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Original Article

Asset Energisation in China's Large Construction Firms: Advancing Renewable Energy Integration and Low-Carbon Development

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Abstract:
This study examines the application of sustainable asset management in China's large construction firms, focusing on the integration of renewable energy and its role in driving industrial sustainability. As the construction sector faces challenges related to energy consumption, carbon emissions, and the transition to sustainable practices, this study investigates how effective asset management practices can facilitate the adoption of green technologies and help construction firms achieve low-carbon economic goals. Through a SWOT analysis, this study identifies key strengths, weaknesses, opportunities, and threats in the process of asset energization within large construction enterprises. The findings reveal that, while these firms possess strong infrastructure resources and financial support, they face challenges in adopting emerging energy technologies. Opportunities are presented through policy support and the declining costs of renewable energy technologies, although external threats such as market volatility and financial constraints persist. Finally, this study offers strategic recommendations to help construction firms enhance their asset management through the integration of renewable energy, fostering innovation and development in the green-building sector.
Key words: Construction, Management, Asset, SWOT analysis, Energy, Sustainable

1. Introduction

1.1 Background and Global Relevance

In 2022, carbon-dioxide emissions from building operations and construction accounted for 37 percent of global energy- and process-related emissions—roughly 10 gigatonnes of CO_2 (International Energy Agency, 2023a). Building activities also consume approximately one-third of the global final energy, mainly electricity and direct fossil fuels for space conditioning and on-site processes (IEA, 2023b), placing the sector at the heart of the climate–energy nexus. Unlike power generation or transport, however, the building stock turns over slowly; more than two-thirds of the floor area that will still be in service in 2040 already exists today (GlobalABC/UNEP, 2023). Therefore, each year of delay locks in high carbon performance for decades.

To confront this challenge, the UN Agenda 2030 and Sustainable Development Goal 13 highlight buildings as a priority mitigation domain (Soergel et al., 2021), while the Paris Agreement calls for the sector to achieve nearly zero operational emissions by the mid-century (IPCC, 2022). Governments respond accordingly. For example, the European Union’s recast Energy Performance of Buildings Directive sets minimum energy performance standards for the poorest-performing stock (Dulian, 2024), and jurisdictions such as Australia, Canada, and Japan have announced net-zero building codes scheduled to enter into force between 2025 and 2030 (Rodrigo and Jayathilaka, 2025; Leandro, 2024). These regulations are buttressed by financial institutions tying lending terms to verifiable emission trajectories, and by corporate tenants demanding certified low-carbon workplaces (Gupta & Deb, 2023).

China—the world's largest construction market—is at the center of this transition. The total annual emissions reaching 2.27 billion tonnes, accounting for 45.5% of the country's total energy consumption (Yang et al., 2024). The World Bank forecasts that energy efficiency and emission reduction targets will be met by 2030, with 70% of this potential coming from improvements in the building energy efficiency (Akram et al., 2022). This indicates that energy savings and emission reductions in buildings will be a key focus of the future construction industry and have attracted significant attention from countries and regions worldwide. Meeting the "dual-carbon" goals—peaking emissions before 2030 and achieving carbon neutrality by 2060—will depend heavily on how Chinese construction firms manage both new and existing assets (Yang et al., 2024).

At the same time, rising fuel prices, supply chain disruptions, and heightened investor scrutiny have exposed the vulnerability of carbon-intensive portfolios; however, they also highlight the financial upside of early low-carbon upgrades (Zhu et al., 2021; Mubarak et al., 2021; Li et al., 2023).

Turning this opportunity into reality requires strategies that move beyond flagship demonstration projects and address whole-portfolio decarbonization. Nevertheless, existing research has largely focused on new builds and has paid far less attention to reorienting extant asset portfolios towards low-carbon value creation.

Against this global backdrop, it is imperative to reconceptualize how infrastructure assets contribute to sustainable development. The following section introduces the conceptual foundations underpinning asset energization (AE), framing it as a strategic and integrative response to the complex challenges facing the construction sector.

1.2 Conceptual Foundations

Traditionally, the noun asset designates any physical infrastructure—buildings, plants, or equipment—that embodies economic value for its owner. The verb to energize, in contrast, stems from power-sector practice and denotes the act of applying voltage to equipment, so it can operate safely. In engineering manuals, energization marks the commissioning milestone when a substation, transmission line, or solar farm is first brought online (National Grid Electricity Transmission plc, 2015). The term has since been used metaphorically in sustainable finance debates to describe reviving potentially stranded fossil-fuel assets by converting them to low-carbon applications (Caldecott et al., 2015). While these readings differ in scope, they share a project-level focus: both are concerned with making a single piece of infrastructure technically or financially viable.

This study reuses the expression as asset energization (AE) and widens its scope to the portfolio scale of large construction firms. This study defines AE as the strategic integration of distributed renewable-energy systems, on-site storage, and digital optimization into legacy physical assets to extend their utility, cut emissions, and unlock new revenue streams. In other words, the concept shifts from "switching on" an individual asset to "switching over" an entire asset base to a low-carbon operating model driven by renewable energy integration (REI).

The three design principles differentiate AE from conventional physical asset management. First, renewable energy is framed not as a compliance cost but as an energizing vector capable of generating surplus power sales, flexible services, and higher resale values (Lund et al., 2015). Second, technological retrofits—rooftop photovoltaics, solar-thermal collectors, ground-source heat pumps and battery banks—are coupled with real-time analytics for portfolio-wide optimization. Third, these operational levers are embedded in capital-budgeting and risk-management processes so that decarbonization targets align with shareholder value (Caldecott et al., 2013).

By adopting AE, this study positions renewable-energy integration as the primary operational lever for decarbonizing large Chinese construction-firm portfolios and avoiding the risk of stranded assets. The next section reviews the existing literature to situate AE within broader debates on physical asset management, REI, and corporate decarbonization.

Having outlined the conceptual lens through which asset energization is approached in this study, it is essential to position this perspective within the existing academic discourse. The following literature review critically examines how AE-related themes have been explored, highlighting both established insights and underdeveloped areas.

1.3 Literature Review

1.3.1 Physical Asset Management

Increased competition, deregulation, external pressures, and technological advancements have prompted companies to monetize their investments and develop new strategies to ensure their long-term survival (Gavrikova et al., 2020). In this context, the management of physical assets has become increasingly significant in scientific research as companies aim to identify new competitive factors that can render their investments profitable (Syed, 2020).

Physical assets, also referred to as engineering assets, play a crucial role in generating tangible value for organizations, particularly in sectors such as transport services, electricity supply, water supply, construction, and mining (Almeida et al., 2022). Additionally, there is a strong link between physical asset management (PAM) practices and companies' sustainability performance. For instance, a study (Maletič, 2022) using data from various organizations across six European countries—Greece, Poland, Slovakia, Slovenia, Sweden, and Turkey—demonstrated that PAM practices have a positive impact on sustainability performance outcomes, including economic, environmental, and employee-related social performance. Similarly, a systematic review (Sandu, 2022), drawing on statistics and data from over 2,800 journal articles, highlighted the role of physical asset management as a key resource in achieving competitive advantage within the framework of sustainable development.

The effective management of available resources enables companies to gain a competitive edge over their rivals (Gavrikova, 2020; Varadarajan, 2023; Mahdi and Nassar, 2021). Companies can secure substantial advantages by prioritizing the development of their resources through the management of physical assets, particularly by determining the economic lifespan of their equipment.

However, data gaps within current asset management practices have hindered the advancement of more sophisticated asset management approaches. Many asset managers still adhere to traditional methods of data collection, where decision-making is based solely on scheduled visual inspections and basic performance assessments (Tervo, 2021). Shifting from this approach towards a more strategic decision-making system will significantly enhance asset management outcomes by providing better quality information to those making strategic decisions.

