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Power Generation in China: A Survey on Current Grid Infrastructure, Policy, and Advancements Towards Energy Security

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Executive Summary

This paper explores the trajectory of China's energy and power generation landscape by addressing topics related to policy, technology, infrastructure, and investment. Over the past 25 years, China has implemented a wide range of policies and initiatives aimed at expanding power generation capacity.

The paper starts with a concise background on China's geography, population and energy demands to provide further context for understanding energy distribution. Then the paper reviews China's energy policy evolution, demonstrating how China underwent market liberalization to improve energy efficiency and generation. By identifying key national policies that promote power generation, the literature also identifies conflicting regulations, fragmented regional planning, and inefficient oversight of SOEs that hamper these efforts.

Next, the paper examines the current status of China's grid infrastructure, specifically generation and transmission for various sources of energy. While the national grid has expanded dramatically, regional disparities, and regulatory inefficiencies continue to limit overall resilience and reliability. Fourth, the paper highlights several major technological advancements that enhance China's ability to generate, transmit, and store power. These include the deployment of clean coal technologies, innovations in nuclear and renewables, expansion of ultra-high voltage transmission lines, and advancements in energy storage methods. These tools have helped China manage growing energy loads and regional supply imbalances more effectively.

Fifth, the paper examines the present and future outlook for investment. Domestically, future investments are expected to concentrate on smart grids, energy storage, renewables, and AI integration. Internationally, China's energy strategy continues to be shaped by foreign infrastructure projects, particularly through the Belt and Road Initiative (BRI). These efforts also serve broader geopolitical objectives, an important factor in national security. The paper also examines AI policy and technology evolution, including future predictions for the development and policies surrounding AI.

Overall, China's energy system demonstrates a pattern of ambitious goal setting, rapid technology adoption, and significant investment capacity. However, it also suffers from fragmentation, competing priorities, which are most evidently seen through inefficiencies and overcapacity. The country's ability to reconcile its AI development goals with its environmental and energy security objectives will shape the success of its long-term power generation strategy.

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Introduction: China's Geography, Population, and Energy Demands

To understand the current landscape and analysis of China's electricity sector, a survey of China's geographic, economic, political, and population distribution is important for comprehending electricity demands, energy security, evolution, and challenges facing the overall electricity industry in China.

Electricity Demands (Why Electricity is Important to China)

In 2010, the US and China had equal demand for power generation at roughly 4 million Gigawatt hours (GWh). China has since increased its demand to 8.9 million GWh, in large part due to increases in industrialization and urbanization (Ball, et al, 2025). In contrast, the US demand has remained steady at around 4 million GWh. In analyzing demand and energy consumption by sector in China, the industrial and mechanical sectors account for 66% of electricity consumption, with significant increases in residential consumer electricity consumption (CSIS, 2018). The manufacturing of renewable energy technologies, which aids in the green transition for China, is one of the highest electricity intensive industries. Additionally, the growth of AI, Data Centers, 5G, and emerging technology has placed increased and growing pressure on China's electricity demands. Estimates by the Chinese government report that the demand for electricity from only AI and data centers will account for up to 4% of global electricity consumption by 2030 (Xue, 2024). Further, in comparison to the growth in China's GDP, the demand for electricity has grown at a faster pace over the past five years, linking the importance of electricity generation to China's economy and industrialization (IEA, 2025). As seen in the total global demand for electricity, China has consumed one-third of worldwide demand, illustrating the vast amounts of demand for electricity to keep up with increased economic output and pressures (IEA, 2025).

Energy Security

China, to ensure the stability of its energy supply and electricity infrastructure, has implemented numerous policies towards centralizing and reforming the processes and industries for reliable and efficient electricity. For example, the implementation of Five-Year Plans (FYPs) has been a routine effort by the Chinese government to establish measured goals guiding energy technology and infrastructure development, carbon emission reduction, and increasing the output of energy generation. Utilizing State-Owned Enterprises (SOEs), China's government retains control over the upstream, midstream, and downstream power sectors allowing efficient implementation of policies and reforms. As seen in 2002 with state reforms breaking up the monopolized State Power Corporation into smaller state-controlled oligopolies, this allowed for more influence on the localized and nationalized electricity grid due to their control of the generation and transmission sectors (Pittman and Zhang, 2015).

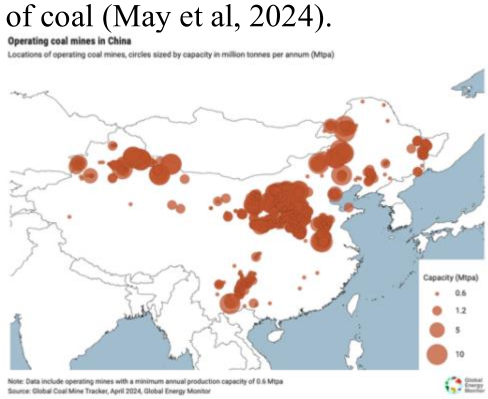
These reforms are one component of China's aims towards ensuring effective and stable power that retain autonomous energy security. Energy security is crucial to China's economic and political agenda, ensuring a stable supply of energy to meet growing domestic demand. Through identifying methods, bottlenecks, and opportunities in China's current power generation, electricity transmission and distribution, and emerging technologies, China will be able to establish initiatives to fill growing demand while ensuring energy autonomy. Increasing domestic energy production will allow China to decrease their reliance on unstable energy imports. Additionally, energy security for China consists of ensuring domestic centralization and international interconnection of the electricity grid through the policies of the Belt Road Initiative and Global Energy Interconnection.

Geographic Resource Distribution

China is a geographically diverse and expansive country with numerous sources of natural resources that are key to the energy and power generation sectors. Spanning over 9 million square km of territory, China faces geographic expansiveness to be a main challenge of efficient and stable energy transfers (CIA, 2025). From West to East, which is a common route for energy transfers, China spans around 5,200 km. Industrialization is concentrated in the eastern regions, while the Western provinces of China are critical for the development of power generation due to the available land and natural resources for efficient solar and wind power plants. Further, China's water distribution is another resource that is distributed in an uneven manner across China's territory with the largest concentration of major rivers being in the Southern half of the country. Yet, many industries that need water as part of their manufacturing are in the Northern territory of China which holds only a quarter of natural water resources (May et al, 2024).

Critical Minerals: China plays an important role in the global critical mineral supply chain, holding the largest share of refinement capacity for critical minerals even though its territory does not necessarily hold the largest concentration of rare earth minerals. According to the IEA, China mines 68% of rare earth minerals while holding 70% of the market for graphite mining (IEA, 2023). Regarding mineral refinement, China holds dominance in all the critical mineral and rare earth refinement industries which are critical especially in the development of new renewable technologies (IEA, 2023).

Coal: With significant domestic coal mines, China domestically produces over 4,700 million tons per year of coal using underground and surface mining with its output concentrated highly in the Shanxi, Shaanxi, Upper Mongolia, and Xinjiang regions of China (May et al, 2024). This exemplifies the fact that 86% of coal reserves and industry are in the Northern regions of China (May et al, 2024). With its high demand for coal as a critical energy source, China is the world's largest importer and producer of coal (May et al, 2024).



