energy-Efficiency and Carbon-Reduction Strategies

Google's green energy strategy is multifaceted, integrating energy efficiency improvements, on-site power generation, PPAs for renewable electricity, and REC purchases. Each component offers unique advantages and responds to specific circumstances, factors, and market conditions.

Energy Efficiency Enhancement lies at the foundation of Google's green energy strategy. In 2021, Google annual average PUE was 1.10 (Google, 2022). Google employs advanced technologies and innovative techniques, including machine learning for power usage optimization and carbon intelligent computing. For instance, Google's use of DeepMind's machine learning algorithms to predict and manage power usage in its data centers has resulted in a 30% reduction in cooling energy usage (Google DeepMind, 2016). Meanwhile, the company's Carbon Intelligent Computing platform intelligently schedules non-urgent computational tasks when carbon-free energy is most plentiful, further optimizing energy usage without compromising service delivery (Clifford, 2022; Sverdlik, 2021).

Power Generation: Like what is being discussed in the Apple case, the benefits of this approach are two-pronged: it allows Google to obtain energy independence, thereby reducing reliance on external energy providers and ensuring a continuous supply of renewable energy. Google deploys this strategy under specific circumstances, such as when it owns or co-owns data centers, when local regulations allow for such installations, and when sufficient resources and land are available for the generation facilities. Google's data center in Changhua County, Taiwan, serves as an exemplar, with solar panels reducing grid reliance and a thermal storage system ensuring uninterrupted renewable energy supply (Google Cloud Blog, 2022).

Power Purchase Agreements (PPAs) for Renewable Electricity are contracts in which Google commits to buying energy directly from a renewable energy generator. These contracts are usually negotiated at a fixed price for an extended period, often spanning 10 to 20 years. This strategy offers multiple benefits, including predictable operating expenses, less upfront capital cost, and reduced need for specialized expertise in renewable energy generation.

Google typically utilizes PPAs in deregulated energy markets where it can negotiate directly with energy producers. This strategy becomes particularly advantageous in situations where Google's on-site renewable energy generation is insufficient to meet its requirements. Hence, PPAs serve as a strategic tool to supplement Google's energy supply and help the company maintain its commitment to renewable energy.

For instance, Google has leveraged PPAs extensively, signing contracts in several U.S. states, the Netherlands, and Finland. Through these agreements, Google has successfully secured over 3 GW of renewable energy (Google Sustainability, 2016; Sverdlik, 2015, 2021). This strategy not only ensures a consistent supply of green energy but also helps promote the development of new renewable energy projects. By entering into long-term PPAs, Google provides energy producers with the financial security needed to invest in new renewable energy infrastructure, thus driving the wider adoption of green energy.

Google's use of PPAs reflects its adaptability in navigating complex energy markets and regulatory environments and its commitment to fostering a greener and more sustainable future. However, it's crucial to note that the feasibility of PPAs is contingent upon the nature of the energy market and the availability of renewable energy producers willing to enter into such agreements.

Renewable Energy Certificates (RECs) comprise another critical component of Google's green energy strategy. Each REC represents proof that one megawatt-hour (MWh) of electricity has been generated from an eligible renewable energy resource and delivered to the electricity grid. Google resorts to purchasing RECs in regulated energy markets where PPAs are not feasible, and on-site generation isn't viable or sufficient.

The REC strategy offers Google higher flexibility in site location selections and scalability of the IT capacity in its pursuit of a 100% renewable energy goal. This is because RECs allow Google to support renewable energy generation even when it is not directly consuming the generated green energy. By purchasing RECs, Google effectively subsidizes the production of renewable energy, thereby contributing to the overall growth of the green energy market.

However, Google's REC strategy has not been without criticism. A significant concern raised is that RECs do not guarantee that the electricity Google uses is from green sources; they merely certify that a certain amount of green energy was added to the grid. The disconnect between the energy consumed by Google and the energy offset by its RECs can lead to a situation where Google's operations might still rely on fossil-fuel-based power, even as it purchases RECs equivalent to its energy consumption.

Despite the criticism, in the current energy market structure, RECs remain an essential tool for Google to reach its 100% renewable energy goal. It represents a pragmatic approach, given the existing challenges in the energy market, to promote the production of renewable energy and reduce the overall carbon footprint. Yet, the REC strategy's underlying complexities and potential shortcomings underline the need for comprehensive and transformative changes in our energy systems toward a truly sustainable future.

In conclusion, Google's green energy strategy is complex and responsive to the diverse conditions in which it operates. It is characterized by a multi-pronged approach that includes energy efficiency, on-site power generation, PPAs, and REC purchase. This diversified strategy not only ensures Google's resilience in varying market conditions but also demonstrates its commitment to a sustainable future.

4.3.5 The Future: Overcoming Challenges

With its commitment to sustainability and its history of innovation, Google is poised to continue leading the way in corporate renewable energy use. Google's ultimate goal is to match its energy consumption with carbon-free energy production on an hourly basis to address the issue of non-direct carbon emission reduction. Achieving this will involve overcoming significant technological and regulatory challenges.

One significant challenge is the regulatory hurdles present in different regions, which can complicate the procurement and utilization of renewable energy in various political frameworks. To overcome this, Google must actively engage with policymakers and stakeholders to advocate for regulations supporting renewable energy use and carbon reduction.

Another critical challenge is the technological complexity of hourly matching energy consumption with carbon-free energy production. This goal requires not only reliable renewable energy sources but also advanced grid infrastructure and storage solutions. Google is investing in advanced energy technologies and collaborating with utilities and energy providers to build a more flexible and resilient energy grid.

4.4 Comparative Analysis: Towards an Integrated Approach for Optimal Outcomes

In this section, we will conduct a comparative evaluation of the strategies adopted by Apple and Google as depicted in the case studies. These strategies will be evaluated based on their inherent advantages and disadvantages. Further, we will discuss the factors and considerations that determine the effectiveness of each strategy in different situations. Lastly, we will highlight the potential benefits of integrating multiple strategies to achieve optimal outcomes in the pursuit of green energy goals.

4.4.1 Unpacking the Strategies: Comparative Evaluation of Advantages and Disadvantages

Apple and Google, despite sharing common objectives in their green energy goals, employ different strategies with distinct mechanisms and implications. The balance between the strategies and the techniques employed varies between the two companies, reflecting their unique circumstances, market dynamics, and strategic priorities.

Apple's green energy strategy is heavily tilted towards on-site renewable energy generation and the direct ownership of renewable energy projects. This approach provides Apple with greater control over its energy sources, reducing reliance on third-party suppliers and ensuring energy security and a consistent supply of renewable power. Second, it allows Apple to match its energy generation with consumption, supporting real-time carbon neutrality. Finally, direct ownership sends a strong message about Apple's commitment to sustainability, reinforcing its corporate image as a green energy leader.

However, this strategy is capital-intensive and requires significant upfront investments in renewable energy infrastructure and systems, posing financial risks. Apple has a lot of cash on its balance sheet to cushion this risk. But this may not apply to all companies. Moreover, it requires in-depth technical expertise in renewable energy technologies and project management, which necessitates a substantial commitment of resources and skills. This approach also exposes Apple to potential risks associated with infrastructure ownership, such as maintenance costs, technological obsolescence, and regulatory changes affecting project viability.

On the other hand, Google's strategy is more focused on leveraging PPAs and RECs. PPAs offer Google a way to secure a long-term, stable supply of renewable energy at a fixed price without the need to invest heavily in the direct ownership of renewable energy projects. This approach provides flexibility, allowing Google to scale its renewable energy procurement according to its needs and market conditions. Similarly, RECs offer Google an additional tool to support renewable energy generation, even in markets or situations where direct renewable energy consumption is not feasible. They also reduce the need for upfront capital expenditure and technical expertise associated with owning and operating renewable energy facilities.

However, both PPAs and RECs have been subject to criticism for their indirect nature. While they contribute to the overall growth of the renewable energy market, they do not guarantee that the electricity consumed by Google is directly sourced from renewable resources. This can lead to a discrepancy between Google's renewable energy procurement and the actual greenness of its energy consumption and criticisms about the actual 'greenness' of Google's energy consumption. Moreover, the effectiveness of PPAs and RECs is highly dependent on the regulatory framework and market dynamics, making these strategies susceptible to changes in policy and market conditions.