1.3.2 Renewable energy Investment with Sustainable

Renewable energy power generation is a cornerstone of the low-carbon transition for power systems (Nguyen et al., 2024). Wind and photovoltaic power generation have become the most prominent renewable energy technologies in recent years, with installation costs consistently decreasing as technology advances (Osman et al., 2023). However, because both wind and photovoltaic power generation are heavily dependent on weather conditions, inherent characteristics such as uncertainty and variability make their integration into the power system costly (Hu et al., 2024). For instance, the need for rapid peak regulation units, such as gas-fired power plants and costly energy storage systems, further adds to this expense. The rapid expansion of the installed capacity for wind and photovoltaic power is likely to significantly increase the overall cost of the power system and may even lead to higher levels of wind and photovoltaic power curtailment (Frew et al., 2021).

China's installed renewable energy capacity is growing rapidly, driven by a combination of factors, such as energy security, carbon emission reduction, environmental protection, and global trade (Yao et al., 2025). At the end of 2020, China's installed capacity for wind and photovoltaic power generation ranked first in the world, reaching 281 million kilowatt and 253 million kilowatt, respectively (Yao et al, 2022). The Chinese government has implemented a range of incentive policies for renewables, including construction subsidies, price subsidies, priority grid connections, and emission trading schemes (Hayat et al., 2025). The challenge facing China, as well as other countries committed to a low-carbon energy transition, is the effective integration of large-scale renewable energy generation into existing power systems.

Energy infrastructure investments are crucial for driving economic growth, fostering the development of new businesses, and ultimately, increasing the availability of energy resources at reasonable prices (Mahmood et al., 2024). These investments can be directed towards cleaner energy sources and low-carbon technologies, helping to address energy security challenges and facilitate carbon emission reductions. Long-term energy security in developing countries largely depends on energy-related investments that meet the demands of economic development while aligning with sustainable environmental goals (Elkhatat and Al-Muhtaseb, 2024). Three of the 17 Sustainable Development Goals (SDGs) are directly linked to infrastructure enhancement, which is also a key component of the 2030 agenda. In fact, improvement in both the quality and quantity of infrastructure capital is considered a vital factor of production, and infrastructure has become a central element in sustainable development policies (Du et al., 2022).

It is important to note that the accessibility, quality, and quantity of economic infrastructure in low-income and emerging economies (such as those in Asia) significantly lag behind those in advanced market economies (Wu and Pan, 2021). This gap has a profound impact on sectors, such as energy generation and power supply, particularly in terms of accessibility, purchasing power, and income. Pankratz et al. (2023) note that temperature and climate change have a direct effect on firm performance.

Kang and Sohn (2024) developed a threshold effect model to examine the relationship between renewable energy investment and green development index across 150 renewable energy companies in China. The study found that renewable energy investment has a dual impact on the development of the green economy. Additionally, the influence of renewable energy investment on green energy investment exhibited a single threshold for large companies, whereas medium and small companies experienced a dual-threshold effect, particularly in relation to green credit.

This study addresses the growing need for sustainable transformation in the construction industry by exploring how the integration of the energy sector and information technology can enhance asset management practices and contribute to the achievement of Sustainable Development Goals (SDGs). To this end, the study applies a SWOT analytical framework to examine the asset energization process in large construction firms—an area that remains underexplored.

The primary contributions of this research are threefold:

1) It investigates how digital energy integration supports sustainable asset management in alignment with global climate targets.
2) It introduces SWOT analysis as a strategic tool to evaluate asset energization in the construction sector.
3) It focuses on identifying the key strengths and opportunities that can inform decision-making for low-carbon development. In doing so, this study provides both theoretical insights and practical guidance for promoting energy transitions within the built environment.

1.4 Research Gaps and Objectives

Renewable-energy-driven asset integration offers a cross-cutting solution that supports each mitigation pathway outlined above. Empirical studies have proliferated around large-scale renewable power projects and building-integrated photovoltaic (BIPV) systems (Shono et al., 2023; Singh et al., 2022); However, these findings shed little light on how the same approach could unlock value from the legacy asset portfolios of large construction firms or reshape corporate asset management practices. In fact, the emerging scholarship on asset energization (AE) is still scattered and displays three distinct gaps:

1) Conceptual integration: Existing studies seldom weave together AE's three design principles of AE —value creation, techno-digital enablement, and governance/ finance—into a single analytical framework.
2) Knowledge mapping: No bibliometric synthesis yet traces how these three themes have co-evolved within the literature, leaving the intellectual landscape opaque.
3) Context-specific evidence – Empirical evaluations of AE are scarce at the portfolio scale of large Chinese construction firms, particularly regarding the strengths, weaknesses, opportunities, and threats that shape strategic decision making.

Given the above, this article will attempt to answer three questions:

1) How can the integration of the energy sector and information technology promote sustainable asset management practices in the construction industry and contribute to achieving Sustainable Development Goals (SDGs)?
2) What strategic pathways enable large construction firms to integrate distributed renewable energy and digital optimization across their asset portfolios, and how do these pathways reflect AE's three design principles of value creation: techno-digital enablement and governance?
3) Within a SWOT framework, the strengths, weaknesses, opportunities, and threats characterize AE in Chinese construction conglomerates, and how can these insights guide portfolio-level strategies and policy design?

The following chapter details the methodological approach adopted in this study to address the identified research gaps and pursue the outlined objectives. It combines bibliometric techniques with a structured SWOT–AHP framework to explore the strategic potential and positioning of asset energization within Chinese construction conglomerates.

2. Methodology

2.1 Methodological Framing: Linking Asset Management and SWOT

2.1.1 Asset Management

Various models exist to describe the asset management process, and asset managers are encouraged to assess which approach works best based on the nature and context of their assets (Campbell et al., 2024). The UN Handbook on Managing Infrastructure Assets (2021) provides a framework for asset management, highlighting the key elements required to establish an effective asset management system (Figure 1). To successfully implement asset management, asset managers should define service levels, performance metrics, and targets. Furthermore, data should be collected to identify potential issues and decisions must be made to adapt solutions in line with the changing risk profiles of the network. Additionally, asset managers are responsible for ensuring that strategic objectives are met and that the network is maintained in a manner that effectively meets the needs of all end users (United Nations, 2021).

Figure 1 Asset Management Framework

(From Managing Infrastructure Assets for Sustainable Development, by United Nations)

The International Infrastructure Management Manual (IIMM) has developed a globally recognized asset management process that integrates levels of service, performance measures, data collection, decision-making, and implementation (IIMM, 2002). The manual outlines two tiers of asset management: core and advanced. The primary objective of core asset management is to gain a comprehensive understanding of an asset and its needs. In contrast, advanced asset management focuses on understanding the relationship between performance, funding requirements, and risks associated with failing to meet service-level agreements (Aguilera et al., 2024).

2.1.2 SWOT Approach

The previous section highlighted several themes that helped frame SWOT analysis within the context of this study. These themes focused on various areas that can be examined using the SWOT framework. SWOT analysis not only helps identify key factors influencing the adoption of the research, but also provides actionable strategies for leveraging its strengths and opportunities while mitigating its weaknesses and risks. The "S" (Strengths) and "W" (Weaknesses) factors pertain to internal elements within the company or organisation that can impact its performance, while the "O" (Opportunities) and "T" (Threats) factors are external elements that could influence its performance (Galpin, 2023).

Understanding both the internal and external factors affecting renewable energy-driven sustainability, sustainability, and AI in China's Large Construction Firms, sustainable asset management is essential for developing strategies that foster responsible practices and meaningfully contribute to the broader goals of sustainable development.

Despite increasing policy support and rapid technological advancements promoting green transformation, large construction enterprises in China continue to encounter substantial barriers to the practical implementation of sustainable asset management. These challenges are not limited to technological or financial constraints but also involve organizational inertia, limited integration between energy and information systems, and gaps in strategic planning. Furthermore, the adoption of renewable energy within corporate asset structures remains fragmented, with few firms being able to systematically align energy transition goals with asset management strategies.

To better understand these dynamics, this study applies a SWOT analysis to assess the asset energization process in large construction firms. This structured approach enables the identification of internal strengths and weaknesses, as well as external opportunities and threats, thereby offering a strategic lens through which to guide decision-making and support the transition towards low-carbon, sustainable operations. However, SWOT constitutes only one element of the broader methodological framework. The following section provides an integrated overview of the combined methods employed, namely bibliometric mapping and AHP-based prioritization, and explains how these were sequenced to address the research objectives.