Source: Global Energy Monitor

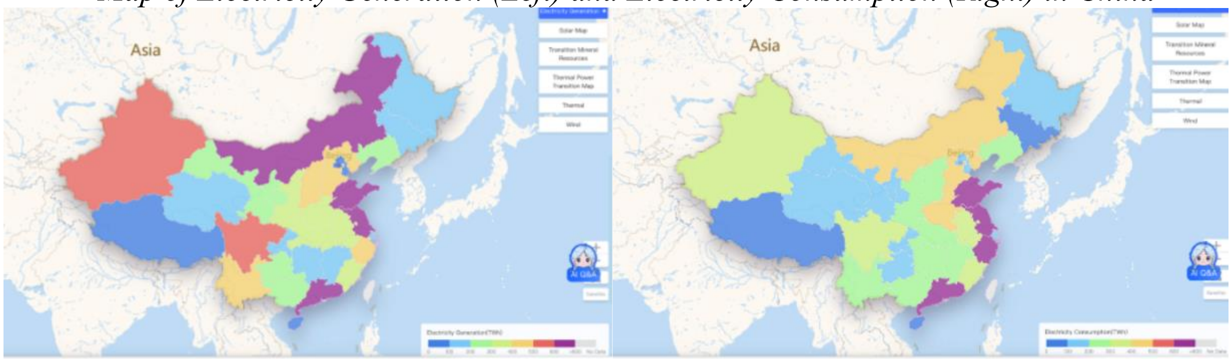
Population Distribution

An analysis of the Heihe-Tengchong line is important to understand the challenges that China's electricity grid and infrastructure face within successful centralized and efficient transfers of energy (Nitkoski, 2024). According to academic literature, the Heihe-Tengchong line is a drawn designation that splits China into roughly equal landmasses and emphasizes unequal population distribution. Under the Heihe-Tengchong line, the population of China is unevenly distributed as 96% of the country's population resides in 36% of the Southeastern and Eastern coastal territories (Wang & Xue, 2025). The issues of population density reflect onto China's levels of electricity consumption and demand and emerging bottlenecks facing the transmission of electricity as China's current population is around 1.4 billion emphasizing vast amounts of demand (CIA, 2025).

For example, the Xinjiang province, located in the far Western territory of China provides numerous natural resources towards energy supply including large contributions to coal and natural gas while only having a population of 26 million (Nitoski, 2021). Additionally, Xinjiang has recently emphasized clean energy, transmitting over 210 billion kWh of renewable solar and wind sources to other Chinese provinces in 2023 (State Council-PRC, 2024). Yet, Guangdong in Southeast China consumed the largest amount of electricity of all provinces at 850 TWh of electricity followed by Jiangsu and Shandong both upper coastal provinces that have high industrialization and urbanization trends contributing to their electricity consumption demands (IPE, 2018). These are high shortage groups, as seen in the figure below highlighted by the dark purple provinces, which are categorized in China as being high consumers of electricity while having low capacity to produce electricity at the same rate. This creates deficits due to urbanization and industrialization. These regions additionally face issues with energy efficiency, which have led to historical electricity shortages and power outage crises within the demand and lack of supply. Electricity demand is further concentrated in the Southeast area which has high electricity and power consumption with limited regional access to electricity, power sources, and generation.

With the push to clean sources of energy, there is a growing imbalance between centers of energy production and centers of increasing energy demand and consumption. The challenge that has highly shaped China's electricity sector is how to transfer energy that is produced in the largest section of territory yet holds the least amount of the population. Coal has continued to remain a dominant facet of China's electricity makeup since many of China's pre-existing coal power plants are relatively close in proximity to areas of energy and electricity demand (Abhyankar, 2022). For example, the top three provinces of coal production were Inner Mongolia, Shanxi, and Shaanxi provinces which are all in relative proximity to the urban Beijing area and subsequent urban coastal provinces that demand the greatest amount of electricity (Vavilina et al, 2025).

Map of Electricity Generation (Left) and Electricity Consumption (Right) in China



Source: China Institute of Public and Environmental Affairs

What is Power?

Power is fundamental to modern life and drives global operations ranging from everyday household devices to large-scale industrial facilities. Within the context of this analysis, power refers to electrical energy or electricity. A power system includes the following components: generation, transmission, distribution, storage, and consumption of electricity (Breeze, 2019).

Power generation converts various energy sources into electricity. Literature classifies energy sources into categories like renewable (solar, wind, hydro, geothermal, biomass) and non-renewable (coal, oil, natural gas, nuclear). Clean energy sources include renewables and nuclear power due to low emissions. Fossil fuel-based energy sources include coal, oil, and natural gas, which are non-renewable and polluting. Power is measured in watts (W), typically scaled as kilowatts (kW), megawatts (MW), gigawatts (GW), or terawatts (TW). The total amount of power produced or consumed is measured by watt-hours (Wh). For example, a 100-watt light bulb used for 5 hours consumed 500 Wh of power (Understanding the Difference, 2024). In 2022, the average US home used 10,791 kilowatt-hours (kWh) (U.S. Energy Information Administration, 2024). Capacity refers to the maximum electricity output a generator can produce at a given point.

Power transmission transports electricity between locations. Because electricity must be used immediately after generation, power plants are connected to a network that distributes it across regions. These networks follow a hierarchical structure. Electricity is generated at power stations, transported through a transmission network which serves as a “high-voltage backbone”, then carried by local distribution networks that deliver electricity to consumers (Breeze, 2019). Voltage is the pressure that drives the electrical current through the transmission lines – often compared to water pressure in a garden hose. The hose is the conductor (transmission line), pressure is voltage, and the amount of water flowing through represents current (Go Green Electrically, 2017). High-voltage transmission lines reduce energy loss while delivering the same amount of electricity. This interconnected network of power plants, substations to control voltage and electricity flow, transmission lines, and distribution lines make up the electricity grid.

Power storage refers to methods of storing electricity for future use, with batteries being the primary technology. Power storage plays a vital role in stabilizing the grid and integrating renewable energy sources. Batteries store electricity produced in excess during low-demand periods and release it during peak demand. They can power anything from calculators to industrial plants, and their capacity describes the maximum amount of electricity they can store.

Major Energy Goals

Since the 2000s, China has had three major energy goals: (1) meet growing energy demands (2) reduce domestic air pollution (3) reduce dependence on imported energy (Larson et al., 2003). To achieve this, China adopted a "more renewables, more coal" strategy, leveraging advanced coal and nuclear energy technologies for stable power while implementing renewables on a large-scale for long-term sustainability (Yang et al., 2025). Coal provides reliable and consistent energy to balance the grid, unlike solar and wind (You, 2024). However, China's heavy coal dependence in the mid-2000s led to severe pollution and public discontent, prompting the government to "make strategic investments in all aspects of renewable technologies" (Hilton, 2024). In 2020, Xi Jinping committed China to a carbon neutrality goal by 2060, which China continues to aggressively pursue.

Historical Context

Background 1949-1985

Since China's founding in 1949, energy and power generation were nationalized and operated as a state-owned monopoly. Electricity was managed by the Ministry of Electric Power. Widespread power shortages were caused by underinvestment and planning inefficiencies. A steady exploration of energy policy began in 1978, mostly focusing on coal mining, management, and power construction. However, persistent power shortages from 1978 to 1985 hampered economic development. This chronic shortage motivated the government to allow domestic private enterprises and foreign investors to invest in energy generation beginning in 1985. Before 1990, China's main energy focus was on developing the coal industry to achieve self-sufficiency. (Zhang, et al. 2017)