In deciding between these strategies, companies need to consider various factors. Their energy demand and usage patterns are of paramount importance; specific situational factors, such as proximity to city centers or optimal connectivity locations, may dictate certain energy choices over others. The availability and cost of renewable energy resources in the region of operation also weigh heavily on strategic decisions.

Table 1. Comparison Associated With Energy Efficiency Measures and Green Energy Integration

Strategy	Benefits	Drawbacks	Risks
Energy Efficiency Measures	- Immediate energy savings - Reduced carbon emissions - Long-term cost savings	- Upfront investment costs - Complex retrofitting projects - Requires ongoing monitoring	- Unintended consequences (rebound effect) - Diminishing returns over time
Self-generated Power	- Direct control over energy sources - Reduced reliance on grid energy - Long-term cost savings - Enhanced corporate reputation	- High upfront capital costs - Land and resource constraints - Technical expertise required	- Fluctuating renewable energy generation - Changing regulations and incentives - Technology obsolescence
PPAs for Renewable Energy	- Scalable renewable energy sourcing - Long-term power price stability - Reduced operational responsibility	- Complex contractual arrangements - Limited local renewable resources	- Counterparty risks - Changes in regulations and incentives - Fluctuating renewable energy generation
RECs Purchase	- Demonstrated commitment to sustainability - Flexibility and scalability - No need for tech expertise - Supports China's green energy market	- Limited direct impact on operations - Reliance on third-party providers - Less revenue opportunity	- Price volatility - Questions regarding actual environmental impact - Fraud or misrepresentation

Moreover, each strategy comes with its unique set of risks and challenges (Table 1). These range from policy and regulatory risks associated with energy procurement to technical and operational challenges in green accessibility and efficiency improvement. Regulatory environments play a crucial role, as certain markets may favor direct renewable energy ownership, while others may be more conducive to indirect procurement methods like PPAs and RECs. Companies' financial resources and risk management capabilities also shape the choice of strategies, as direct ownership involves substantial capital expenditure and operational risks, while PPAs and RECs require sophisticated contract negotiation skills and market analysis capabilities.

4.4.2 The Path Towards Integration: Harnessing Synergies for Optimal Outcomes

In the context of increasing scrutiny of corporate sustainability practices, companies need to assess the potential reputational impacts of their energy strategies. Stakeholder expectations, both internal and external, are shifting towards greener practices, making sustainability a strategic imperative rather than a mere compliance requirement.

Therefore, the choice of green energy strategies involves intricate trade-offs. Control over energy sources and flexibility to respond to market changes, direct contribution to renewable energy generation and indirect support through market mechanisms, and upfront investment in renewable infrastructure versus long-term commitment to renewable energy procurement - these are the considerations that define a company's green energy strategic landscape. The optimal strategy may well be a hybrid approach that combines different methods, tailoring them to the company's unique needs and circumstances.

For instance, a company might invest in on-site renewable energy generation for its main operational sites, enter into PPAs to secure a stable supply of renewable energy for its data centers, and purchase RECs to offset its energy consumption in locations where direct renewable energy generation or procurement is not feasible. Such an integrated approach can enable companies to maximize the environmental benefits of their energy strategies while managing the associated costs, risks, and complexities.

CHAPTER 5 FORMULATING A CONTEXTUAL, HIERARCHICAL DECISION-MAKING FRAMEWORK FOR GREEN ENERGY STRATEGIES IN CHINA'S DATA CENTERS

5.1 Establishing the Decision-Making Framework: An Overview

This chapter seeks to accomplish several objectives. Firstly, it aims to provide a clear understanding of the process through which green energy strategies adopted by global tech giants, as explored in Chapter 4, are tailored and applied to the unique context of China's data centers. Secondly, the chapter highlights the distinct features of China's green energy landscape, underscoring how they shape and constrain the choice of green energy strategies. Finally, this chapter intends to construct a hierarchical decision-making model to guide data center owners, providers, and relevant stakeholders in selecting suitable green energy strategies in China, taking into account a multitude of factors, including demand, supply, regulatory compliance, financial considerations, technical feasibility, and risk management.

The significance of this endeavor lies in its holistic approach to strategy selection, which acknowledges the complex interplay of diverse factors that influence decision-making. Traditionally, economic theory has often oversimplified decision-making processes, primarily attributing them to cost-benefit analyses that pivot around the principle of rational choice. However, this perspective neglects the multifaceted nature of decision-making in the real world, where decisions are shaped not just by economic considerations but also by technological capabilities, regulatory pressures, stakeholder interests, and environmental uncertainties, among others.

In response to this limitation, this chapter adopts a hierarchical decision-making model, a powerful tool that captures the complexity and dynamism of decision-making in a structured, logical manner. This model, structured in layers, allows for a systematic analysis of the different facets of decision-making, from identifying the energy needs and usage patterns of data centers (top layer) to evaluating the potential risks and mitigation strategies associated with each strategy (bottom layer). By unraveling the decision-making process in this manner, the model offers a comprehensive framework that can aid decision-makers in navigating the intricate terrain of green energy strategy selection in China's data centers.

In doing so, this chapter contributes to the broader discourse on sustainable business practices, specifically in the realm of data center operations. As data centers continue to play a pivotal role in driving digital economies worldwide, including China, their energy consumption patterns and environmental footprints become increasingly consequential. Therefore, providing a contextual, nuanced, and practical decision-making framework for green energy strategy selection not only aids in promoting sustainable practices in data centers but also advances our collective quest for a more sustainable digital economy.

5.2 Contextualizing Green Energy Strategies for China's Data Centers

5.2.1 Global Green Energy Themes and Trends in China's Context

The strategic landscape of green energy utilization in data centers is not isolated from the global trends and themes that shape it. Indeed, the context of China's data centers reflects a microcosm of the global discourse on energy saving, carbon reduction, and sustainability in the digital economy.

As the world grapples with the existential threat of climate change, a consensus has emerged on the imperative for energy saving and carbon reduction. This global sentiment is echoed strongly in China, not least due to its commitment to peak its carbon emissions by 2030 and achieve carbon neutrality by 2060. Against this backdrop, data centers in China, like their counterparts globally, are under increasing pressure to align their operations with this environmental mandate.

The impact of better energy and carbon performance transcends the boundaries of the data center industry. As discussed in Chapter 3, various stakeholders in China - from customers and regulators to the public at large - stand to benefit from improvements in the energy efficiency and carbon footprint of data centers. Therefore, pursuing green energy strategies is not only an environmental obligation but also a strategic move that can yield significant stakeholder value.

Energy efficiency enhancement serves as a crucial precursor to the achievement of energy saving and carbon reduction goals. By maximizing energy use efficiency, data centers can make significant strides toward reducing their overall energy consumption and carbon emissions. This principle holds true in the Chinese context, where energy efficiency is increasingly recognized as a key performance indicator for data centers.

The nature of the data center - including its type, size, and IT capacity - is a critical factor influencing the selection of green energy strategies. These characteristics determine the demand for energy and, consequently, the feasibility and priority of renewable energy resources. In China, the diverse range of data center types, from cloud service providers to enterprise data centers, necessitates a nuanced approach to green energy strategy selection that considers the specific energy needs and usage patterns of each type. Furthermore, the demand in the Eastern and coastal areas remains strong. However, they also face extremely strict energy performance requirements, which impose additional constraints on the choice of green energy strategies.

Supply-side considerations also play a pivotal role in shaping green energy strategies. The availability and accessibility of renewable energy resources and technologies can significantly influence the choice of strategy. In the Chinese context, the geographic distribution of renewable energy resources, coupled with regional variations in energy policies and market conditions, adds an additional layer of complexity to the supply-side dynamics. Moreover, the abundance of renewable energy resources in certain regions could incentivize the relocation of some types of data centers, adding another dimension to the decision-making process.

The global strategies explored in Chapter 4 have their unique applicability and have been seen in the practice in China. The upside and downside of each strategy apply to China as well. However, their implementation is shaped by a range of factors, including China's regulatory environment, technological capabilities, market conditions, and stakeholder expectations. Therefore, while these strategies provide a useful reference point, their adoption in China requires careful adaptation and contextualization. Understanding these trade-offs is crucial in making informed decisions about the adoption of these strategies in China's data centers.