2.2 Methodological Framework Overview

This study adopts a mixed-methods approach combining bibliometric analysis and a structured SWOT–AHP evaluation to identify strategic pathways for asset energization (AE) in Chinese construction conglomerates. This research unfolds into three phases:

1) bibliometric mapping of relevant literature;
2) systematic extraction and classification of SWOT factors; and
3) quantitative prioritisation using the Analytic Hierarchy Process (AHP).

The overall methodological workflow is depicted in Figure 2.

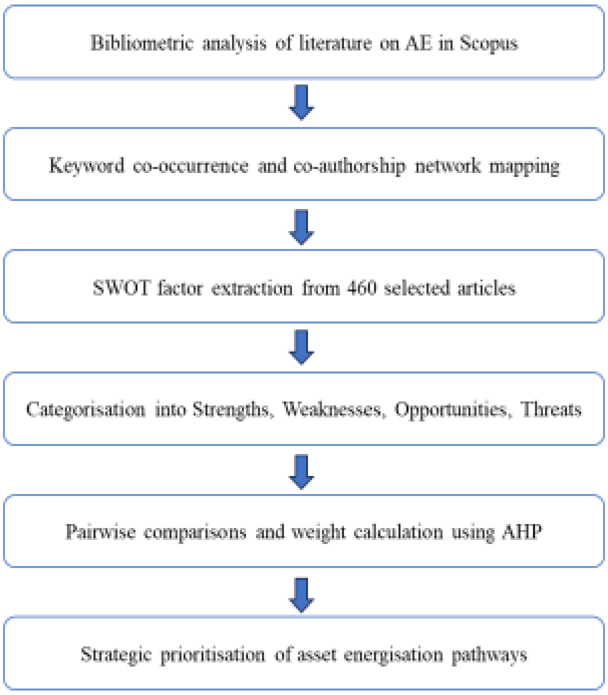

Figure 2 illustrates this workflow.

2.2.1 Bibliometric Techniques and Data Source

The Scopus database was selected for data collection for several reasons. Scopus encompasses approximately 20,000 peer-reviewed journals published by renowned publishers such as Elsevier, Informs, Inderscience, Taylor and Francis, Springer, and Emerald. Given the challenges of synchronizing bibliographic data from multiple databases, which could limit the effectiveness of a bibliometric review, this study relied on Scopus data for collection (Masic, 2023). Scopus is a crucial resource for evaluating research outcomes because of its consistent structure and extensive coverage. It is also worth noting that the use of a single database, as seen in previous bibliometric analyses, is a standard and widely accepted practice in academic literature.

In bibliometric analysis, various types of analyses can be performed, each focusing on different units such as words, authors, citations, documents, sources, organizations, or countries. These analyses may include co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation. While several software tools are available for bibliometric analysis, opted to use VOSviewer is preferred because of its user-friendly interface, free accessibility, and ability to generate a wide range of analytical outputs (Cherian, 2024).

To achieve the objective of exploring the themes in the reviewed studies, this study performed a co-occurrence analysis to identify thematic clusters and conceptual linkages between keywords, and co-authorship analysis to examine collaboration patterns among institutions and researchers.

To gather relevant sources, this study conducted a search in the Scopus Database using the following keywords: new energy investment, new energy construction, sustainable energy construction, sustainable energy investment, new energy, sustainable energy, enterprise asset management, enterprise asset, enterprise management, and asset reutilization.

A total of 1101 records were initially retrieved from the Scopus database in RefWorks-compatible. txt format. These were imported into NoteExpress 3.6.0 for deduplication and metadata screening. Items with missing author names, institutional affiliations, publication year, or keywords were excluded, along with non-peer-reviewed records such as news reports, editorials, and conference announcements. After the initial filtering, 460 records remained. A further round of relevance screening, focused on thematic alignment with asset management, sustainable energy, and digital optimization in construction, yielded 400 articles for the final analysis, as shown in Figure 3.

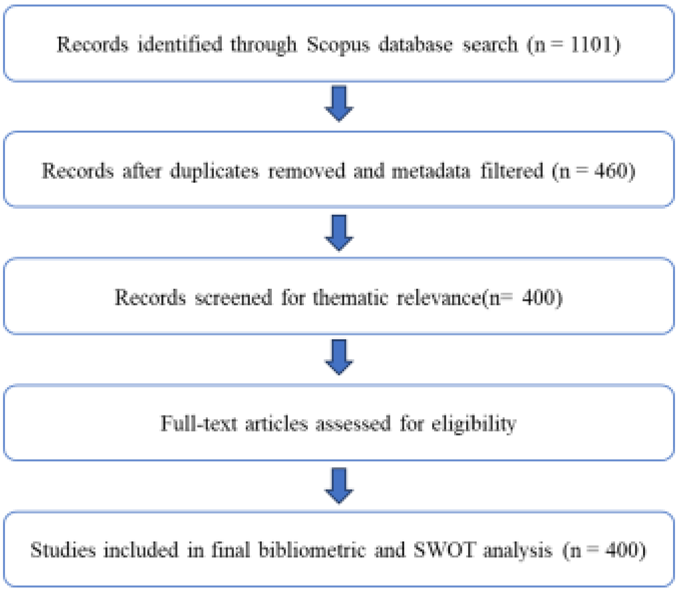

Figure 3 Literature screening process

2.2.2 SWOT Factor Extraction and Cleaning

The SWOT factors were identified through qualitative content analysis of 400 peer-reviewed articles published between 2014 and 2024, filtered using keywords such as “renewable retrofit,” “digital optimisation,” “construction portfolio,” and “low-carbon strategy.” Duplicates and semantically similar expressions (e.g., “energy savings” and “operational efficiency” operational efficiency’) were consolidated into unified factors. The factors were grouped into strengths, weaknesses, opportunities, and threats based on their functional implications.

2.2.3 AHP Weight Assignment without Expert Panels

Due to the national scale of the analysis and the lack of access to confidential enterprise data or expert interviews, AHP weightings were derived from literature-informed estimations. A judgment matrix was constructed using pairwise comparisons informed by the factor frequency, strategic relevance, and inter-factor consistency across the sampled publications. The matrix was then normalized and the geometric mean method was applied to calculate the relative weights. This semi-quantitative approach preserves analytic rigour in the absence of direct expert input.

Due to the national scale of the analysis and the lack of access to confidential enterprise data or expert interviews, AHP weightings were derived from literature-informed estimations. A judgment matrix was constructed using pairwise comparisons informed by the factor frequency, strategic relevance, and inter-factor consistency across the sampled publications. This enables the semi-quantitative prioritization of SWOT factors without requiring direct expert surveys.

With the established methodology, combining bibliometric mapping and a modified SWOT–AHP framework without relying on expert panels, the study proceeds to present the results. The following chapter outlines the empirical findings derived from both literature network analysis and factor prioritization, offering insights into the thematic structure and strategic potential of asset energization.

3. Results

3.1 Bibliometric Findings

Building on the VOSviewer-based co-occurrence analysis detailed in the methodology section, the bibliometric mapping of 400 selected articles revealed three dominant thematic clusters: (1) sustainable energy and decarbonization, (2) digital transformation and optimization, and (3) governance mechanisms and policy alignment. These clusters were derived from the co-occurrence of author keywords and are visualized in Figure 4, Table 1 and Table 2.

The first cluster, centered on terms such as "renewable energy," "low-carbon," and "green transition," illustrates the sector's commitment to sustainability targets and reflects an increasing academic focus on the role of construction firms in carbon mitigation. The second cluster, featuring keywords like "digital twin," "BIM," and "smart construction," points to the digitalization of asset life-cycle management, highlighting innovations in monitoring, simulation, and predictive maintenance. The third cluster brings together terms such as "policy", "governance", and "investment risk", underscoring concerns regarding institutional coordination and strategic finance.

Together, these clusters confirm that academic discourse around Asset Energisation is coalescing around AE's three design principles: value creation through sustainability (Cluster 1), techno-digital enablement (Cluster 2), and governance integration (Cluster 3). The co-evolution of these themes suggests a maturing field that integrates energy, information, and institutional dynamics into the asset strategies of construction conglomerates.