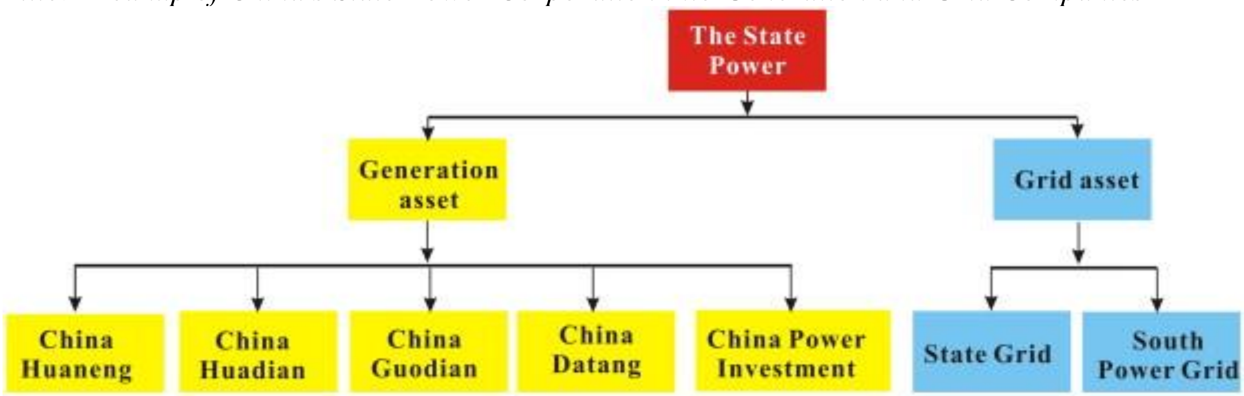
Market Reform 1985-2002

From 1985 to 1996, China's energy policy shifted to allow local governments, private investors, and foreign actors to participate in power generation. Their focus was on raising capital through domestic and foreign investment to resolve power shortages. The earliest stages of China's energy market reform were driven by power shortages. In the late 70's and early 80's, China faced increasing power shortages due to rapid industrialization. This motivated early market restructuring to increase power generation, and in 1997 China moved toward market-oriented restructuring by separating state administration from the energy enterprises. The State Power Corporation (SPC) was established to manage China's power sector and address corruption. It represents one of the first early changes (Ngan, 2009)

Early Liberalization 2002-2014

In 2002, China experienced severe and large-scale energy shortages driven by a sudden increase in energy demand due to rapid industrialization. This prompted a shift in policy to rapidly expand power capacity and continue market liberalization. Liberalization in this context is best understood as reducing government controls and allowing for greater competition and reliance on market forces such as supply and demand. In 2002, the "No. 5 Document" (Scheme 2002) was introduced to unbundle generation from transmission and distribution, marking a transition to a more diverse and scalable generation sector. After addressing power shortages, the government resumed focus on liberalizing the sector. SPC was dismantled, and generation assets were reallocated to the "Big Five" energy companies, while transmission and distribution were inherited by two state grid firms, pictured below. (Zeng, et al, 2015)

Title: Breakup of China's State Power Corporation into Generation and Grid Companies



Source: Wang and Chen, 2012

From 2003 to 2004, another serious power shortage refocused attention on generation expansion. In 2004, 21 of 31 mainland provinces experienced shortages. Between 2003–2010, the installed capacity of the Big Five increased by over 300%, compared to a 253% increase in China's total capacity. Before Scheme 2002, central SOEs controlled 46% of total installed capacity, but by 2010 it rose to control 60%, making China's electricity market-oriented reform less effective. Additionally, the 2002 reform was considered a failure due to continued dysfunctional pricing mechanisms, as the price of electricity was determined by the government on the basis of historical prices, instead of supply and demand. (Ming, et. al, 2012)

Electricity demand in this period was largely driven by energy-intensive industries. In 2004, demand exceeded supply by 10%; in 2008, 19 provinces faced shortages; and by 2011, 24 provinces faced similar problems. In response, China introduced the Middle and Long-Term Development Plan for Energy (2004–2020), which emphasized conservation and structural transformation. Two key strategies to address shortages were: (1) deregulation involving local governments in plant construction, and (2) electricity market reforms to ensure return on investment. These helped enhance efficiency among generators as competition increased. (Kong, Feng and Yang, 2020)

2014-Present Electricity Market Liberalization (EML)

Since 2014, energy policymaking in China has grown rapidly and become more specialized. The 12th Five-Year Plan focused on energy conservation and clean energy, promoting development that is domestic, green, and innovation driven.

In 2015, Document No. 9 laid out a vision for a competitive retail electricity market. It introduced reforms to establish a competitive trading mechanism between generators and large users, promote renewable energy, and enable private investment. The plan liberalized the power market by building a competitive market and setting up rational pricing mechanisms, which transformed the power industry from a state-owned monopoly to market-oriented competition. It established a competitive trading mechanism between generators and large users with an extension of the Direct Purchase of Large Users (DPLU) policy, which allows a large user to purchase power directly from generation enterprises. It also made the energy market competitive for regular consumers, as before all users had to buy electricity at government-set prices through the state grid. The 2015 reform allowed consumers to use a retailer to buy electricity directly from the source, allowing for competitive supply and demand price mechanisms. (Lei, et. al 2018)

Most importantly, “The 2015 reform has also been strongly influenced by the environmental discourse of ecological civilization. Ecological civilization is a state-driven sociotechnical imaginary that envisions a society operating along the principles of environmental sustainability, sustainable development, socialist modernization, a harmonious human-nature relations, and a holistic view of such relations” (Lo and Ngar-yin, 2023) This idea aligns with EML by expediting the transition to renewable energy. However, EML reform disrupts grid companies’ business model, because generators can sell electricity directly to consumers at the market rate. Grid operators will lose their monopoly, instead income will come from transmission and distribution fees. Therefore, state-owned grid operators want to ensure EML reforms produce favorable outcomes.

Domestic Grid Infrastructure

Grid Infrastructure

Under China’s initial 2020 dual carbon policy, which aimed to peak carbon emissions prior to 2030 and achieve carbon neutrality by 2060, China has undergone significant infrastructure and investment centralization to ensure domestic and global grid expansion, energy security, and address disparities in power generation (Zhen et. al, 2022).

In a progressive push to centralize, expand, and transition its electricity grid towards carbon reductions, China has invested heavily into reviewing current infrastructure and policies, advancements in technology such as ultra-high voltage transmission lines, and options for energy storage to account for the shift to renewable energy. Amidst these innovations and investments, significant challenges remain for China. For example, due to imbalances between areas of generation and demand and the undercapacity of current infrastructure, there is a lack of modern infrastructure for efficient energy transmission. Such inefficiency makes transitioning away from coal difficult while retaining and increasing energy security.

Across all energy sources, companies, and technologies there are three distinct phases of the electricity grid that have emerged with key players contributing to the uniformity of the grid. A series of 2002 electricity reforms focused on the centralization of different stages of electricity generation and the power grid through restructuring and establishing a new series of SOEs (Pittman & Zhang, 2015). These reforms and SOEs fall into the upstream, midstream, and downstream segments of the electricity grid. Upstream processes refer to power generation and creation of electricity from various energy sources (CGEP Columbia, 2022). Midstream refers to the companies and methods of investing in transportation, transmission, and distribution of electricity. Downstream electricity processes refer to the direct delivery of electricity to different consumers (Wang & Xue, 2025). For the context of the current nationalized grid infrastructure and policy, the following parts of the paper will focus on key players and infrastructure in both the upstream and midstream segments regarding investment and innovation for new technologies and storage techniques.

Overview of China's Energy Infrastructure

Infrastructure	Total Units	Length
Transportation:		
Crude pipelines	107	28,852 km
Product pipeline	105	46,073 km
NG Pipeline	431	114,203 km
Hydrogen pipelines	2	560 KM
UHV Lines	38	48,000 KM
Storage Components:		
NG Storage	53	N/A
Oil storage	295	N/A
EVB Factories	343	N/A
Generation:		
Oil refineries	213	N/A
Oil ports	67	N/A
NG Power Plant	254	N/A
LNG Terminal	81	N/A
Coal Power Plants	3820	N/A
Nuclear Power Plants	163	N/A
Hydrogen facilities	77	N/A
Solar power plants	12,265	N/A

Wind power plants	7988	N/A
CCS Projects	21	N/A
Mining properties	11,526	N/A

Source: Baker Institute Center for Energy Studies

Generation

Today in China's energy sector coal remains a critical source of domestic energy for electricity consumption. In 2023, 60% of China's electricity generation came from coal, followed by renewable energy comprising 33% of supply (US EIA, 2025). Due to vast and rising demands in consumption, in addition to generation energy imports play an important role in energy security.
In the upstream power generation, the Huaneng Group, Huadian Power, Guodian Power, Datang Power, and China Power Investment Group are the five major SOE players in power generation, although smaller players also contribute to regional power generation (Pittman & Zhang, 2015). Under the guidance of these electricity corporations the current infrastructure of power generation is characterized heavily by coal and mining, with increasing investment in renewable energy power plants, alternative low carbon generating sources of energy, and efforts to shift current infrastructure towards repurposing for other low-carbon generation (Pittman & Zhang, 2015).