In summary, the transition towards green energy in China's data centers is a complex, multifaceted process influenced by a range of factors. The following section digs deeper into the unique features of China's green energy landscape and how they shape the choice of green energy strategies in the data center industry.

5.2.2 Distinctive Features of China's Green Energy Landscape

China's green energy landscape is unique, shaped by a distinctive blend of regulatory, economic, technological, and environmental factors. As such, the formulation of green energy strategies for China's data centers must take into account these features to be effective and sustainable.

Regulatory Framework

China's approach to regulating the green energy sector is characterized by a top-down framework guided by national targets for carbon reduction. In 2020, China announced its ambition to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. These targets have laid the foundation for a stringent regulatory environment that emphasizes energy conservation and emissions reduction. For data centers, this translates into strict energy performance requirements, particularly in the Eastern and coastal areas, which remain the hubs of digital infrastructure.

Policy and Incentives

Policy and incentives form a critical part of China's green energy landscape. The government has implemented a variety of measures to promote green power production, ranging from subsidies for renewable energy projects to preferential tariffs for clean energy. These incentives have catalyzed the growth of renewable energy sources such as wind, solar, and hydropower, making them viable options for powering data centers.

Renewable Energy Trading Patterns

China's renewable energy trading patterns are distinct. The majority of electricity generated by renewable energy generators is procured by grid companies under government planning, leaving limited space for market participants to purchase. However, consumers can buy green electricity through the grid without guaranteeing the power source. China's green electricity trade pilot program has begun to introduce more flexibility, enabling consumers to ensure they are utilizing purely green power. Despite its potential, the current trading systems are complex and present challenges for market participants.

Electricity Tariff Reforms

China's electricity tariff reforms have opened up new avenues for the integration of renewable energy into data centers. These reforms, introduced over the past few years, aim to liberalize the electricity market by breaking up state monopolies and introducing competitive mechanisms. One significant consequence of these reforms is the ability of data centers to purchase green power from producers directly, bypassing traditional utility companies. This direct PPA model offers data centers greater control over their energy mix and costs. Furthermore, data centers with on-site renewable energy generation facilities can now sell excess power back to the grid, creating an additional revenue stream and a buffer against their own energy consumption demand fluctuations.

Geographic Energy Resource Abundance

The geographic diversity of China presents a rich tapestry of energy resources, with certain regions being particularly abundant in renewable energy. For instance, the western provinces are rich in solar and wind resources, while the southern provinces have substantial hydropower potential. This regional abundance of renewable energy resources can significantly influence data center location decisions. The 'East computing West store' plan, a policy initiative encouraging the establishment of data storage facilities in western provinces, has further incentivized the geographical diversification of data centers.

In conclusion, China's green energy landscape, marked by its unique regulatory framework, policy incentives, electricity market reforms, and geographic energy resource abundance, provides a dynamic context for the formulation of green energy strategies for data centers. Understanding these features is a prerequisite for making informed decisions about green energy adoption in China's data center industry. The next section will build upon this understanding to develop a hierarchical decision-making framework for green energy strategies in China's data centers.

5.3 Constructing a Hierarchical Decision-Making Model

In the realm of green energy strategy formulation for data centers, a systematic, hierarchical decision-making model is instrumental in navigating the complex web of factors involved. This section outlines such a model, with a focus on the unique context of China's data centers. Stakeholder considerations permeate each layer of the model, underscoring the importance of a multi-stakeholder approach in driving sustainable outcomes.

The hierarchical model (Figure 8) proposed here comprises six layers, each representing a key aspect of decision-making. It is crucial to note that while this model is presented in a sequential manner for clarity, in practice, these layers are interdependent and often need to be considered simultaneously.

The **top layer** of the model is dedicated to **demand analysis**, which encompasses an examination of the energy needs and usage patterns of data centers. This understanding forms the bedrock of any green energy strategy, as it shapes the selection of data center locations, their size, and the most suitable energy solutions. In China, the demand for data centers manifests significant geographical variability. For instance, data centers in the Eastern and coastal regions, which serve as the nerve centers of the country's digital infrastructure, exhibit a robust and growing energy demand. However, the nascent data centers in areas surrounding tier-1 cities and those in the mid and western regions of China symbolize new foci of demand growth.

The **second layer**, **supply analysis** necessitates an evaluation of the availability and accessibility of renewable energy resources and technologies, along with other vital resources like land and connectivity. The geographical diversity of China, combined with policy initiatives such as the 'East computing West store' plan, significantly impacts supply dynamics. For instance, the western provinces, with their abundant solar and wind resources, could provide an ample energy supply for data centers, provided land availability and seamless connectivity are ensured. It's worth highlighting that insufficient connectivity could be a definitive deal-breaker for location selection, regardless of the richness of energy resources.

The **third layer** concerns **regulatory compliance**. it is driven by China's top-down regulatory framework. Data centers are required to tailor their green energy strategies in alignment with the prevailing energy and environmental regulations, which vary across different regions. Compliance not only mitigates legal risks but also enhances the centers' legitimacy and public trust.

The **fourth layer**, **financial considerations**, involves a comprehensive cost analysis associated with the implementation of green energy strategies. This encompasses direct capital costs such as the construction of power generation facilities, operational costs which could be impacted by fluctuations in market prices, and indirect costs like infrastructure improvements. In the Chinese context, these costs can somewhere be offset partially by policy incentives, especially in less developed areas with supportive initiatives. Paying attention to leveraging the incentives can result in better economic performance. Furthermore, certain strategies like on-site renewable energy generation can unlock new revenue streams, such as selling excess power back to the grid.

The **fifth layer** considers **technical feasibility**. The technical capacity to implement and maintain green energy solutions is a critical determinant of the choice of strategy. This includes the capacity to install, operate, and maintain renewable energy generation facilities and the ability to integrate them seamlessly with the data center's existing infrastructure. For example, deploying solar panels requires suitable rooftop or ground space, and in the case of wind turbines, adequate wind speed and the absence of noise restrictions are essential considerations.

Finally, **the sixth layer** is dedicated to **risk management**. Each green energy strategy is associated with potential risks that need to be identified, assessed, and mitigated. In the Chinese context, these risks can be multifaceted, ranging from regulatory uncertainties, such as sudden policy changes, to technological risks, like the failure of green energy equipment, and market risks, such as fluctuating energy prices and the availability of subsidies.

In conclusion, this hierarchical decision-making model offers a comprehensive framework for formulating green energy strategies for China's data centers. It integrates stakeholder considerations into each layer, emphasizing the multi-stakeholder nature of sustainable decision-making. Moreover, it draws attention to the unique features of China's green energy landscape, underscoring the need for context-specific strategies.