In addition to the three dominant themes, a fourth cluster emerged that focused on asset reutilization, life-cycle optimization, and energy efficiency. While not central to the AE framework as initially conceptualized, this cluster represents an emergent theme in academic discourse, suggesting a growing interest in operational optimization and circularity in asset management practices.

These findings provide a conceptual bridge for subsequent SWOT analysis that translates these clusters into actionable strategic factors.

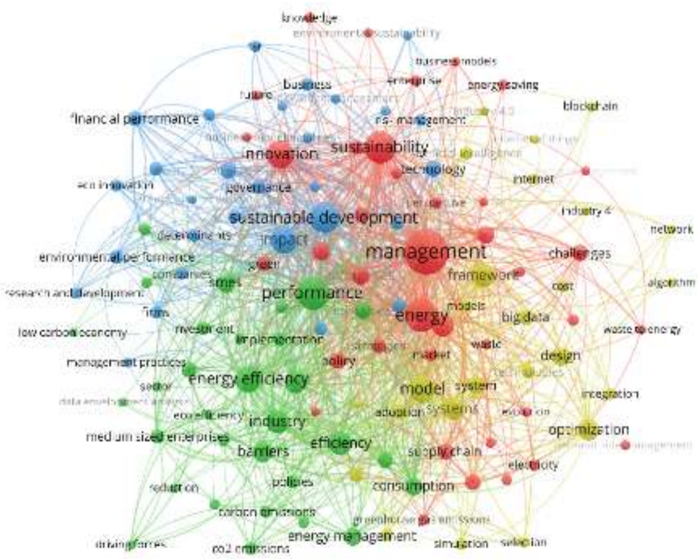

Figure 4 the keywords and the relationships between them under that particular theme

Table 1 Keywords Cluster

Cluster 1	Energy Management and Sustainability Innovation
keywords:	management, energy, sustainability, innovation, renewable energy
main focus:	Exploring the Role of Energy Efficiency, Renewable Energy, and Supply Chain Management in Advancing Corporate Sustainability.
Description:	This cluster focuses on how energy management, the utilisation of renewable energy, and supply chain management influence corporate sustainability. It highlights the importance of innovation in enhancing energy efficiency and driving the circular economy, while also addressing the impact of policies and market behaviour on these areas.
Cluster 2	Efficiency and Performance Optimisation
keywords:	performance, energy efficiency, industry, efficiency, china
main focus:	Analyse how different industries enhance overall performance by improving energy efficiency and optimising decision-making processes.
Description:	This cluster explores energy efficiency, industry performance, and how optimising decision-making and management processes can enhance corporate efficiency. It specifically focuses on practices in China within these areas, as well as the challenges and opportunities faced by small and medium-sized enterprises (SMEs) in achieving these objectives.
Cluster 3	Sustainable Development and Technological Impact
keywords:	sustainable development, impact, technology, corporate social responsibility, financial performance
main focus:	Examine how technological advancements influence corporate sustainability and social responsibility.
Description:	This cluster focuses on how technology, particularly information technology and green innovation, assists businesses in achieving sustainability goals. It explores aspects such as corporate social responsibility, environmental management, and quality control, and how these factors are linked to a company's financial performance and competitiveness.
Cluster 4	System Optimisation and Innovation Models
keywords:	model, framework, systems, optimization, design
main focus:	"Explore how system performance can be optimised through models and frameworks, and the role innovation plays in this process.
Description:	This cluster focuses on the development and application of various models and frameworks to optimise system performance, including energy systems, production systems, and supply chain systems. It highlights the importance of design, optimisation, and simulation in enhancing system efficiency and sustainability, while also exploring the role of big data and artificial intelligence in these areas.

Table 2 the keywords identified in the reviewed studies

Cluster 1			Cluster 2		
Kw	Occ	Tls	Kw	Occ	Tls
Management	228	982	Performance	124	602
Energy	129	452	Energy Efficiency	81	379
Sustainability	116	560	Industry	65	300
Innovation	86	388	Efficiency	62	260
Renewable Energy	56	244	China	59	249
Supply Chain Management	39	176	Barriers	50	269
Circular Economy	37	187	Consumption	37	173

Enterprises	37	207	Energy Management	37	145
Challenges	32	151	Emissions	35	164
Policy	31	151	Decision Making	28	160
Life Cycle Assessment	29	145	Drivers	28	163
Green	26	169	Medium Sized Enterprises	24	142
Climate Change	24	103	Implementation	22	121
Strategies	24	109	Investment	21	100
Behavior	19	84	Co2 Emissions	20	87
Market	17	60	Policies	20	81
Electricity	16	67	Carbon Emissions	18	99
Economy	15	68	Productivity	18	78
Renewable Energy Sources	15	60	Resources	17	59
Energy Saving	14	34	Cleaner Production	15	67
Power	13	68	Economic Growth	14	75
Demand Side Management	12	23	Reduction	12	67
Business Model	11	37	Driving Forces	11	69
Environmental Sustainability	11	38	Eco Efficiency	11	56
Business Models	10	52	Low Carbon Economy	11	19
Cluster 3			Cluster 4		
Kw	Occ	Tls	Kw	Occ	Tls
Sustainable Development	108	430	Model	81	301
Impact	85	416	Framework	62	337
Technology	32	139	Systems	57	271
Corporate Social Responsibility	29	154	Optimization	51	189
Financial Performance	27	143	Design	41	181
Environmental Performance	24	105	System	36	140
Governance	23	118	Big Data	28	104
Quality	23	97	Energy Consumption	26	120
Strategy	22	87	Adoption	24	135
Green Innovation	21	102	Technologies	21	96
Business	20	109	Artificial Intelligence	20	90
Environmental Management	20	112	Indicators	19	88
Determinants	19	102	Simulation	17	73
Firms	19	91	Cost	15	57
Information	19	85	Integration	14	70
Companies	18	92	Internet	14	68
Eco Innovation	17	89	Models	14	50
Risk Management	17	56	Selection	13	67
Research And Development	16	79	Blockchain	12	43
Capabilities	14	65	Industrial Transition	11	71
Competitive Advantage	14	59	Network	11	39
Energy Sector	12	52	Algorithm	10	42
Management Practices	12	65	Industry	10	62
Digital Transformation	10	43	Internet Of Things	10	31
Technological Innovation	10	60	Sustainable Manufacturing	10	40
Keywords: KW; Occurnces: Occ; Total Link Strength: TLS.					

3.2 SWOT analysis of China's Large Construction Firms

This analysis examined the strengths, weaknesses, opportunities, and threats (SWOT) of China's large construction firms, as shown in Figure 5. This provides an in-depth understanding of their competitive position within the industry, highlighting the key factors that influence their performance and future growth prospects.

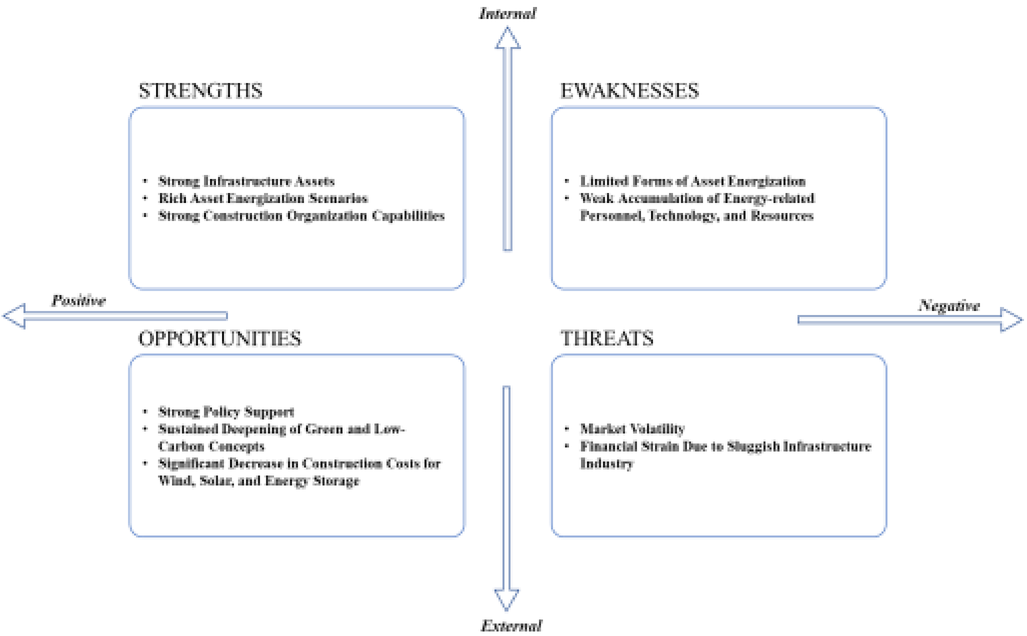

Figure 5 SWOT analysis of China's Large Construction Firms

To reinforce the theoretical chain of reasoning, the four keyword clusters (C1–C4) identified earlier are explicitly linked to the SWOT factors and subsequent recommendations, as shown in Table 3.