<u>Coal:</u> Representing the largest share of contribution to electricity generation, coal serves a historically important role in influencing regulation, policy, and structure of China's electricity sector. While increasing the capacity and promoting the use of alternative forms of electricity, China has continued to expand its coal capacity. This is evident by China's 2024 projections of adding 48 GW to the national coal capacity amidst policies aiming to reduce coal's contribution to the makeup of China's electricity sector (US EIA, 2025). Additionally, the current strategy of using long-term coal-based electricity contracts for players buying into the electricity grid creates substantial delays and less space for integrating other forms of renewable energy into the electricity grid. China's current coal capacity sits at over 6 million GWh of generation across 3,800 power plants, placing a high dependency of the electricity sector on coal (IEA, n.d).

The repowering of coal facilities provides a unique policy option for assisting China in energy infrastructure transition and the rapid integration of new clean energy technology. Through using small modular reactors (SMRs), coal power plants can be repowered for purposes of generating geothermal, bioenergy, or nuclear energy (Yang et al, 2025). Yet, coal's embedded importance in China's electricity consumption and generation leads to numerous opposing regulatory and policy challenges.

<u>Renewable:</u> China's investment into research and design surrounding renewable energy has exponentially grown in importance as new policies aim to reduce carbon emissions and transition away from coal reliance. Due to current investments, innovations, and infrastructure projects, IEA projects that by 2050, renewable energy could power up to 80% of the total electricity supply of China. This aligns with the 14th FYP goal to increase non-fossil generation to 39% of the electricity supply (Yang et al, 2025). Recent reports have shown that initial 2030 renewable energy

generating capacity levels have already been met, reaching levels of over 3,300 GW by the end of December 2024 (Wang, 2025). For these energy transition goals to be reached, significant investment and expanded capabilities of energy storage need to be developed to ensure reliable energy grid security. Current renewable energy infrastructure includes hydropower at the forefront of renewable energy infrastructure at 13.5% of energy, wind at 9%, solar at 6%, followed by nuclear energy making up 4.6% of the total renewable energy infrastructure (IEA, n.d.).

China's Renewable Energy Makeup			
Renewable energy source	TWh	Capacity (2024)	% of total electricity source
Bioenergy	TWh	193	< 2%
Hydropower	TWh	1285	13.5%
Nuclear Power	TWh	444	4.6%
Wind Power	TWh	989	9%
Solar Power	TWh	853	6%

Source: IEA

Solar: China is the global leader in the production of photovoltaic (PV) panels, holding over 80% of global PV panel manufacturing capacity. EIA reports estimates that by the end of 2024, the capacity of China's large-scale solar power industry has reached up to 880 GW （EIA, 2025). According to data compiled by the Global Energy Monitor, China has close to 13,000 solar PV farms in operation with over 3400 additional PV farms in differing planning stages that will add over 700 GW of solar capacity for China (GEM, 2022). Inner Mongolia and Xinjiang provinces have the largest solar PV farm developments due to being resource rich areas for generating higher amounts of solar capacity.

Wind: Wind capabilities in China are concentrated on becoming a leading global producer of power generation through offshore wind farms. Although offshore wind generation of 13.6 TWh is a small contributor to China's overall electricity consumption, as a part of global offshore wind technology, China has played a significant role in contributing to emerging power generation technologies (Deng et al, 2022). Under the technologies that are being developed for China to meet carbon reduction demands by 2050, the offshore wind production of China is expected to expand up to 336.8 TWh of electricity (Deng et al, 2022). Onshore wind electricity in 2021 added over 30 GW of capability and is expected to substantially increase as more companies contribute to the growth in wind turbine technology (Yu et al, 2024). Yet, onshore wind electricity generation faces numerous setbacks and challenges in its cost for development, the reliability of wind sources for power generation, and the upfront costs of electricity generation compared to other renewable forms of energy

Hydropower: Hydropower is the largest source of renewable energy today and provides around 436 GW of electricity (Wang, 2025). It is important to note that this capacity of hydropower is only operating at 13% of what hydropower capabilities could be operating at due to the present infrastructure capabilities (Wang, 2025). The Three Gorges Dam in Central China's Yangtze River represents the largest capability of any hydropower generating infrastructure in the world at 22.3 GW, with Chinese investments planning on developing even larger capacity dams. Further, the importance and growth of hydropower demand capabilities is seen through focus on pumped hydro-electricity storage holding the largest capacity of China's storage methods (Sandalow et al, 2022).

Nuclear: China's development of nuclear power has increased in capacity as a method of providing alternative low carbon forms of energy to supplement coal in the electricity makeup and ensure energy security. China has strategically developed its nuclear reactor infrastructure to be in proximity to China's demand for electricity alongside the Eastern Coast. This removes transmission challenges that other sources of energy face. Currently, China's nuclear total net capacity can produce 53.2 GW of electricity across 55 operating reactors with an additional 23 reactors under current development and construction (U.S. Energy Information Administration, 2024). China's nuclear policy follows a long-term outlook strategy to meet increasing energy demands. This has led to ambitious goals of constructing 150 new nuclear reactors between 2020 and 2035 in China and BRI countries (Nordquist, 2024).

Natural Gas: Natural Gas (NG) is seen as a strategic source of energy under China's policy of carbon neutrality. As a fossil source, on average natural gas produces 45% lower CO2 emissions (Zhen et. al, 2022). Additionally, due to uncertain renewable energy technology, expansion of the natural gas industry can play a strategic role for compensating in electricity and power generation stability, making up for where renewable energy continues to lack (Zhen et. al, 2022). Numerous regulatory challenges and lack of a developed natural gas industry and transmission capabilities have hindered natural gas' emergence as a key player in electricity generation. Under the 14th FYP, the beginnings of expanded NG pipelines and reserve capacity are expected due to pre-existing long-term NG import contracts and investments in increasing domestic natural gas production capacity (Zhen et. al, 2022).

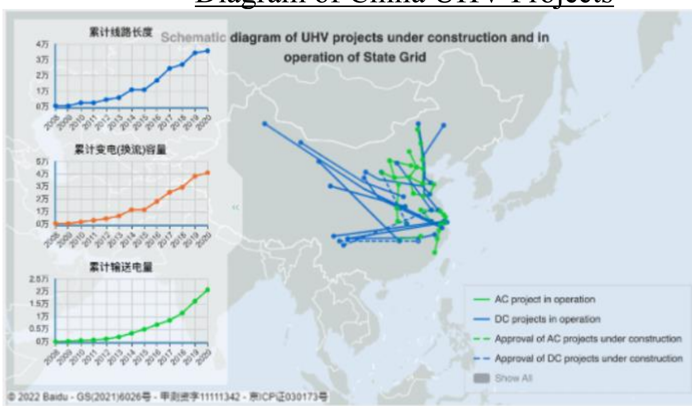
Transmission

As part of the initial 2002 reforms of China's electricity sector, the electricity grid was restructured into two SOEs: The State Grid Corporation and The China Southern Power Grid. State Grid Corporation accounts for 80% of electricity transmission, while China Southern Power Grid accounts for the southern half of China (Sandalow et al, 2022). Combined, the two corporations hold approximately 95% of China's electricity transmission and distribution.