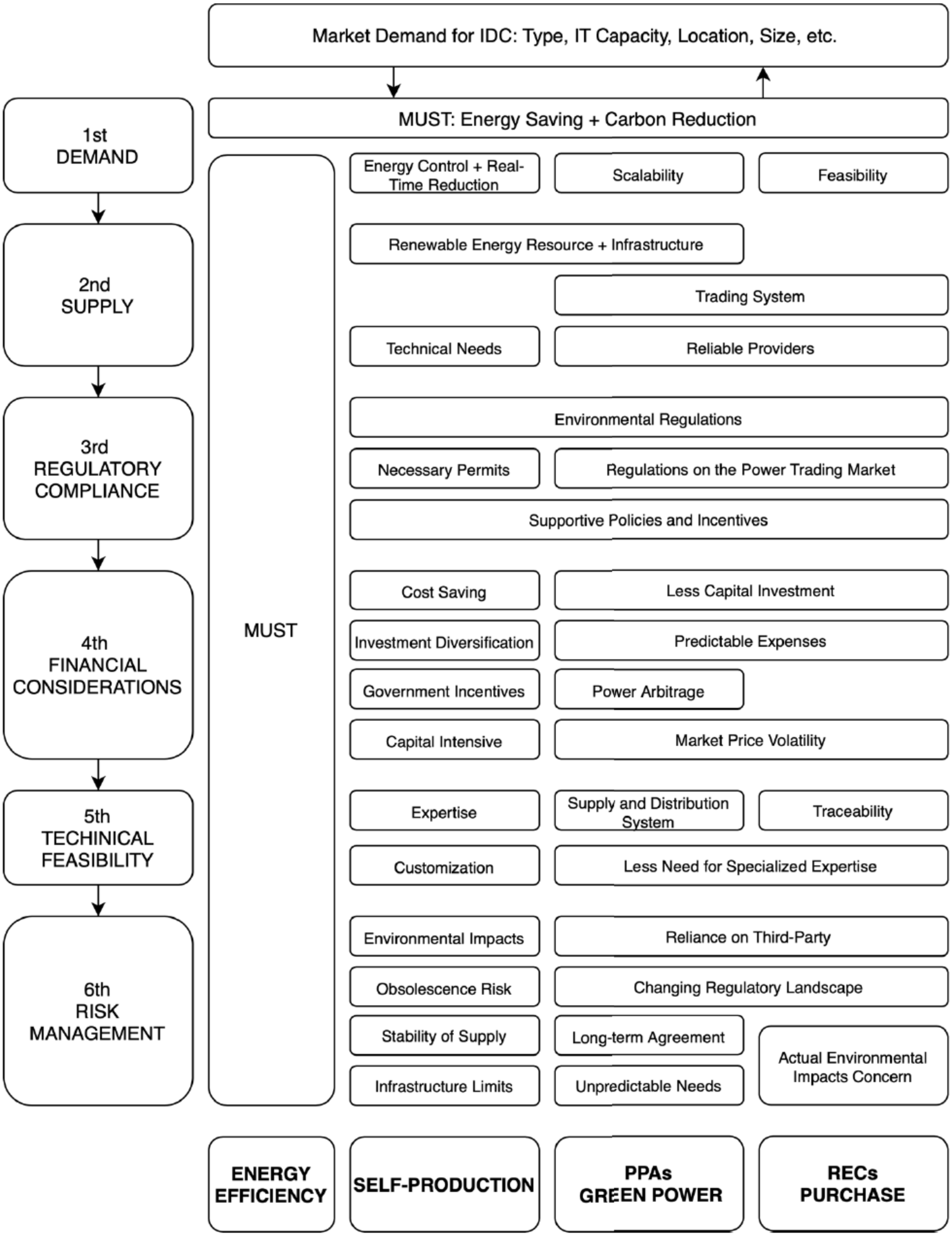

Figure 8. Hierarchical Decision-Making Framework for Green Energy Strategies in China's Data Centers

5.4 Key Findings and Implications for Decision-Making

This chapter has presented a comprehensive analysis of the multiple dimensions involved in formulating green energy strategies for China's data centers, culminating in the development of a hierarchical decision-making model. The model is founded on a systematic and critical examination of the distinctive features of China's green energy landscape and the global themes and trends contextualized within this unique setting.

Among the key findings, the following stand out:

1. Demand Analysis: The energy needs and usage patterns of data centers in China exhibit significant geographical diversity. This highlights the importance of a nuanced, location-specific approach in formulating green energy strategies.

2. Supply Analysis: The availability and accessibility of renewable energy resources and technologies, land, and connectivity are pivotal considerations in supply analysis. This suggests that green energy strategies must take into account the local resource endowments and infrastructural capacities.

3. Regulatory Compliance: China's top-down regulatory framework necessitates the alignment of green energy strategies with regional energy and environmental regulations. This implies that regulatory compliance should be a core aspect of strategy formulation.

4. Financial Considerations: The costs of implementing green energy strategies can be substantial, but there can be opportunities to offset partially by policy incentives potentially. This points to the need for a thorough financial analysis in strategy selection.

5. Technical Feasibility: The technical capacity to implement and maintain green energy solutions is crucial in strategy selection. This highlights the importance of assessing technical feasibility and capacity building in the adoption of green energy strategies.

6. Risk Management: Potential risks associated with green energy strategies need to be identified, assessed, and mitigated. This underscores the importance of risk management in strategy formulation and implementation.

The developed hierarchical decision-making model can guide decision-making in several ways. Firstly, it provides a structured approach to strategy formulation, helping decision-makers navigate the complex array of factors involved. Secondly, it underscores the need for a multi-stakeholder approach, emphasizing the importance of taking into account the perspectives and interests of different stakeholders. Thirdly, it draws attention to the unique features of China's green energy landscape, underscoring the need for strategies that are tailored to this context. Finally, the model underscores the interdependence of different aspects of decision-making, highlighting the need for a holistic approach. For instance, decisions about the adoption of certain technologies must take into account not only their technical feasibility but also their financial implications, regulatory compliance issues, and potential risks.

In conclusion, the hierarchical decision-making model developed in this chapter offers a comprehensive and nuanced framework for formulating green energy strategies in China's data centers. By guiding decision-making, this model can play a crucial role in promoting the adoption of green energy solutions, thereby contributing to the sustainable development of China's data center industry.

CHAPTER 6 APPLYING THE DECISION-MAKING FRAMEWORK TO CHINESE CASE STUDIES

6.1 Introduction to Case Application

In China's evolving landscape of data centers, discerning the intricacies of green energy strategy selection is a nuanced and complex task. This chapter aims to demystify this process by applying the decision-making model developed in Chapter 5 to two illustrative case studies - Tencent and The D.

This application serves a dual purpose. Firstly, it provides a practical demonstration of the model's utility in guiding decision-making in the adoption of green energy strategies. Secondly, it enriches our understanding of the model's dynamics by highlighting the interplay of various factors across its layers in real-world scenarios. The key questions addressed in this chapter are: How have Tencent and The D navigated the complexities of green energy strategy selection? What insights can we glean from their experiences about the model's applicability and effectiveness in China's unique context?

To provide the necessary background for these analyses, we begin with a recap of the distinctive features of China's data center industry. The industry is characterized by its vast size and diversity, with a wide range of data center types - from cloud service providers to enterprise data centers. Coupled with this is the rapidly evolving regulatory environment and the unique geographical distribution of energy resources, which significantly influence the choice of green energy strategies.

The first case study in this chapter is Tencent, one of China's leading internet service providers. As a major player in the industry, Tencent's data centers have a substantial energy footprint. Recognizing its environmental responsibility, Tencent has embarked on a journey towards greener data centers, employing multiple green energy strategies discussed in Chapter 4.

The second case study focuses on The D, a startup data center provider. Unlike Tencent, The D has opted for an on-site green energy strategy, specifically deploying green-powered shells. This unique business model presents a fascinating contrast to Tencent's multi-pronged approach, offering valuable insights into the versatility of our decision-making model.

The following sections will delve deeper into each company's green energy strategies and examine them through the lens of our decision-making model. By doing so, this chapter aims to highlight the model's applicability to a diverse range of scenarios in China's data center industry and demonstrate its potential as a practical tool for guiding green energy strategy selection.

6.2 Case Study: Tencent's Transition to Green Data Centers

6.2.1 Introduction to Tencent and Its Environmental Commitment

As a leading provider of value-added Internet services in China, Tencent wields significant influence over the nation's digital infrastructure. Boasting a sprawling portfolio of businesses across sectors including social networking, music, web portals, e-commerce, and multiplayer online games, Tencent's operations are heavily reliant on data centers.

In recent years, Tencent has committed itself to environmental sustainability, recognizing the potential environmental ramifications of its data center operations. This commitment is epitomized by its ambitious goal to operate fully on green energy by 2030 (Nelson, 2022; Tencent, 2020). Tencent's commitment to sustainability is not only a response to regulatory pressures but also an acknowledgment of the company's environmental responsibility and the strategic advantages of transitioning to a greener business model.

6.2.2 Tencent's Green Energy Strategies

In its pursuit of sustainability, Tencent has adopted a comprehensive approach that involves four main strategies:

1. **Energy Efficiency Improvement:** Tencent continually optimizes its data center designs for energy efficiency, employing advanced technologies such as high-efficiency power supply units, cooling systems, and AI algorithms to enhance cooling efficiency and lower PUE to as little as 1.06 (PR Newswire, 2022).
2. **Renewable Energy Generation:** Tencent has significantly invested in on-site renewable energy generation, including solar and wind power installations at its data centers. It is implementing more than 80 MW of distributed on-site solar cell projects, which are expected to generate over 80 GWh annually upon completion (PR Newswire, 2022). To enhance the load resilience of its data centers, Tencent also plans to integrate energy storage stations into its infrastructure. Specifically, the company has plans for energy storage stations in the Qingyuan Qingxin and Shanghai Qingpu parks, which will enable the data centers to achieve adjustable power nodes (Reuters, 2022). Furthermore, Tencent is exploring the establishment of centralized renewable-energy power plants close to its data centers. These initiatives contribute significantly to Tencent's green energy targets, reducing reliance on grid electricity and decreasing its carbon footprint.