Table 3 Mapping between keyword clusters SWOT factors and strategy

Keyword cluster	Representative keywords	Mapped SWOT factor(s)
C1 Green energy & decarbonisation	renewable energy, carbon neutrality	Opportunity O1 (policy incentives)
C2 Digitalisation & efficiency	BIM, digital twin, IoT	Strength S2 (data-driven capability) Weakness W1 (system fragmentation)
C3 Governance & policy support	governance, regulation, ESG	Opportunity O3 (regulatory dividend) Threat T2 (policy uncertainty)
C4 Systems optimisation & circularity	system modelling, circular economy	Strength S3 (life-cycle perspective) Opportunity O4 (circular construction market)

3.3 SWOT Summary of China's Large Construction Firms

The SWOT analysis distilled from the reviewed literature and bibliometric clusters reveals four key strategic dimensions relevant to asset energization (AE) in Chinese construction conglomerates. Rather than treating AE as a technical intervention alone, the analysis highlights the organizational, institutional, and strategic contexts that either enable or constrain its broader deployment.

3.3.1 Strengths

Strengths include advanced internal capabilities in digital construction, prior experience with renewable energy integration, and growing organizational awareness of sustainability imperatives. Some leading firms have already piloted smart infrastructure and green-building projects, demonstrating proof-of-concept for AE-aligned practices. These factors indicate an emerging foundation for AE-oriented transformation and suggest readiness to scale with appropriate enabling conditions.

3.3.2 Weaknesses

Weaknesses revolve around internal fragmentation, inconsistent application of asset-management systems, and lack of standardized metrics for evaluating energy performance. Many firms still operate under siloed project management models, with limited visibility over portfolio-level sustainability performance. These institutional and operational gaps limit the scalability and replicability of the AE solutions across projects and regions.

3.3.3 Opportunities

Opportunities are driven by strong policy incentives, alignment with global carbon neutrality agendas, and rapid technological innovations in the energy and construction sectors. National policy frameworks such as the "Dual Carbon" targets, alongside provincial pilot zones, offer a regulatory tailwind for low-carbon innovation. Coupled with the advances in digital monitoring, predictive analytics, and clean energy technologies, these conditions create a conducive environment for scaling AE strategies across portfolios.

3.3.4 Threats

Threats include regulatory uncertainty, high capital costs for energy retrofits, and the risks associated with cross-sectoral integration. Policy fragmentation among energy, urban development, and construction governance bodies can lead to contradictory standards or implementation gaps. Moreover, many AE-related investments are long-term and capital intensive, exposing firms to financial and operational risks in the absence of stable incentives or cross-sector alignment. These challenges underscore the need for robust governance frameworks, adaptive investment planning, and cross-sector dialogue.

A full list of the SWOT sub-factors, explanations, and supporting references can be found in Appendix 1.

The identification and prioritization of strengths, weaknesses, opportunities, and threats provide a comprehensive view of the strategic environment surrounding asset energization. Building on these insights, the following chapter interprets the findings from a theoretical and practical perspective, highlighting their implications for construction conglomerates navigating the transition towards low-carbon development.

4. Discussion

4.1 Strategic Layout Based on SWOT Analysis Results

the S-O, W-O, S-T, and W-T strategies are derived from the SWOT analysis framework (Strengths, Weaknesses, Opportunities, Threats). These strategies result from a comprehensive analysis of both the internal and external environments of an organization, and are used to guide how businesses can formulate strategies based on their current strengths, weaknesses, opportunities, and threats. Specifically, these four strategies arise from a cross-analysis of the relationships between the four elements of SWOT, resulting in distinct strategic options. Below is a detailed explanation of how each of the four strategies was developed.

Table 4 The S-O, W-O, S-T, and W-T strategies

S-O Strategy	**W-O Strategy**
Combining Internal Strengths with External Opportunities for Growth and Expansion	Addressing Internal Weaknesses While Seizing External Opportunities
S-T Strategy	**W-T Strategy**
Using Internal Strengths to Mitigate External Threats	Defending Against External Threats While Addressing Internal Weaknesses

4.1.1 S-O Strategy: Growth Strategy, Rapid Development

To achieve robust and sustainable growth, a company must strategically leverage its existing brand advantage and financial strength to capture emerging market opportunities. Building on its strong brand identity, the company can gain a competitive edge in new sectors, particularly in the rapidly growing clean energy industry. With increasing global focus on sustainability and the shift towards renewable energy sources, this sector presents a unique opportunity for growth (Al-Shetwi, 2022). Therefore, companies should actively expand their footprint in the clean energy market and participate in national energy transition projects that align with both regional and global sustainability objectives. By doing so, the company will not only contribute to the global transition towards green energy, but also strengthen its market position in a sector that is expected to experience exponential growth over the coming decades.

Furthermore, the company can capitalize on the "Belt and Road" Initiative (BRI) to expand its operations in overseas energy markets. The BRI, which promotes infrastructure development and investment across Asia, Africa, and Europe, offers significant potential for cross-border partnerships and market penetration (Kovalova and Gogolova, 2023). By increasing efforts to explore and establish a presence in emerging international markets, particularly those with underdeveloped or rapidly evolving energy sectors, companies can enhance their competitiveness. This expansion will not only diversify revenue streams, but also position the company as a key player in the global energy transition, increasing its visibility and influence in the international arena.

A critical component of this growth strategy is investment in technological innovation. The company should prioritize the development and application of advanced technologies, particularly in relation to asset energy projects. The incorporation of cutting-edge technologies, such as artificial intelligence (AI), Internet of Things (IoT), and renewable energy solutions, can significantly enhance the efficiency and scalability of energy assets (Rane, 2023). By applying these technologies, a company can improve project efficiency, reduce operational costs, and enhance overall quality, all of which are essential factors for maintaining a competitive edge in a rapidly evolving industry. In doing so, the company will not only accelerate its development but also establish itself as a leader in innovative, high-quality energy solutions that contribute to sustainable development and energy resilience.

4.1.2 WO Strategy: Turnaround Strategy, Play to Strengths and Address Weaknesses

The turnaround strategy in the WO framework is specifically designed to address a company's internal weaknesses while capitalizing on its existing strengths. This strategic approach is particularly relevant when a company faces challenges that hinder growth or operational efficiency, and focuses on transforming these challenges into opportunities for improvement.

A crucial element of turnaround strategy involves strengthening talent development and recruitment (Aithal, 2024). In the fast-evolving energy sector, a skilled and knowledgeable workforce is a key competitive advantage. The company must invest in developing its talent pool by providing training and professional development opportunities for its employees. This could include fostering expertise in emerging energy technologies, sustainability practices, and energy-transition strategies. Moreover, the proactive recruitment of highly skilled professionals in areas such as engineering, project management, and regulatory affairs can fill gaps in the company's capabilities, enabling it to tackle more complex projects and improve operational efficiency. A highly skilled workforce will not only enhance the company's professional capabilities, but also create a culture of innovation and continuous improvement, driving the company towards its long-term strategic goals.