State Grid Corporation, comprising of the largest portion of Chinese territory has spearheaded efforts of Ultra High Voltage (UHV) Transmission Projects, aiming to reduce bottlenecks in the electricity grid, achieve increased energy efficiency and capacity, and promote the use of UHV lines for renewable energy (Wang et al, 2023). In the shift towards green energy alternatives, UHV lines play a vital role in alleviating power demand and decreasing regional carbon emissions due to their ability to transmit power over long distances.

The transmission and distribution of natural gas through pipelines for energy production rather than electricity transmission, is confined under a separate operating SOE, PipeChina (Zhen et al, 2022). The 2020 China Natural Gas High-Quality Development Report placed emphasis on identifying and addressing structural issues in China's natural gas industry (Zhen et al, 2022). Findings of the report highlighted that China's natural gas pipelines are underdeveloped with a lack of national natural gas reserve capabilities. Additionally, the development of PipeChina was a critical policy in 2019 towards reforming oil and gas and assisting provincial pipeline companies instead of creating a centralized monopoly over transmission of natural gas in China (Zhen et al, 2022).

Diagram of China UHV Projects

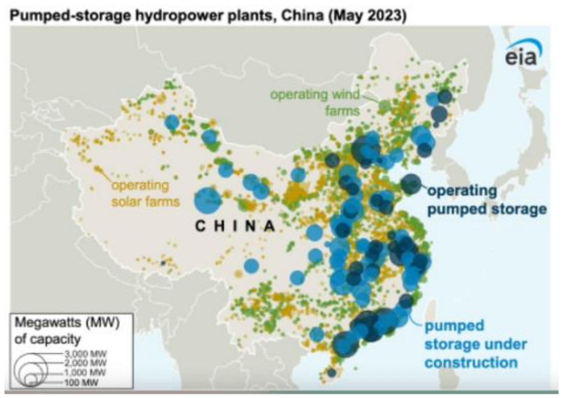


Source: State Grid Corporation

Storage

Advancements in storage technology play a critical role for players in both the upstream and midstream sections of electricity infrastructure, as under China's green energy transition it provides a stable method towards increasing energy reserves, the capacity for electricity demand, and serves to stabilize the electricity grid. With $6 billion in investment towards research, design, and development, energy storage capacity is set to surpass 100 GW by the end of 2025 (Yang A, 2025). As demand for electricity increases alongside the percentage of renewable energy sources, storage infrastructure is critical to providing secure energy reserves at every stage of the process. Therefore, players at both the upstream and midstream processes are contributing highly towards investments in research and design towards advanced storage capabilities.

Pumped Hydro-electricity storage is the most advanced energy storage research in China, holding 99% of the cumulative storage capacity in 2017 (Tong et al, 2021). The technology behind pumped hydro-storage electricity allows for the storage of excess renewable energy through low operational costs and high return on investment as a result of long operating lifespans. State Grid corporation has constructed 75 hydropower pumped facilities helping to balance an excess of electricity from renewable energy sources (Antonio et al, 2023). Additionally, as seen in the EIA figure, China has strategically located its pumped storage hydro-power plants along the eastern coastal region, accounting for the geographic distribution in demand for energy. The proximity of energy storage facilities to not only renewable energy generating plants but also consumers remove technical challenges that have faced mid-stream transmission (Antonio et al, 2023).



Source: EIA

Hydrogen Storage: Hydrogen technology, including the development of hydrogen energy and storage, is a rapidly expanding technology in China, that is helping China to achieve its dual-carbon goals as a low-carbon and renewable source of energy. Hydrogen production allows for the repurposing of old oil and gas fields to transition to hydrogen production fields (Meng, et al, 2022). This repurposing can also occur with offshore oil fields, allowing for offshore hydrogen production using wind power. Specific literature argues that due to China's rapid technological expansion of hydrogen, it will serve a role in replacing coal as a top source of power (Meng, et al, 2022). The technological storage of hydrogen has been achieved through solid-state, gaseous, and liquid hydrogen storage. Yet currently the use of industrialized high-pressure hydrogen cylinders is the most advanced and prominent technology.

Compressed Air Energy Storage (CAES): This energy storage method is achieved through taking excess electricity and storing it through technology pressurizing the energy into high pressure air. When energy is released, it is converted into electrical energy that will generate the turbine to create electricity (Tong et al, 2021). Due to the maturity of the technology, CAES provides an option that allows for large-scale and low-cost storage. The use of CAES within pre-existing geological features through underground storage in salt caves or mines provides a storage option that allows for flexibility while not placing excess strain on the environment. China's cave geography has around 80% of formations located in Western and Northern China, which provides some flexibility for electricity storage near high power consumption areas (Tong et al, 2021). Additional CAE storage options include pressure vessels and pipelines through above ground storage, as well as liquid air storage and underwater CAES, both technologies that are under continued development and expansion.

Battery Storage**:** If China is to successfully transition away from prominent usages of coal towards renewable energy, batteries will play an increasingly substantial role in energy security as seen by significant investment in China for battery R&D. Investments in downstream localized battery storage have increased since 2021 to allow for increased grid flexibility and the proximity of energy storage to consumers demands, meeting targets towards achieving 100 GW of storage capacity in the next 10 years (Amir et al, 2023).

Key Technology Advancements

This section lists key technology advancements that are driving China's transition to clean energy. China's innovations reach across energy sources and generation, transmission, and storage sectors. To support its 2060 carbon neutrality goal, China has focused on making heavy coal use more sustainable, rapidly expanding nuclear and renewable capacity, and enhancing grid stability through innovations in electricity transmission and storage. The following tables present key technologies, brief explanation of their significance, and a note on the current stage of development or deployment. This analysis defines 5 stages of technology development based on deployment quantity, not commercialization. These categories are broad and may involve subjective judgements on whether technologies are small or large scale.

1. *Under development* means in the research phase.
2. *Under construction* means currently being built.
3. *Small-scale deployment* means deployed in limited quantities.
4. *Large-scale deployment* means deployed at grid-scale.
5. *Completed* means fully built and operational.

Clean Coal Technology

Traditional coal-fired power plants use coal to heat water and create steam, which turns a steam turbine to generate electricity (Coal Fired Power Plant, n.d.). However, the process of burning coal creates harmful carbon emissions, which China aims to reduce. The following technology advancements have allowed China's heavy coal use to be more sustainable as they expand other low-emissions and renewable energy sources.

Clean Coal Technology Advancements		
Technology	Why It Matters	Development/Deployment Stage
Supercritical & Ultra-supercritical coal plants	Highly energy-efficient coal power plants	*Large-scale deployment*: By 2010, China had commissioned or started construction for over 150 supercritical or ultra-supercritical units (Chen & Xu, 2009).
Carbon capture, utilization, and storage technology (CCUS)	Stores carbon emissions from coal plants underground	*Large-scale deployment*: By November 2022, more than 100 CCUS demonstration projects were operational or in progress (Li, 2025).
Circulating Fluidized Beds (CFB)	Burns coal without flames and has low emissions	*Under development*: In late 2024, China's Harbin Electric Corporation (HEC) successfully tested its ultra-supercritical CFB power generation unit with a record-breaking capacity of 660 MW (Amiri, 2025).

Nuclear Energy Technology

Nuclear energy is considered clean energy due to its negligent emissions relative to its large generation capacity. Nuclear energy is one of China's "most important decarbonization electricity supply" (Sun et al., 2016). Modern nuclear power plants use nuclear fission where atomic nuclei (typically of Uranium-235) are split in half and cause a chain reaction, producing a significant amount of heat in the process. This heat energy is used to vaporize water and power a steam turbine to generate electricity, similar to a coal-fired power plant. A nuclear reactor produces approximately 1 GW of power, which is equivalent to the power produced by 431 utility-scale wind turbines or over 3.1 million solar panels (The Ultimate Fast Facts, n.d.). By June 2024, China had 56 operational nuclear reactors and another 27 reactors under construction (Ezell, 2024). Most of these reactors are 3rd generation reactors that were designed by the Westinghouse Electric Company - a company based in the US before being acquired by Toshiba in 2006 (Ezell, 2024). The following technology advancements have expanded China's domestic nuclear capacity and laid the groundwork for nuclear energy to be a stable long-term energy source.