3. **Power Purchase Agreements (PPAs):** Tencent enters long-term PPAs with renewable energy providers. In 2022, the company signed sustainable power trading contracts amounting to a total of 534,000 MWh for the use in 2023, accounting for 43.5% of the annual power consumption. The Tencent Qingcheng Data Center in Guangdong now operates on 100% renewable energy through these agreements (PR Newswire, 2022). These agreements not only ensure a stable supply of green energy but also support the development of new renewable energy projects by guaranteeing a market for the energy they produce.
4. **Renewable Energy Certificates (RECs) Purchase:** Tencent has shown a strong commitment to exploring various renewable energy power solutions, focusing on high-quality renewable energy. One critical aspect of Tencent's values in these solutions is Traceability, which signifies that Tencent's procurement behavior can be directly linked to physical renewable energy plants and carries green attribute certification (Tencent, 2022). Participation in China's pilot green electricity trade program, "bundled green electricity + green attribute certificate," is a form of PPAs for green power combined with RECs purchase. The procurement method allows Tencent to access green power while not only supporting the Additionality[4] of the green power production industry but also guaranteeing that the electricity Tencent uses originates from green sources.

[4] Additionality refers to the concept that the purchase of RECs should lead to the development of new renewable energy projects or capacity, which would not have been built without the demand created by REC purchasers. Ensuring additionality is crucial for verifying the environmental impact and effectiveness of REC purchases in promoting the growth of the renewable energy sector (CRS, 2016).

Tencent's strategies align with global green energy trends, demonstrating a holistic approach to adopting green energy. The results of these strategies are evident in Tencent's progress toward its green energy goals. The company has significantly reduced its carbon footprint and energy consumption, earning it the top spot in Greenpeace's clean energy rankings for Chinese tech companies in 2021, surpassing another tech giant, Alibaba. However, the transition to green energy is an ongoing process, and Tencent continues to face challenges in its pursuit of 100% green energy operations. The next section will examine these challenges and discuss how Tencent navigates them using our decision-making framework.

6.2.3 Application of the Decision-Making Model to Tencent

It is beneficial to apply our decision-making model to gain a comprehensive understanding of Tencent's strategic transition towards greener data centers. This model facilitates the identification of crucial considerations and aids in comprehending how Tencent navigated its current green energy strategies.

Demand Analysis: Tencent's data centers exhibit a high electricity demand, driven by its extensive array of internet services. As the company expands, so do its energy requirements, necessitating scalable and sustainable energy solutions. Tencent's commitment to operating entirely on green energy by 2030 exemplifies its cognizance of this demand and its proactive approach towards sustainable energy solutions.

Supply Analysis: The availability and accessibility of renewable energy resources and technologies significantly influence Tencent's strategies. Although Tencent heavily invests in on-site renewable energy generation, not all ideal data center locations provide the necessary foundation for the self-production of renewable energy. Here, Tencent's Power PPAs demonstrate its ability to source renewable energy from external suppliers, ensuring a consistent supply of renewable energy within its operational regions.

Regulatory Compliance: Operating in such an increasingly environment-focused regulatory environment, Tencent's green energy strategies align with these regulations and may even preempt future regulatory tightening. Tencent's participation in China's green electricity trade program illustrates its commitment to compliance and reaping benefits from state-led green initiatives. This policy-driven approach provides Tencent with economic incentives while encouraging environmental responsibility.

Financial Considerations: The transition to green energy entails significant initial costs but also harbors opportunities for long-term cost savings and financial stability. Tencent's investments in renewable energy installations or PPAs reflect a recognition of the trade-off between upfront costs associated with long-term benefits but less flexibility and immediate benefits coming with scalability and, however, such as contract negotiation complexities. Moreover, Tencent's purchase of RECs emphasizes its understanding of the incentives associated with green power trading and its role in contributing to the green power production industry.

Technical Feasibility: Tencent's strategies are a testament to its technical capacity to implement and maintain green energy solutions. The company's ongoing optimization of data center designs for energy efficiency showcases its capability to integrate cutting-edge technologies into its operations. The Tencent Qingcheng Data Center in Guangdong, operating entirely on renewable energy, is a testament to Tencent's technical prowess in harnessing and managing renewable energy.

Risk Management: Tencent faces a myriad of risks associated with its green energy strategies, including potential supply instability of renewable energy and technical challenges in maintaining green data centers. Its diversified approach to sourcing renewable energy—through self-generation, PPAs, and RECs—and enhancing the power storage system helps mitigate these supply risks. Continuous investments in technology and expertise aid in managing technical risks. Furthermore, as a tech behemoth and Hong Kong-listed company, Tencent's alignment with global sustainability trends mitigates regulatory and reputational risks.

In conclusion, Tencent's green energy strategies are a product of a systematic and informed decision-making process that considers demand and supply factors, regulatory compliance, financial implications, technical feasibility, and risk management. This holistic approach places Tencent on a strong footing for a successful transition to sustainable data centers, albeit continuous monitoring and adaptation will be crucial in navigating future challenges and uncertainties.

6.3 Case Study: The D's Powered Shells Business Model

6.3.1 Introduction to The D's Business

The D, a young data center provider company in China, has been operating at the forefront of the data center industry, focusing on the needs of IDC operators and hyperscale data center users. The company's operations are notable for their innovative approach, emphasizing the integration of green power solutions in strategic locations within the Datong-Zhangjiakou-Ulanqab (D-Z-U) region in China.

The D's innovative business model, "Green-Powered Shells," represents a significant shift in the traditional data center industry. The model revolves around constructing powered shells that are energy-efficient and customizable according to the tenant's specific needs. The approach, coupled with the company's strategic focus on green power production, composite The D's sustainable data center solutions. The company aims to integrate solar farms as a new line of business with its existing "shell" operations, thereby creating a comprehensive green power solution for its clients and aligning with the Chinese government's regulatory initiatives that encourage balanced economic development and reduction in the environmental impact of data centers.

6.3.2 Description of The D's Business Model

At its core, the "Green-Powered Shells" business model focuses on developing energy-efficient data center facilities that utilize green power sources. This approach involves constructing purpose-built data center structures, known as powered shells, which incorporate green power generation and energy-efficient design elements.

A powered shell includes the basic building infrastructure (walls, roofing, and structural support, designed with energy-efficient materials) and construction techniques to minimize energy loss and the power infrastructure (transformers, switchgear, and backup power systems, which are designed to integrate seamlessly with renewable energy sources, thereby ensuring a stable and reliable green power supply).

The business model involves several key steps:

1. Land and Building Development: The D procures land and constructs the building shell from a greenfield state, creating a foundation. The company prioritizes locations with access to abundant renewable energy resources.
2. Permit Acquisition: The company obtains the necessary permits, ensuring regulatory compliance and alignment with local and national green energy initiatives.
3. Power and Fiber Infrastructure: The D builds the required infrastructure to connect the facility to the electrical grid and fiber providers, prioritizing access to renewable energy sources and efficient energy distribution.
4. Power Procurement or Self-production: The company procures or produces power for the site, focusing on integrating green power solutions, and secures a margin through tailored offerings to IDC operators.
5. Site Leasing: The D leases the empty building shells to IDC operators or end-users, who then install the necessary M&E (which is at higher risk of technological obsolescence) according to their specific requirements and charge for their energy consumptions.
6. Property Management: The company provides ancillary services to tenants, such as assistance with M&E installation, property management, and bandwidth bundling, while promoting best practices in energy efficiency and green power utilization.

The "Green" of the "Green-Powered Shells" business model represents The D's strategic plan of stepping into the green power production side, specifically through solar resources, to achieve "self-production, self-use." This model is a substantial departure from traditional IDC platforms (Table 2). By concentrating on green power solutions, The D addresses environmental sustainability and risks associated with equipment obsolescence, rapidly evolving technological demands, and regulatory compliance in the data center industry.