Another vital component of this strategy is the collaboration with traditional energy enterprises. Partnering with established players in the energy sector can help bridge operational gaps and provide access to proven management practices. By learning from the operational expertise of more established companies, a company can enhance its own management capabilities, streamline its operations, and adopt best practices in areas such as project execution, risk management, and supply chain management. Such collaboration can also open doors to joint ventures, knowledge-sharing initiatives, and access to new markets or technologies, further enhancing a company's competitive advantage.

Furthermore, in today's dynamic energy landscape, companies must remain vigilant about policy changes (Falcone, 2023). Government policies, regulations, and incentives in the energy sector are continuously evolving, and failure to adapt to these changes can result in missed opportunities or increased risk. Therefore, the company should establish a dedicated team or function to monitor and analyze policy developments at the national and international levels. By staying informed about new regulations, subsidies, or carbon-related policies, a company can adjust its business strategies accordingly, ensuring that it remains compliant and capitalizes on any favorable policy changes. This proactive approach minimizes the risks posed by sudden policy shifts and ensures that the company remains agile and responsive in a highly regulated industry.

4.1.3 ST Strategy: Diversification Strategy, Seek Profit and Minimise Harm

The diversification strategy in the ST framework focuses on mitigating risk while simultaneously pursuing new opportunities for profit generation. To effectively implement this strategy, the company must leverage its existing technological and engineering capabilities to strategically expand into both the upstream and downstream segments of the energy industry (Mosch et al., 2021). This vertical integration not only opens up new revenue streams, but also enables the company to diversify its operations, reducing dependency on any single market segment or product. For example, by entering the upstream market (e.g., raw material extraction) and downstream markets (e.g., energy distribution or retail), the company can better manage market fluctuations and avoid exposure to the risks inherent in relying on one area of the energy sector.

In addition to market diversification, establishing and strengthening robust risk management mechanisms is essential to safeguard companies from external uncertainties, such as market price fluctuations and environmental risks (Settembre-Blundo et al., 2021). The volatility of energy prices and the potential for environmental challenges, whether due to natural disasters, climate change, or regulatory changes, pose significant risks to long-term profitability. Therefore, the company must implement sophisticated forecasting, risk assessment, and mitigation strategies. This may include hedging techniques, diversification into more stable sectors, and adoption of environmentally sustainable practices to ensure long-term operational resilience.

Furthermore, to foster long-term competitive advantage, a company must focus on strengthening its brand and marketing efforts. In a competitive energy market, brand recognition is key to establishing trust and differentiation (Agu et al., 2024). A strong brand will not only help the company retain loyal customers, but also attract new business opportunities, partnerships, and talent. Effective marketing strategies tailored to both domestic and international markets will improve a company's visibility and reputation, positioning it as a leader in innovation and sustainability within the energy sector. This enhanced visibility can also open doors to collaboration with other major players in the industry, further solidifying the company's market position.

4.1.4 WT Strategy: Defensive Strategy, Maintain the Status Quo

The defensive strategy in the WT framework is designed to help a company preserve its market position while proactively managing external risks that could potentially harm its stability. This strategy is particularly important when a company faces external threats such as market volatility, regulatory changes, or increasing competition. The goal is not necessarily to pursue aggressive growth, but to maintain a strong, stable presence in the market and protect the company from potential disruptions.

A key aspect of the defensive strategy is the optimization of the business structure. This includes re-evaluating the company's current portfolio and reducing its dependence on traditional energy sources, which are often subject to price fluctuations, regulatory pressures, and environmental concerns. By diversifying into green and low-carbon energy sources, companies can better align with global sustainability trends and government policies favoring renewable energy (Falcone, 2023). Transitioning to renewable energy sources not only reduces exposure to market risks related to fossil fuels, but also positions the company to take advantage of the rapidly growing clean energy market. This shift is vital for ensuring long-term sustainability and avoiding the potential risks associated with the decline in traditional energy markets.

Another critical element of the defensive strategy is the strengthening of cost control measures. Financial resilience is paramount in times of uncertainty. By focusing on operational efficiency, a company can streamline its processes and reduce waste, thereby increasing overall profitability (Taher et al., 2024). This includes reviewing supply chains, renegotiating contracts, and implementing energy-saving initiatives to lower operational costs. In addition, reducing unnecessary expenditures and ensuring that resources are allocated effectively will help a company maintain a strong cash flow and preserve its financial health. Tight cost control can also help a company withstand external shocks, such as sudden fluctuations in energy prices or adverse market conditions, enabling it to maintain profitability even in challenging times.

Finally, to stay competitive in a rapidly changing market, it is essential for the company to remain informed about industry trends. Constant monitoring of market developments, technological advancements, and regulatory changes will allow companies to adapt their business strategies in response to emerging threats and opportunities (Zaslavska and Zaslavska, 2024). Awareness of trends such as the growth of renewable energy technologies, changes in global energy demand, and evolving government regulations will allow the company to pivot its strategy as needed. This adaptability ensures that the company can avoid being caught off guard by market disruptions, thereby enabling it to remain competitive and safeguard its position in the industry.

The strategic typology emerging from the SWOT–AHP evaluation underscores both the opportunities and constraints facing AE implementation in large construction firms. While these strategic orientations provide a structured basis for decision making, their translation into actionable initiatives requires further consideration. The following chapter outlines targeted suggestions for advancing AE in practice while also reflecting on the conceptual and methodological challenges encountered in this study.

5. Suggestions and Challenges

5.1 Suggestions

To implement Asset Energisation (AE) effectively at the portfolio level, large construction firms must adopt a comprehensive, multilayered strategy that aligns with the three core design principles articulated in this study: value creation, techno-digital enablement, and governance integration. The following targeted suggestions synthesize insights from bibliometric analysis, the SWOT framework, and broader empirical observations.

5.1.1 Strengthen internal digital capabilities and asset lifecycle intelligence

Firms should prioritize the deployment of integrated digital infrastructure, such as Building Information Modelling (BIM), Internet of Things (IoT) systems, and energy analytics platforms, which facilitate predictive maintenance, real-time performance tracking, and scenario-based planning. Simultaneously, enhancing digital literacy across departments and establishing centralized asset databases can break down information silos and embed AE principles across all project phases from design to post-construction operations.

5.1.2 Establish sector-wide standards and benchmarking mechanisms

To address inconsistencies in AE performance evaluations, industry actors should collaborate to develop standardized metrics. These should include carbon intensity, renewable energy adoption rates, digital maturity, and asset reutilization potential. Robust benchmarks not only support regulatory coherence but also strengthen investor confidence and long-term planning.

5.1.3 Expand access to green financial mechanisms

Construction conglomerates should strengthen their participation in sustainable finance ecosystems, including green bonds, ESG-linked loans, and carbon credit markets. These tools can reduce risk exposure, attract long-horizon capital, and incentivize AE-aligned investments. Its effectiveness depends on the adoption of transparent disclosure standards and AE-specific credit evaluation frameworks.

5.1.4 dvance local AE demonstration initiatives

Municipal governments should be encouraged to develop AE pilot zones that combine regulatory experimentation, land-use optimization, and blended financing. These initiatives can function as scalable laboratories, facilitating policy learning and diffusion of AE technologies. Priority should be given to regions, such as industrial parks or smart eco-districts, that exhibit high potential for distributed renewable integration.

5.1.5 Institutionalise governance structures for AE coordination

To ensure effective cross-departmental collaboration, internal governance frameworks should be restructured to include AE-specific mandates, inter-departmental task forces, and designated accountability mechanisms. Externally, partnerships with utilities, digital service providers, and regulatory bodies should be formalized to ensure alignment in implementation. Instruments such as AE readiness assessments, foresight planning, and integrated reporting can further enhance data-informed decision making and organizational adaptability.

Although these strategic recommendations provide a constructive pathway for AE adoption, their implementation is not without obstacles. The following section examines the key barriers that may hinder AE integration in practice, particularly in the context of organizational inertia, regulatory uncertainty, and fragmented stakeholder interests.