Nuclear Energy Technology Advancements		
Technology	Why It Matters	Development/Deployment Stage
Hualong One	First domestically produced 3rd generation nuclear reactor	*Small-scale deployment*: In late 2020, the first Hualong One reactor was connected to the grid (First Hualong One, 2020). There are 41 units commissioned, under construction, or operational (The Hualong One, 2025).
LingLong One	World's first commercial land-based small modular pressurized water reactor	*Under construction:* In May 2024, China completed construction of the main control room. Construction is anticipated to be completed in 2026 (GT staff reporters, 2024).
High Temperature Gas-Cooled Reactor – Pebble-bed Module (HTR-PM)	China's first 4th generation nuclear reactor and world's 2nd SMR	*Small-scale deployment*: In 2021, the first HTR-PM was connected to the grid at Shidao Bay Nuclear Power Plant (Shidaowan HTR-PM 1, n.d.). There is one operational unit.
Thorium-fueled Molten Salt Reactor Prototype	Enhanced safety and less nuclear waste	*Under development:* In 2025, the prototype was successfully refueled during operation, marking a breakthrough in nuclear innovation (China Refuels Thorium Reactor, 2025).
Experimental Advanced Superconducting Tokamak (EAST) *aka "artificial sun"*	World's first nuclear fusion demonstration reactor (up to 4 times more energy than nuclear fission)	*Under development:* By 2035, China aims to construct the first nuclear fusion demonstration reactor (Ezell, 2024).

Solar Energy Technology

Solar energy is a significant driver of China's transition to clean energy. China's technology developments in solar energy encompass improvements to solar panel efficiency and expansions to vast solar farm infrastructure. China is home to 6 of the 15 largest solar farms in the world in terms of generation capacity (Gill, 2024). These massive solar panel deployments located in China's arid regions showcase strategic repurposing of land for clean energy and China's ability to build large-scale solar infrastructure in harsh environments. In 2024 alone, China added nearly 277 GW of additional solar capacity, which is an even greater increase from 2023 (Myllyvirta, 2025). This brought China's total utility-scale solar capacity to over 887 GW, solidifying the nation's dominance in solar energy expansion (China's Solar Capacity Installations, 2025). On a smaller level, distributed solar, which is small-scale decentralized solar energy deployment, provides 41% of China's total solar capacity, with residential rooftop installations making up a significant share of that 41% (Yu et al., 2024).

Solar panels are made up of smaller PV cells, typically made of crystalline silicon layers, and convert sunlight into electricity (U.S.–China Economic and Security Review Commission, 2022). When sunlight hits a PV cell, electrons are knocked around and flow in one direction, which produces an electric current. This current can travel through an external circuit and power a household appliance (with enough solar panels) (TED-Ed, 2016). Traditional solar panels are made up of monocrystalline and polycrystalline cells. The following technology advancements have exponentially expanded China's solar energy capacity and showcase China's commitment to clean energy.

Solar Energy Technology Advancements		
Technology	Why It Matters	Development/Deployment Stage
Monocrystalline Passivated Emitter Rear Cells (PERC)	Makes solar panels more efficient and weather resistant	*Large-scale deployment*: In 2017, 20 MW of solar panels using monocrystalline PERC technology were connected to the grid in Golmud (World's Largest Bifacial Solar, 2018).
Bifacial Solar Panels	Uses both sides of the panel to generate electricity	*Large-scale deployment*: In 2025, Midong Solar Park entered operation with millions of bifacial monocrystalline silicon panels (Soul, 2025).
Xinjiang Solar Farm	World's largest solar farm (by capacity)	*Completed*: In June 2024, China completed constructing the 3.5 GW capacity solar farm (Howe, 2024).
Solar Great Wall	Could generate enough electricity for Beijing	*Under construction*: By 2030, China aims to complete construction, but less than 6% has been installed so far (Voiland, 2024).

Wind Energy Technology

Wind is the second largest renewable energy source, only behind hydropower ("China: Highlights," 2025). Once China started mass manufacturing wind turbines, domestic generation capacity increased exponentially. China is now the world's largest wind turbine manufacturer (Cytera & Lagercrantz, 2024). Wind turbines utilize long, flat-shaped blades to catch the wind and generate lift, like the effect created by airplane wings. As the wind turns the blades, they rotate a generator inside the turbine, which converts the kinetic energy into electrical energy (Wind Explained, 2023).

China's wind energy technology developments largely involve increasing individual turbine generation capacity and expanding large-scale wind farm projects. The following technology advancements highlight China's investments in expanding its wind energy capacity.

Wind Energy Technology Advancements		
Technology	Why It Matters	Development/Deployment Stage
World's Largest Offshore Wind Turbine (Dongfang Electric Corporation)	Could generate enough electricity for 55,000 homes	*Small-scale deployment*: In 2024, Dongfang Electric Corporation constructed an offshore wind turbine with 26 MW generation capacity (Hale, 2025).
Gansu Wind Farm	World's largest operational onshore wind farm	*Under construction (but operational)*: As of June 2025, the farm has a nearly 10 GW generation capacity. China plans to increase the capacity to 20 GW (Jessen, 2025).

Electricity Transmission Technology

The intermittent nature of renewable energy sources presents a major challenge for China's initiative to expand its renewable energy generation capacity. China's largest renewable power plants are located in remote regions or the western part of the country, far from the densely populated urban centers in the east. China has found viable solutions in expanding and upgrading its transmission networks.

UHV transmission lines deliver electricity from remote electricity generation stations to densely populated urban centers. High voltage enables the same amount of power to be transported through the transmission lines with a lower current, reducing power loss. China has 42 UHV transmission lines which take electricity from large central power plants to consumers across regions (U.S. Energy Information Administration, 2025). UHV lines can hold one of two types of currents: direct currents (DC) or alternating currents (AC). Direct currents have a constant voltage and current direction while alternating currents can change voltage and current direction. Chinese Ultra High Voltage Direct Current (UHVDC) lines operate at least 800 kilovolts (kV) and Ultra High Voltage Alternating Current (UHVAC) lines operate at least 1000 kV. UHVDC lines reliably carry more power across longer distances, enabling the grid to meet increasing energy demands, while shorter AC lines are used to connect to local electricity grids. China has a mix of both types of lines (You, 2024). The following technology advancements have expanded China's ability to transport electricity from sparsely populated regions to high-demand urban centers.

Electricity Transmission Technology Advancements		
Technology	Why It Matters	Development/Deployment Stage
Changji-Guquan UHVDC Link	Hosts world's longest HVDC lines	*Completed*: In 2019, the link connecting Xinjiang to eastern China was connected to the grid (U.S. Department of Energy, 2020).
Zhangbei-Shengli UHVAC Project	Connects arid regions of inner Mongolia with densely populated areas	*Completed*: In late 2024, the project began operation and is expected to generate over 70 billion kWh of electricity per year (Xinhua, 2024).
Smart Grids	Monitors and enhances grid stability	*Under development*: Smart grids are still in the pilot phase. As of June 2025, several small-scale experimental projects are in operation.