Table 2. A comparison of the Green-Powered Shells business model with traditional IDC platforms

	Traditional IDC Leasing	**Powered Shell**
Physical Site		
Land Planning & Development	Owned/Leased	Owned
Design	Outsourced	In-house Design
EPC[5] (Core Shell)	Outsourced	In-house EPC
EPC (Municipal Works)	Outsourced	In-house EPC
Operation & Maintenance	In-house O&M	In-house O&M
Equipment		
Racks/IDC Modules	Installed and procured from 3rd party suppliers	Option for customers to purchase on their own to meet their specific requirements
Power Equipment		
Cooling Equipment		
Energy		
Energy Quota/ESA	NDRC approval required	Secured by adopting renewable energy
Power Connection	Outsourced to specialized service providers	
Renewable Energy	Option to purchase RECs	Self-owned
Power Transmission	Not involved	Self-owned
Energy Storage	Not involved	Self-owned

[5] EPC: Engineering Procurement Construction, a type of project delivery model where contractors are responsible for the project from start to finish. EPC are often used for complex infrastructure projects, such as renewable energy projects, aiming to minimize risks and costs for owners by transferring them to the contractor (Source: Wikipedia).

6.3.3 Market Analysis

The D's focus on green data center solutions, specifically its innovative "Green-Powered Shells" business model, is a strategic response to these market and regulatory trends.

Demand for Green Data Centers in China

The explosion of data-driven technologies such as 5G and Artificial Intelligence (AI) and the accelerated digital transformation caused by the Covid-19 pandemic contributed to the need for robust and reliable data center infrastructure. However, the traditional data center infrastructure, notorious for high-energy consumption and environmental impact, has faced difficulties maintaining business growth strength in China's competitive IDC sector and daily stricter regulatory environment. Consequently, there is a growing demand for energy-efficient green data centers.

Government's Balanced Economic Development Plan

The Chinese government's plan to balance economic development across the country has significantly influenced the data center industry. This includes initiatives to promote industries in the western and central regions of the country, where renewable energy resources are abundant, especially wind and solar energy.

Availability of Renewable Energy Resources

The D-Z-U region is rich in renewable energy resources, primarily wind and solar. This renewable energy abundance offers a unique advantage for data center operations, which traditionally consume large amounts of electricity. By utilizing these renewable resources, data centers can significantly reduce their carbon footprint and operate more sustainably.

Coming with its relatively lower land cost and proximity to the network bone and Tier-1 city (Table 3), Beijing, consequently, data center providers like The D are incentivized to establish operations in these regions and integrate renewable energy into their operations, aligning with the government's broader economic and environmental objectives.

Table 3. A Comparison of the Key Features of Each Location

Location	Connectivity	Natural Resources	Land	Policy
Datong	• ~200km distance Beijing. Direct connected to the backbone network	• Annual average temperature is around 0-15°C • Low power price (0.3-0.35/kWh for data centers) • National Tier II: solar resource area	• Significantly lower prices compared to Beijing, while maintaining good connectivity to Beijing	• Data centers are a supported industry by the local government
Zhangjiakou	• ~150km distance to Beijing • Direct connected to the backbone network	• Annual average temperature is around 4-15°C • Relative low power price • National Tier II: solar & wind resource area	• Abundant land resources at a relatively low price	• One of the "Eastern Data and Western Computing" national nodes
Ulanqab	• ~300km distance to Beijing • 144 cores fiber directly connect to Beijing; latency < 10ms	• Annual average temperature is around 5-7°C • Low power price (0.26/kWh for data centers) • National Tier I: wind & solar resource area	• Significantly lower prices compared to Beijing, while maintaining good connectivity to Beijing	• One of the "Eastern Data and Western Computing" national nodes

6.3.4 Application of the Decision-Making Model to The D

The D's strategic move towards the "Green-Powered Shells" business model is a nuanced decision best examined through our layered decision-making model. This model entails six stages of analysis: Demand, Supply, Regulatory Compliance, Financial Considerations, Technical Feasibility, and Risk Management. Conversely, it also shows the interdependence among each layers.

Demand Analysis

In the face of the exponential growth in data usage and the subsequent demand for data centers, The D recognized the need for increased capacity. Concurrently, increasing societal and regulatory expectations for sustainability highlighted the desirability of green solutions in this sector. Thus, the dual pressures of capacity and sustainability formed the basis of demand driving The D's move towards a green business model. The company's model caters to key market demands for sustainable data center solutions. By doing so, it opens up earning opportunities for market share growth, premium pricing, and potential first-mover advantages.

Supply Analysis

The D-Z-U region, with its abundant renewable energy resources, presented an attractive proposition for The D to meet this demand. Leveraging these resources allowed The D to supply green data center solutions that aligned with both consumer demand and the broader trend of sustainability in the corporate world. Additionally, by leveraging renewable energy resources, the company reduces its dependence on traditional, non-renewable energy sources, thus minimizing associated price volatility and supply risk. The D's model also reduces capital risk and technology risk by investing in proven renewable technologies and utilizing existing infrastructures in the D-Z-U region.

Regulatory Compliance

Government regulations in China actively encourage the transition towards renewable energy and balanced economic development. The D's transition to a green data center model dovetailed with these policies, thus ensuring regulatory compliance. One the other hand, the alignment of the model with regulatory requirements reduces regulatory risk and positions the company to take advantage of any future incentives for green business practices.

Financial Considerations

The upfront investment for transitioning to a green data center model was significant. The D excludes expenditure on IT equipment to give more space to allocate capital. In addition, it calculates the long-term benefits outweighed the initial costs, including the potential cost savings from renewable energy use, reduced exposure to potential carbon taxes, increased revenue from power arbitrage to the IDC customers, and access to green investment funds and subsidies.

The company's focus on environmental sustainability also plays a pivotal role in enhancing its reputation and brand value. In an era where corporate sustainability is increasingly critical, The D's commitment to green practices positions it favorably in the eyes of consumers, investors, and regulators alike. This, in turn, can lead to rewards in the form of increased customer loyalty, investor interest, and regulatory goodwill.

Technical Feasibility

The D carefully evaluated the technical feasibility of operating green data centers. This involved a rigorous examination of the available renewable energy technologies, the potential for incorporating these technologies into their operations, and the infrastructural needs of such a shift. The availability and viability of renewable energy in the D-Z-U region confirmed the technical feasibility of this transition.

Risk Management

Finally, The D evaluated the potential risks associated with this strategic shift. These include: operational risks such as reliability issues with renewable energy, market risks such as potential changes in demand or regulatory environment, and financial risks such as high upfront capital expenditure. The D mitigated these risks through strategic planning, including diversifying energy sources and implementing rigorous operational protocols. The company's strategic approach through multi-layer interacted consideration led to mitigating these risks, further underscoring its robustness and its potential for long-term success in the green data center industry.

The implementation of The D's "Green-Powered Shells" business model has resulted in a series of significant achievements. Initially, the three successful executions of the green data center projects in Shanxi and Hebei are a testament to the company's technical prowess and ability to operationalize complex green energy technologies. Furthermore, the model's effectiveness is seen in the optimization of energy resources. By strategically placing two solar farms in the D-Z-U region, the company has maximized the use of available renewable energy, thus mitigating environmental impacts while ensuring operational efficiency.

The market, in turn, has positively received the "Green-Powered Shells" business model. This is evidenced by the increase in The D's market share, the premium pricing it has been able to command for its services, and the heightened investor interest in the company.

In conclusion, The D's decision to shift to the "Green-Powered Shells" business model represents careful navigation through various strategic layers. The move not only aligns with the current market and regulatory trends but also positions the company to meet future demand in a sustainable manner. This case highlights the crucial role of layered decision-making in facilitating strategic corporate transitions toward sustainability.

6.4 Comparative Analysis of Tencent and The D

The comparative analysis of Tencent and The D demonstrates the adaptability and versatility of the decision-making model. The layered framework, encompassing Demand Analysis, Supply Analysis, Regulatory Compliance, Financial Considerations, Technical Feasibility, and Risk Management, provides a comprehensive strategic decision-making approach applicable to different contexts and industries.

Both Tencent and The D recognized the escalating demand for data centers, indicative of the first layer, "Demand Analysis." However, the nature of this demand differed for both. Tencent, a tech giant, experienced internal demand driven by its expanding array of digital services. On the other hand, The D, as a data center provider, acknowledged the external demand for sustainable data center solutions in the market.