5.2 Implementation Barriers

Although the integration of clean energy solutions into large-scale construction enterprises' infrastructure projects offers significant opportunities, several limitations must be considered. These limitations present potential challenges for the successful implementation and long-term sustainability of such initiatives.

5.2.1 High Initial Investment

The deployment of renewable energy technologies such as solar panels, wind turbines, and hydropower stations typically requires substantial initial capital. Large construction enterprises may encounter financial constraints when allocating resources to such investments, particularly in regions with limited access to financing options or government incentives. This can hinder the ability to expand and develop clean energy projects at the necessary scale to meet the growing demand.

5.2.2 Technical Challenges

The integration of advanced energy technologies such as energy storage systems, smart grids, and automated energy management platforms presents technical challenges. The complexity of implementing these systems often requires highly specialized expertise, which can lead to delays and additional costs. Furthermore, the continuous evolution of energy technologies may necessitate ongoing adjustments and upgrades, thereby increasing the burden on enterprises to maintain cutting-edge systems.

5.2.3 Regulatory and Policy Barriers

The energy sector is subject to stringent regulatory frameworks that can vary significantly across different regions and countries. Navigating these regulatory landscapes, particularly when operating in foreign markets or countries with evolving environmental and energy regulations, can be challenging. This may result in delays or unexpected compliance costs, hindering the ability of large construction enterprises to effectively implement clean energy initiatives in a timely manner.

5.2.4 Resource Availability and Site Selection

While certain regions possess abundant renewable energy resources such as solar and wind, the availability of suitable land for large-scale energy infrastructure projects can be limited. Additionally, geographical factors such as terrain and local weather conditions may influence the feasibility of specific projects. For example, the development of hydropower stations may be constrained by the availability of water sources or appropriate topography, whereas wind farms may be affected by local wind patterns.

5.2.5 Market Uncertainty

The renewable energy market is subject to fluctuations in energy prices, technological advancements, and shifts in consumer demands. These market uncertainties can complicate the long-term strategic planning of large construction enterprises. For instance, price volatility in renewable energy credits, changes in government policy, or technological breakthroughs could significantly alter the economic viability of energy projects, potentially impacting their profitability and long-term success.

5.2.6 Integration with Existing Infrastructure

Integrating new renewable energy technologies into the existing infrastructure can be a complex and costly process. The need for major upgrades to legacy systems may lead to resistance, particularly in regions with older infrastructure.

This could result in operational disruptions, increased costs, and slower implementation timelines, ultimately hindering the smooth integration of clean energy solutions into the traditional infrastructure.

The strategic suggestions outlined above highlight the multifaceted nature of AE implementation, spanning policy alignment, technological integration, and organisational change. While these proposals offer directions for practice, it is essential to reflect on the study's overall contributions and acknowledge its methodological and conceptual boundaries. The following chapter synthesizes the key conclusions and outlines the study's limitations.

6. Conclusions and Limitations

6.1 Conclusions

This study explored the evolving concept of asset energization (AE) as a strategic framework for promoting sustainable transformation in China's large construction firms. Rather than treating AE as a purely technical or project-based initiative, this research positions it as an io-wide operational model that bridges digital technologies, renewable energy integration, and low-carbon asset management.

Through a combined bibliometric analysis and SWOT–AHP evaluation, this study identified three core design principles that underpin AE: value creation, techno-digital enablement, and governance integration. These principles serve as the foundation for reconfiguring legacy infrastructure portfolios toward greater sustainability, energy efficiency, and resilience in the face of emerging climate and regulatory challenges.

Bibliometric mapping revealed that academic discourse around AE is coalescing around four thematic clusters: renewable energy and decarbonization, digital optimization, institutional governance, and system modelling. This confirms the multidimensional nature of AE and highlights the growing alignment between research, industry practices, and policy direction.

The SWOT analysis further identified key internal strengths, such as digital construction capabilities and pilot experience in green infrastructure, and external opportunities, including favorable national policy frameworks and declining costs in renewable energy technologies. However, significant weaknesses persist, including fragmented asset management systems and insufficient energy-related expertise. Meanwhile, threats, such as regulatory fragmentation and financial risks, continue to limit scalability.

Together, the findings suggest that AE can serve not only as a mechanism for technological upgrades but also as a strategic pathway for aligning enterprise-level asset strategies with national low-carbon goals. To fully realize this potential, construction firms must invest in digital infrastructure, build cross-sector partnerships, and proactively engage with emerging financial and regulatory mechanisms.

Given that building-energy demand in China continues to rise steadily, the AE framework, which combines renewable energy integration with digital optimization, offers a practical pathway for meeting growing service needs while markedly lowering carbon intensity.

While the study provides a structured and original contribution to the discourse on asset energization in construction, it is also important to acknowledge its limitations. The following section outlines the conceptual, methodological, and contextual boundaries that may affect the interpretation and generalizability of the findings.

6.2 Limitations

Despite offering a novel conceptual and strategic framework for Asset Energisation (AE) in large Chinese construction firms, this study has several limitations that should be acknowledged and addressed in future research. These limitations arise from theoretical, methodological, empirical, and contextual constraints, each of which may influence the generalizability and applicability of our findings.

6.2.1 Conceptual Boundaries

The definition and application of AE in this study were primarily conceptual and exploratory, respectively. While AE is framed as a systemic portfolio-level approach that integrates renewable energy and digital optimization into legacy assets, its theoretical underpinnings remain emergent. Although supported by the literature and SWOT-AHP synthesis, the construct lacks validation across diverse industry segments, organizational types, and national contexts. Consequently, its generalizability beyond the large construction conglomerates in China remains uncertain.

6.2.2 Methodological Constraints

This research adopts a mixed-methods design that combines bibliometric analysis with a semiquantitative SWOT–AHP framework. However, it is constrained by its exclusive reliance on secondary data. The absence of primary data, such as expert interviews, enterprise surveys, or project-level case studies, limits the empirical robustness of the SWOT factor weighting. Moreover, the AHP weighting scheme, informed by literature-based frequency and relevance scoring, does not incorporate validation from practitioner or policymaker perspectives, which could enhance the credibility and practical value of the results.

6.2.3 Absence of Empirical Implementation Evidence

Although this study identifies strategic pathways for AE and evaluates the internal and external factors affecting its adoption, it stops short of assessing implementation outcomes. No empirical evidence has been presented on how AE has been applied in practice, what institutional or financial barriers have emerged, or how firms have responded to evolving regulatory landscapes. Without real-world case data, strategic implications remain largely theoretical and speculative.

6.2.4 Contextual and Temporal Volatility

The policies and market environment for renewable energy and sustainable infrastructure in China are highly dynamic. Government incentives, regulatory frameworks, and financial instrumentssuch as green bonds or carbon pricingcontinue to evolve rapidly. While this study captures a snapshot of the current landscape, future developments may shift the relative importance of the identified SWOT factors, rendering recommendations outdated or less effective. This temporal limitation is inherent in policy-sensitive research, and highlights the need for continuous monitoring and adaptive strategy formulation.

Together, these limitations underscore the need for future research to refine the AE concept, validate it through multilevel empirical studies, and align it with shifting policy and market dynamics. Addressing these challenges will improve the analytical depth, operational relevance, and strategic foresight of AE as a viable pathway for low-carbon transformation in the construction sector.

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I have no research data outside the submitted manuscript file, and have not published it on any other platform. The data supporting the findings of this study are openly available in The Scopus database.

Author Contributions Statement

Tiesen Zeng was responsible for the experimental design and data collection, and was the first author. Jinwei Ding was responsible for data analysis, paper writing, and other tasks and is the second author and the corresponding author. These authors contributed equally to this work.

Ethics Statement

This study does not involve clinical trials, nor is it applicable to any clinical trial; therefore, there is no clinical trial registration number. Additionally, this research does not involve any live subject (human or animal) studies, surveys, or participation.

Clinical Trial Number

Not applicable.

Consent to Participate

This study was based on publicly available data and websites and did not require informed consent.