Energy Storage Technology

Energy storage methods convert electricity into a variety of energy sources, and vice versa. This technology facilitates decentralization of the grid, which accelerates the integration of renewable energy sources into the grid (Wang & Xue, 2025). Today, popular energy storage options include compressed air energy storage (CAES), lithium-ion batteries, and sodium-ion batteries. All these methods essentially store surplus electricity by converting it into a more stable form of energy, which can later be transformed back into electricity when needed. The following technology advancements have expanded China's energy storage capacity and highlight China's investments in diverse energy storage methods.

Electricity Storage Technology Advancements		
Technology	Why It Matters	Development/Deployment Stage
World's Largest CAES Facility	Environmentally sustainable energy storage method	*Completed*: In 2025, the facility entered operation with a 300 MW capacity in Hubei province (Maisch, 2025).
Sodium-Ion Battery Energy Storage System Project	Cheaper and widely used storage method used on a grid scale	*Under construction (but operational)*: In 2024, the project's first phase connected to the grid with 50 MW capacity, with plans to double it to 100 MW (Murray, 2024).
Dalian Flow Battery Energy Storage Peak-shaving Power Station	Stable and reliable energy storage for renewable energy	*Completed*: In 2022, the power station was connected to the grid with a 100 MW capacity (Zhang, 2022).
Dinglun Flywheel Energy Storage Power Station	Stores energy quickly and provides grid stability	*Completed*: In 2024, the power station was connected to the grid with a 30 MW capacity (Undecided with Matt Ferrell, 2024).

AI Advancements

AI can optimize electricity grids by balancing supply and demand fluctuations and enhancing equipment performance. China has already started integrating AI into its electricity grid through various ways. A utility company implemented a smart grid management system in Guangzhou to predict maintenance needs and search for issues, resulting in fewer power outages. A thermal power plant implemented an AI-powered maintenance system to predict equipment issues. Another renewable energy technology company leveraged AI models to predict wind energy generation, mitigating the intermittent nature of renewables from the receiving side (Li & Zhang, 2024).

Despite these achievements, AI integration into the grid still faces significant challenges from the regulatory, technological, and operational sides. Focusing on the technological limitations, it is difficult to gather large quality datasets to train AI models. Furthermore, AI models are largely in the pilot stage and limited to the datasets they are trained on. Moving forward, it is crucial for China to continue integrating human operation and AI capabilities to improve its energy industry (Li & Zhang, 2024).

Major Takeaways: Key Technology Advancements

This section outlined China's key technology advancements across its power generation, transmission, and storage sectors. Specifically, the discussion focused on individual technologies and large-scale projects in various development and deployment stages that are driving China's transition to clean energy and carbon neutrality. China is leveraging advanced clean coal and nuclear energy technologies to enhance the sustainability of its stable energy sources, supporting the growth of its renewable energy power generation capacity. China's UHVDC transmission lines and advanced energy storage projects enable rapid and large-scale expansion of its power generation capabilities by improving grid stability and transporting electricity from arid regions to dense urban cities. Experimental projects with AI integration into the electricity grid offer potential improvements in efficiency and reliability, but face challenges for large-scale deployment. These technology advancements enable China's growing dominance in the energy sector and reflect the success of its energy policies and state-backed research and development efforts.

Domestic Policy Environment

Domestic Policy Drivers

China's greatest challenge and advantage is one in the same: their top-down approach to policy implementation. China's policy implementation is defined as fragmented authoritarianism, with the central government creating institutional policy, but implementation occurring on a local level. (Lo and Ngar-Yin, 2023) Local officials are incentivized to implement policies efficiently through a cadre evaluation system, with performance targets ranked in terms of significance; the harder a target they accomplish, the more likely they are to receive a promotion. In regard to energy policy, provinces with more state-owned industry are more successful in achieving energy efficiency compared to provinces with greater authority over the local economy, which resist the implementation of central policies that may be at odds with economic growth, like energy efficiency policies. Therefore, when China was faced with increasing energy demands in the past (2002-2005), they reshaped their provincial evaluation system by prioritizing energy usage reduction results. (Van Aken and Lewis, 2015) Although districts with stronger local influence and control may want to prevent regulation, China's centralized system of policymaking allows them to promote energy efficiency policies and manage periods of higher demand on energy grids.

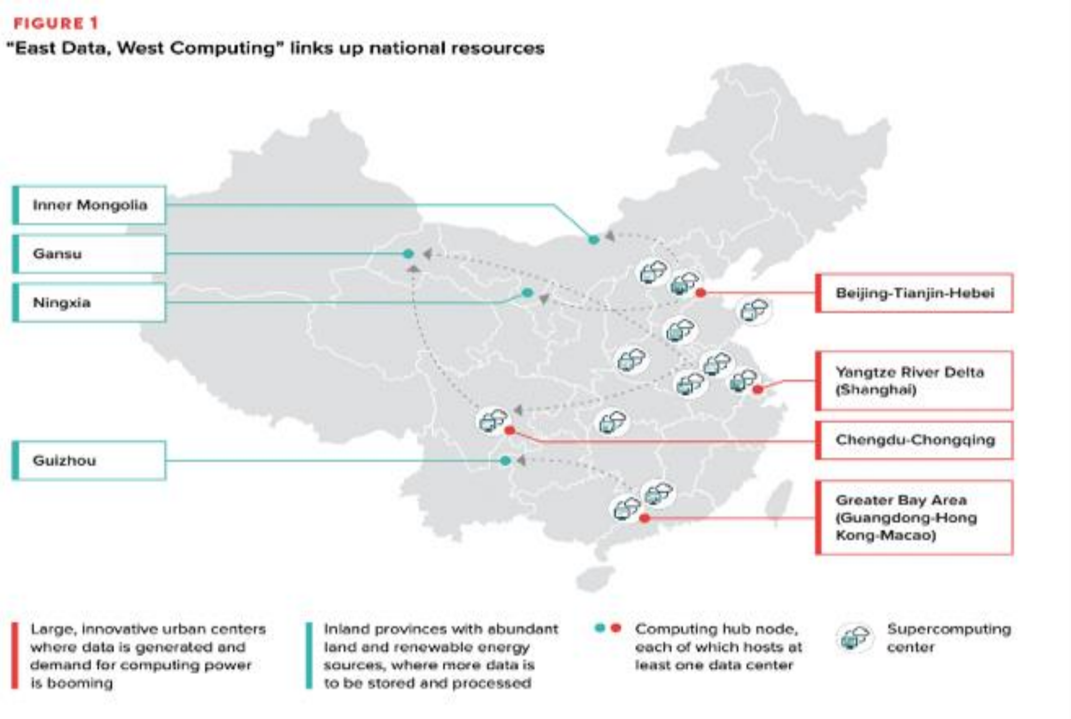
Current Policies and Future Outlook of Domestic Policies

AI Development

In 2017, China released the "Next Generation Artificial Intelligence Development Plan," which outlined China's plan to become the world's primary innovation center by 2030. This plan set AI development targets as a high-priority goal, meaning state officials were highly incentivized to invest heavily in AI research. (Stanford, 2017) While AI is often portrayed as a clean, smart solution, its development and adoption in China create significant new energy challenges. The digital economy is driving up power demand, with AI, cloud computing, big data, and blockchain all needing large-scale infrastructure to function. China had 449 data centers by the end of 2023, the most in Asia-Pacific. The IEA estimates that data centers will consume nearly 6% of China's total electricity by 2026, which is a major share of grid infrastructure. These massive data centers use both electricity and water to operate, and their environmental impact is stronger in resource intensive areas. (Arcesati, 2024)

Due to the energy intensity required by AI, Chinese policymakers are investing in smart grid technology, regional coordination, and new transmission lines to better link supply and demand. In 2021, China announced plans to construct new data centers that are efficient, clean, optimized and circular. Beijing, for example, has supported data centers financially if they can improve their power usage efficiency (PUE), with a target of 1.25 or lower. (Yuan, 2025) China is also exploring utilizing AI to reduce energy intensity at the enterprise level. A study from 2011 to 2019 found that for every robot added per one hundred workers, energy intensity dropped by about 2.5%. This reduction was even larger for SOE's, companies that are not labor intensive, and firms that already heavily rely on energy. AI helps optimize processes, reduce energy waste through automation and monitoring, and can build energy management systems through deep learning. (Zhang and Ming, 2024)