In terms of "Supply Analysis," Tencent's strategy revolved around leveraging its technical prowess to develop and manage its data centers, while The D focused on harnessing the abundant renewable energy resources in the D-Z-U region to provide green data center solutions.

"Regulatory Compliance" played a crucial role in both companies' strategies. Tencent's focus on carbon neutrality and renewable energy aligned with China's environmental policies. Similarly, The D's green business model ensured compliance with the same set of regulations.

"Financial Considerations" differed significantly for both entities. Tencent, with substantial financial resources, could afford significant investments in renewable energy and carbon neutrality initiatives. On the contrary, The D needed to consider the high upfront costs of transitioning to a green data center model, balancing it with the long-term benefits of renewable energy use, potential cost savings, and access to green investment funds and subsidies.

The "Technical Feasibility" of their respective strategies was also distinct. Tencent leveraged its in-house technical expertise and resources to achieve its sustainability goals. Conversely, The D had to rigorously evaluate the available renewable energy technologies and the potential for incorporating these technologies into their operations.

Finally, "Risk Management" was integral to both companies' strategies. Tencent had to manage risks related to maintaining service quality during the transition to greener operations. The D, meanwhile, had to consider operational risks, such as reliability issues with renewable energy, market risks, such as potential changes in demand or regulatory environment, and financial risks, like high upfront capital expenditure.

In conclusion, while Tencent and The D utilized the same decision-making framework, the application, and context varied significantly. The model's flexibility allowed both companies to navigate their unique challenges and opportunities effectively, demonstrating its broad applicability and usefulness in strategic decision-making.

CHAPTER 7 Conclusion

The primary goal of this thesis was to explore and understand the green transition strategies in China's rapidly growing data center industry. The motivation for this research was driven by the increasing energy demands and carbon emissions from data centers due to the rapid digitalization in China. This led to an exploration of the need for green energy strategies within the industry, the strategic options available, and the decision-making process involved in such strategic transitions.

The literature review revealed an intersection of factors influencing the strategic decisions of data center operators. These included the technical aspects of data center operations, the economic implications of energy consumption, the regulatory landscape in China, and the broader societal trend toward sustainability.

Chapter 3 provided a comprehensive analysis of why Chinese data centers must go green. The economic model $\pi\_dc = Q[P-C]-rf(t)$ offered a framework to understand the financial implications of these changes. It was shown that improving energy efficiency and incorporating renewable energy resources can reduce operational costs ('C') and access the land with less residual value ('rf(t)') while also providing an opportunity for power arbitrage and premium pricing, thereby increasing the Sale Price ('P'). The chapter highlighted that aligning IDC operations with China's broader environmental and economic objectives could unlock opportunities for business expansion and financial growth. Yet, it also acknowledged the substantial investments in innovative technology and infrastructure necessary for this transition.

Chapter 4 delved into the available strategies for green transition in the data center industry. It discussed how data center operators could adopt energy-efficient technologies, renewable energy sources, and regulatory compliance strategies. This chapter also highlighted the role of strategic partnerships and alliances in facilitating green transitions.

Chapter 5 presented a layered framework to understand the strategic decision-making process in green transitions. The framework encompassed six layers of analysis - demand analysis, supply analysis, regulatory compliance, financial considerations, technical feasibility, and risk management. This model highlighted the complexity and interdependence of factors influencing strategic decisions.

Chapter 6 applied the decision-making framework to two case studies - Tencent and The D. These case studies showed how different companies navigated the decision-making process to develop their green energy strategies. The case studies further highlighted the flexibility and adaptability of the decision-making framework in different contexts.

Going forward, this research suggests several avenues for future exploration. A broader examination of the decision-making model's applicability across different sectors within China and a comparison with other countries would provide a deeper understanding of strategic decision-making. Longitudinal studies tracking the strategic developments of companies over time would yield insights into the evolution of their green strategies. Further studies on how companies can effectively manage the various risks associated with the green transition are also warranted.

In conclusion, this thesis has highlighted the importance of strategic decision-making in China's data center industry's green transition. It underscores the role of multi-dimensional and layered decision-making in corporate strategy, particularly in the context of transitioning toward sustainability. The decision-making framework serves as a valuable tool for understanding and guiding such complex strategic processes. It has broad applicability across different contexts and industries, thereby contributing to both theoretical and practical understanding of strategic decision-making in the face of environmental challenges.

Appendix A. Key Considerations for Green Energy Integration Strategies

1. Self-Production

On-site self-use is a strategy where green power is generated directly at the data center, granting operators enhanced control over energy supply and potential cost reduction. This approach could also create additional revenue by selling surplus power to the grid.

Important Factors

1) Locating suitable sites: Sites need to have ample renewable energy resources and data center demands. Factors like solar or wind resources, local climate, and proximity to major data center clients should be considered.
2) Close proximity of power producers and data centers: This reduces energy transmission losses, simplifies energy distribution infrastructure, and fosters better coordination between power generation and data center operations.
3) Tailoring strategy to data center size and type: Power requirements and operational dynamics may vary based on the data center's size and type, necessitating a customized approach.
4) Ensuring stable power supply: Employing alternative energy resources or power backup systems is crucial for uninterrupted and reliable operations. This can be achieved by incorporating energy storage systems, multiple types of renewable energy sources, and backup options like grid power or on-site generators.
5) Navigating regulatory hurdles: This involves dealing with the legal landscape related to renewable energy and data center integration, obtaining necessary permits, and staying informed about regulatory changes.

6) Assessing scalability: The potential for growth of renewable energy generation and data center operations should be evaluated. This might involve identifying opportunities for additional renewable energy capacity or partnerships with other green power providers.
7) Wise capital allocation: A robust financial plan should account for both initial and ongoing costs of renewable energy generation and data center operations, potential operational cost savings, new revenue streams, and government incentives for renewable energy projects.
8) Environmental and sustainability considerations: Despite the primary goal being reducing carbon footprint, other potential environmental impacts should also be considered, such as land use changes, habitat disruption, and resource consumption. Implementing sustainable design and construction practices can minimize negative consequences and enhance overall sustainability.

Potential Benefits

1) Cost Reduction: On-site green power generation can significantly decrease energy expenditures and offer long-term savings.
2) Investment Diversification: Investing in renewable energy and data centers diversifies assets, mitigating risk and hedging against future energy price volatility.
3) New Revenue Opportunities: On-site self-use strategies can generate additional income streams, such as charging green energy rates to clients and selling surplus energy to the grid.
4) Customization: Different data center types, like colocation or hyperscale facilities, can have strategies tailored to their specific needs.

5) Efficient Management and Synergy: Co-locating green power production and data center facilities can lead to operational efficiencies through better coordination and shared expertise.
6) Resilience and Energy Independence: On-site green power generation reduces dependence on external energy providers, and having backup systems in place ensures reliable operations.
7) Energy Efficiency: Minimized energy transmission losses due to on-site generation and close proximity of facilities increase overall energy efficiency.
8) Government Incentives: Some governments offer incentives or subsidies to promote renewable energy adoption, enhancing the project's financial viability.

Potential Drawbacks

1) High Initial Costs and Investment Risks: Significant initial investments and the risk of fluctuating energy prices or technological obsolescence can deter investors.
2) Stability of Power Supply: The variable and intermittent nature of renewable energy can pose challenges to maintaining a stable power supply.
3) Unique Challenges: Different data center types can face magnified or mitigated drawbacks.
4) Technical Expertise: Integrating green power production and data center operations requires specialized knowledge, potentially creating a barrier for some organizations.
5) Resource Limitations: Availability and suitability of renewable energy resources can constrain the full realization of potential benefits.
6) Unpredictable Power Needs: Matching fluctuating energy demand and supply can be challenging, leading to energy waste or the need for additional investments.

7) Complex Approval Processes: Navigating regulatory and permitting processes can be time-consuming and costly.
8) Scalability Challenges: Scaling up may require additional investments and regulatory compliance, along with addressing potential constraints related to renewable energy resources.

2. Power Purchase Agreements (PPAs) for Green Power

PPAs are contracts between data center providers and renewable energy generators. These allow data centers to access green energy without direct investment in renewable infrastructure. PPAs provide stable energy costs and potential arbitrage benefits. They aid in integrating green energy, reducing carbon footprint, and enhancing environmental reputation.