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Appendix 1

SWOT analysis of China's Large Construction Firms

Strengths

Strong Infrastructure Assets: Large construction enterprises, with their extensive experience in infrastructure construction and resource integration capabilities, can efficiently integrate upstream and downstream resources across the industrial chain, providing comprehensive support for the implementation of asset energization projects (Huang and Li, 2024). Along with asset accumulation, these enterprises have also developed strong financial strength, which can provide ample funding for asset energization projects. Furthermore, large-scale energy projects are capable of assuming high financial risks and diversifying investment layouts, thereby reducing the risks associated with individual projects.

Rich Asset Energization Scenarios: The infrastructure assets of large construction enterprises cover a wide range of fields. In recent years, as some enterprises have gradually shifted from construction to operation, a large number of suitable scenarios and infrastructure assets for asset energization have emerged (Gollakota and Shu, 2023). These include high-speed highways and subways in the energy integration field, numerous industrial manufacturing plant scenarios, distinctive real estate and office park scenarios, and water conservancy and water service scenarios. These diverse scenarios provide a rich foundation for asset energization and lay the groundwork for low-carbon energy development of enterprises.

Strong Construction Organization Capabilities: Large construction enterprises, especially the eight major central construction companies, cover a wide range of business areas, including railways, highways, municipal infrastructure, residential buildings, urban rail transit, water conservancy and hydropower, airports, ports, and terminals. They can provide the construction industry with "vertical integration" solutions and turn-key services. In terms of construction organization, these enterprises possess unique advantages built over long periods and through multiple projects in various sectors. This experience offers strong organizational support for venturing into new energy sectors and other "second-line" industries.

Weaknesses

Limited Forms of Asset Energization: While large construction enterprises possess vast infrastructure assets and inherent conditions for asset energization, most of their current explorations in this field are focused on areas such as photovoltaic construction and energy management. At this stage, most efforts are still in the construction or exploratory phase, with limited pathways for realizing comprehensive asset energization. There has been little exploration in fields such as wind, geothermal, hydrogen, and energy storage, and even fewer integration scenarios with infrastructure assets (Hassan et al., 2024). As a result, the forms of asset energization remain singular.

Weak Accumulation of Energy-related Personnel, Technology, and Resources: Infrastructure construction remains the core business of large enterprises. Emerging energy sectors, such as photovoltaics and wind power, require significant technical accumulation, innovation capabilities, and market resources for support. However, in the process of realizing asset energization, construction enterprises have revealed several weaknesses such as insufficient experience in energy project operations, inadequate supply chain integration capabilities, and limited market share (Mahmood et al., 2024). In addition, there is a lack of accumulated energy-related personnel and technological achievements, making it difficult for these enterprises to keep up with the rapidly changing energy market.

Opportunities

Strong Policy Support: Asset energization is a complex process that involves treating energy assets as resources capable of generating economic value and maximizing their benefits through effective management and utilization. In this process, the strength of policy support plays a critical role in driving asset energization. Currently, national and local governments have issued favorable policies from various perspectives to support the integration of infrastructure assets and energy. For example, the "14th Five-Year Plan for the Development of a Modern Comprehensive Transport System" encourages the rational layout of photovoltaic power generation along transportation hubs, highways, railways, and other facilities (Zhao and Yuan, 2023). The "Implementation Plan for Promoting Low-Carbon Development in the Railway Sector" calls for the application of energy-saving and new energy technologies, such as photovoltaic power generation, at railway stations, and mandates that new railway station buildings prioritize integrated photovoltaic construction (BIPV) or reserve conditions for the installation of photovoltaic systems. Additionally, the "14th Five-Year Plan for the Development of a Modern Energy System" proposes building a clean, low-carbon, safe, and intelligent modern energy system, promoting the application of solar, wind, and energy storage technologies in infrastructure, and developing green buildings and smart grids (Teng, 2024).

Sustained Deepening of Green and Low-Carbon Concepts: As the national efforts to achieve the "dual carbon" goals intensify, the green and low-carbon concepts within construction enterprises have also been continuously deepened, effectively enhancing the enterprises' sense of social responsibility and brand image, and promoting long-term development. Many construction enterprises have begun focusing on green and low-carbon principles during the investment, construction, and operation phases of infrastructure projects (Chen et al., 2023). During the planning phase, environmental factors were carefully considered to minimize environmental damage. Low-carbon and energy-efficient products are actively used in the construction phase. In the operation phase, energy-saving equipment is adopted, energy structures are optimized, and energy management is strengthened to reduce carbon emissions during operation. Simultaneously, construction enterprises are driving the application and development of green and low-carbon technologies through technological innovation, research, and development (Li et al., 2021). The use of renewable energy, promotion of green buildings, and development of smart transportation are significant initiatives in green and low-carbon fields, and they also lay a strong technical foundation for the realization of asset energization in construction enterprises.

Significant Decrease in Construction Costs for Wind, Solar, and Energy Storage: Owing to continuous technological advancements and improvements in the industrial chain, the construction costs of photovoltaics (solar), wind power, and energy storage have significantly decreased. Since 2021, with further improvements in photovoltaic conversion efficiency and reductions in manufacturing costs, the cost of photovoltaic power generation has continued to decline rapidly. According to the China Photovoltaic Industry Association's recent "China Photovoltaic Industry Development Roadmap", the levelized cost of electricity (LCOE) for ground-mounted photovoltaic power stations with 1500 equivalent full-load hours dropped from 0.25 yuan/kWh to 0.18 yuan/kWh between 2021 and 2023, and for stations with 1800 equivalent full-load hours, the cost decreased from 0.21 yuan/kWh to 0.15 yuan/kWh (CPIA, 2024). In addition to the reduction in photovoltaic power generation costs, energy storage costs have also been rapidly declining. According to Infolink, the cost of lithium-ion battery storage systems has decreased by nearly 80% over the past decade, with the cost per kWh dropping to around 0.3-0.4

yuan by early 2024 (CPIA, 2024). Some lithium battery storage projects have already reached a cost per kWh close to 0.2 yuan (CPIA, 2024). Wind power construction costs have also fallen significantly, with new wind turbines in the northern regions now having a capacity of 8-10 MW, and product prices as low as 1300 yuan/kW, representing a more than 50% reduction compared to three years ago (CPIA, 2024). These cost reductions present excellent development opportunities for large construction enterprises to achieve their asset energization goals.

Threats

Market Volatility: While the construction costs of new energy sources, such as wind and solar power, have generally shown a downward trend, there remains significant volatility in the process. This is particularly evident in the photovoltaic (PV) sector, where the price decline of solar modules has driven costs down, leading to unhealthy competition within the industry. To promote the healthy and sustainable development of the photovoltaic industry and ensure that solar modules can operate reliably for 20-25 years, the China Photovoltaic Industry Association issued a statement declaring that "bidding below cost may be illegal." As a result, the prices of photovoltaic modules have gradually started to rise again in the short term. However, this has also led to a shrinking photovoltaic project market, with some projects and suppliers adopting a wait-and-see approach. Price fluctuations have become an important factor influencing asset energization, introducing substantial risks to the implementation of asset energization projects.

Financial Strain Due to Sluggish Infrastructure Industry: As the national road and railway networks gradually become more complete, the era of high growth in transportation infrastructure investment has come to an end. The infrastructure industry is capital-intensive and the importance of funding cannot be overstated. This slowdown in infrastructure investment has resulted in a continuous decrease in the number of infrastructure projects. Simultaneously, the government has been cleaning up hidden debts and promoting policies such as tax reductions and fee cuts in recent years. Under the GDP-oriented economic development model, some local governments have introduced new project management models like "EPC+F" in traditional construction contracting projects to alleviate fiscal pressure while supporting local economic development (Zhang, 2023). This model significantly reduces project payment ratios, leading to a substantial increase in accounts receivable by construction enterprises. Consequently, many construction enterprises face financial constraints. Because asset energization involves a significant upfront investment and considering factors such as cost and capital, many construction enterprises may not have a strong short-term willingness to pursue asset energization.

Based on the results of the SWOT analysis, this study presents specific strategic recommendations to assist construction firms in fully utilizing their existing advantages, seizing opportunities, and mitigating risks when facing market and technological challenges. The next sections focus on developing feasible strategic layouts based on the analysis results.