Important Factors

1) Choosing Reliable Providers: Selecting a renewable energy provider in China requires assessing their experience, track record, and financial stability.
2) Favorable Contract Terms: Understanding and negotiating contract terms, including pricing, duration, and penalties for non-compliance, is crucial.
3) Monitoring Green Energy Production: Clear protocols for monitoring and reporting renewable energy production ensure compliance with contract terms and sustainability goals.
4) Sufficient Energy Supply: Energy requirements must be considered to ensure the contracted supply meets data center needs.
5) Diversified Energy Procurement: Developing a diversified portfolio minimizes risks and optimizes energy procurement.

6) Managing Long-term Agreement Risks: Aligning PPA contract lengths with data center growth plans and including provisions for contract renegotiation can help manage risks.
7) Geographic Limitations and Infrastructure: Considering local grid capacity and infrastructure ensures reliable and efficient power supply.
8) Impact of China's Renewable Energy Policies: Understanding how China's renewable energy policies affect PPAs can provide insights into potential benefits and challenges.

Potential Benefits

1) Diversified Energy Sources: PPAs provide access to diverse renewable energy sources without the need for significant infrastructure investments.
2) Minimal Capital Investment: PPAs require less upfront capital, freeing operators to focus on their primary activities.
3) Predictable Expenses: PPAs offer stable, long-term, fixed-price contracts, mitigating exposure to volatile energy markets.
4) Arbitrage Opportunities: Operators can leverage the difference between contracted PPA and market prices for additional revenue.
5) Supports Industry Growth: PPAs increase demand for renewable energy, stimulating industry growth and innovation.
6) Reduced Carbon Emissions: PPAs significantly decrease carbon emissions, showcasing commitment to sustainability and improving environmental reputation.
7) Reduced Need for Specialized Expertise: PPAs eliminate the need for in-house renewable energy expertise.
8) Favorable Policies in China: Chinese policies and incentives encourage the adoption of renewable energy, making PPAs more appealing.

Potential Drawbacks

1) Third-Party Dependence: PPAs entail reliance on external energy providers, exposing operators to counterparty risks.
2) Limited Control Over Supply: Operators may have less control over their energy supply due to dependence on the provider's capabilities.
3) Location Constraints: Geographic limitations and transmission infrastructure affect the reliability and efficiency of energy supply.
4) Reduced Flexibility: Long-term PPA contracts can limit flexibility in responding to changing requirements and market conditions.
5) Complex Contract Structures: PPA contracts often require expert guidance to navigate effectively.
6) Renegotiation Challenges: Changes in market conditions may necessitate contract renegotiations. Dependence on specific providers can lead to less favorable terms or higher costs upon contract expiration.
7) Infrastructure Limitations: Despite access to renewable energy, limitations in transmission infrastructure may affect delivery and cost-effectiveness.

3. Renewable Energy Credits (RECs)

RECs offer data centers a means to offset carbon emissions and support renewable energy generation without investing in infrastructure. A REC purchase represents the financing of one megawatt-hour (MWh) of renewable energy supplied to the power grid. RECs have gained popularity globally (ENERGY STAR, n.d.), with China initiating its green certificate trading program in 2017 to boost renewable energy projects and reduce carbon emissions.

Important Factors

1) Credible REC Providers: It's crucial to work with reliable REC providers adhering to stringent standards and ensuring the additionality, i.e., the RECs contribute to new renewable energy generation. Familiarity with China's regulatory framework governing RECs and the roles of national bodies such as NDRC, NEA, and CEC is also essential.
2) Price Volatility in REC Market: Price fluctuations due to supply-demand dynamics, regulatory changes, or renewable energy tech advancements can impact the cost-effectiveness of RECs. To mitigate these risks, data centers should monitor market trends, plan long-term, and explore opportunities for hedging or locking in REC prices when possible.
3) Environmental Impact of REC Purchases: The actual impact of RECs on promoting renewable energy and reducing carbon emissions can be contentious. Therefore, data center operators should perform due diligence in assessing the projects backed by the RECs, including their timeline, location, and dependency on REC revenues to ensure alignment with sustainability goals and measurable environmental impact.

Potential Benefits

1) Sustainability commitment: REC purchases highlight data centers' commitment to environmental responsibility and aid in meeting sustainability targets and complying with environmental regulations.
2) Improved corporate image: RECs can bolster the reputations of data centers and their clients that prioritize sustainable operations.

3) Flexibility and scalability: RECs offer a scalable solution to support renewable energy projects, catering to growing energy needs without major infrastructure investments.
4) Reduced management responsibility: By purchasing RECs, data centers support renewable energy without the need to create and maintain their own infrastructure.
5) No technical expertise needed: RECs allow data centers to support renewable energy projects without needing comprehensive knowledge of renewable energy generation.

Potential Drawbacks

1) Questions about actual environmental impact: Critics argue that RECs may not lead to a direct increase in renewable energy generation or a reduction in overall carbon emissions.
2) Dependence on third-party providers: Purchasing RECs requires reliance on third-party providers, potentially increasing the risk of fraud or misrepresentation.
3) Price volatility in the REC market: The value of RECs can fluctuate, impacting the cost-effectiveness of purchasing RECs and budgeting for green energy initiatives.
4) Reduced revenue opportunities: If clients purchase RECs directly from providers, data center owners who have invested in their own renewable energy solutions or included REC costs in their offerings may face reduced revenue opportunities.

Appendix B. Investment Feasibility in China's Green Power Sector

China's green power production industry offers significant investment opportunities due to favorable government policies, technological advancements, and increasing global demand for clean energy. Investments in this sector may appear financially viable, largely due to external support, which contributes to China's sustainable development goals (Huang et al., 2021; IRENA and CPI, 2023; Relander, 2022).

From the government's perspective, investing in green power production aligns with China's strategic goals of reducing carbon emissions, decreasing reliance on fossil fuels, and transitioning to a more sustainable energy system (Relander, 2022). The Chinese government has implemented various policies and incentives to promote the growth of the green power production industry, such as feed-in tariffs[6] (FITs), tax incentives, low-interest loans, and grants (Guo & Gang, 2016; Jin-shan & Tong, 2013; J. Zhao & Zhang, 2016). The strong government support results in the sector's risk reduction, market creation, technology development, and cost reduction, which is a key driver for the rapid development of the industry and the attractiveness of investments (F. Zhao et al., 2022). In 2020, China had a total installed capacity of renewable energy sources of 934 GW, making it the largest renewable energy market in the world (Y. Li et al., 2022).

[6] A feed-in tariff is a policy mechanism that offers long-term contracts to renewable energy producers to sell their electricity to the grid at a premium price. China introduced pricing mechanisms to the onshore wind, solar PV plants, distributed solar and offshore wind sectors in 2009, 2011, 2013, and 2014, respectively (Song et al., 2023).

From the investor perspective, green power production in China presents a lucrative opportunity. The Chinese government's commitment to renewable energy development, demonstrated by its ambitious targets and supportive policies, has signaled to investors that the renewable energy sector is a priority. This has increased investor confidence in the industry's long-term growth and encouraged both domestic and foreign investments. According to Bloomberg New Energy Finance, China attracted $83.4 billion in clean energy investments in 2020, accounting for 28% of the global total (Pingkuo & Chu, 2018).

However, it is essential to closely examine whether the green power production industry's attractiveness relies too heavily on policy support or other factors, such as market demand (Su, 2023). For example, solar power generation in China grew from 0.3 GW in 2010 to over 250 GW in 2020, largely driven by FITs (J. Zhao & Zhang, 2016). However, in recent years, the government has started to gradually phase out subsidies, which could lead to uncertainty and potentially reduced profitability for investors (Jin & Ruan, 2020b; Zhu & Ye, 2018).

The demand for green power is expected to continue growing in China as the country aims to achieve carbon neutrality by 2060 (Y. Li et al., 2022). However, the pace of growth and the eventual market demand could be affected by factors such as the global economic situation, technological advancements, and changing government policies. These uncertainties could impact the long-term profitability of investments in the green power production industry.

In conclusion, while investing in China's green power production industry currently seems viable due to strong government support and investor confidence, it is crucial to examine factors that impact growth potential. Without policy benefits, the profitability of the investment may be uncertain. Investors should carefully consider these factors and conduct thorough research to identify profitable opportunities and manage risks effectively.

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