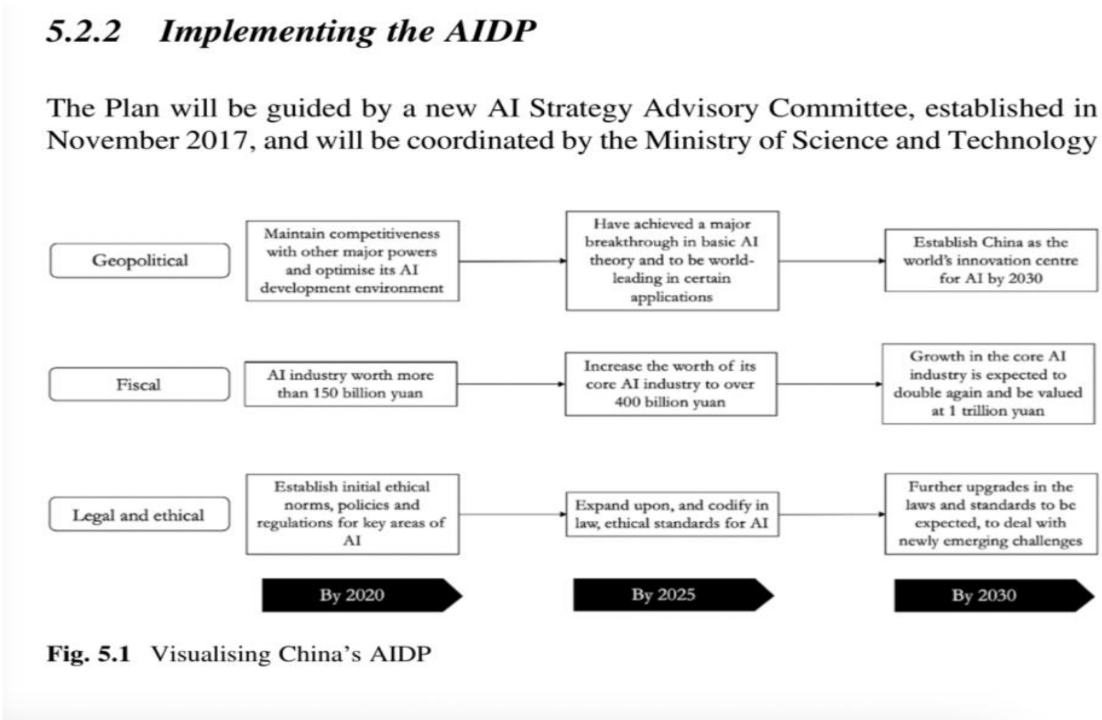
The biggest challenge AI poses is that AI development contradicts China's green energy mission. While clean and renewable energy can be used to power AI, China's clean energy and its digital infrastructure are in different stages of development. (Zhang and Ming, 2024) To address the lack of renewable energy generation capacity in the East, the central government launched the "East Data, West Computing" initiative in 2022. This encourages building new data centers in the west, near renewable energy sources, as pictured below. These centers will handle long-term analysis and storage, while real-time services stay closer to users in the East. This brings the benefits of a digital economy beyond the coastal cities and insulates China's domestic market from external threats as they become more self-sufficient in energy production. (Groenewegan-Lau, 2022)



East Data, West Computing, (Arcesati, 2024)

AI is becoming part of China's national energy and development plans, as seen through their FYPs. It plays a role in improving the power system through predictive maintenance, demand forecasting, and optimization tools. (Liengpunsakul, 2021) Yet, AI's inefficiencies prevent it from becoming a reliable method of energy security, as grid development, clean energy integration, and digital adoption are uneven across provinces. Therefore, central planning is still necessary to keep progress moving. China's "AI Plus" initiative and the National Integrated Computing Power Network are examples of how infrastructure and technology development are being tied together. (Global Times, 2024) Finally, China faces their largest challenge in AI development due to the restriction of semiconductor technology. With ongoing restrictions by the United States on exporting precious semi-conductors and chips, China must resort to smuggling technology to make AI developments.

China's goal is to become the world's primary AI innovation center by 2030. Their 2017 "Next Generation Artificial Intelligence Development Plan" sets AI development as a high-profile goal, which ties back to China's policy implementation. (Yang and Huang, 2021) As a result, local governments are pouring billions of dollars in pursuit of this goal. AI is now central to China's energy policy decisions, and it greatly impacts their ability to gain a competitive edge on the global stage. (Sheehan, 2018) AI is potentially a shortcut to achieve innovation and surpass rivals, but it can also worsen China's unemployment crisis. It has yet to be seen if China's extensive list of demands from local officials will be accomplished. (Hine, Emmie, and Floridi, 2024)



5.2.2 *Implementing the AIDP*

The Plan will be guided by a new AI Strategy Advisory Committee, established in November 2017, and will be coordinated by the Ministry of Science and Technology

Fig. 5.1 Visualising China's AIDP

AIDP Implementation (Roberts et. al, 2021)

Domestic Investment

Overview of China's Domestic Investment Strategy

In China, investment in power generation is an extension of statecraft. Capital is allocated to reduce reliance on foreign energy, build a long-term technological advantage, and address regional imbalances in electricity supply and demand. Through FYP, policy banks, and SOEs, the state manages power generation as a strategic asset rather than a competitive market–with investment decisions tied to political priorities and national planning targets. For the purpose of this analysis, investment is defined as the state-controlled deployment of capital to build, modernize, or secure energy infrastructure in line with national strategic goals.

China's domestic energy investment has expanded rapidly under centralized planning and national security mandates. Fixed asset investment (FAI), which is state-directed capital spending on infrastructure such as power plants, is deployed to reduce reliance on foreign energy and strengthen industrial self-sufficiency. Guided by the FYPs, this investment is executed by SOEs operating under political directives. The 14th FYP (2021–2025) designates the construction of a "modern energy system" as a core objective, prioritizing UHV transmission, grid digitalization, and renewable deployment (*Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China*, 2021). As of 2024, China had already built 42 UHV lines, comprising the world's most expansive UHV network, with State Grid, an SOE, planning to invest nearly ¥380 billion (53 billion USD) in additional UHV projects through 2025 ("China's State Grid Outlays Record $88.7 Bln Investment for 2025," 2025). According to the Center for American Progress, State Grid has committed more than $250 billion over five years, including at least $45 billion toward smart grid technologies, reinforcing the central government's push to digitize transmission infrastructure and manage increasingly complex energy flows (Hart, 2011).

A case study from Jiangsu Province illustrates this model in action: the State Grid Jiangsu Electric Power Company built out advanced digital infrastructure and real-time control systems to meet national modernization targets, exemplifying how provincial SOEs execute central energy planning at scale (Forrest, 2025). Such modernization is intended to accommodate rapid growth in wind and solar while preserving grid stability and reducing China's foreign energy dependence.

Problems with China's Domestic Investment Strategy

Yet despite the scale and coherence of China's investment strategy, there are structural inefficiencies that complicate the execution of such investments and their long-term impacts.

<u>The Lack of Domestic Investment Oversight</u>

While China's central government has set ambitious energy investment goals through its FYPs, the literature shows that weak regulatory institutions have made it difficult to translate these goals into efficient project-level outcomes. The National Energy Administration (NEA), which oversees energy policy, lacks the legal authority to control how investment decisions are made. They are unable to approve or reject specific infrastructure projects or determine electricity pricing; the NEA lacks the institutional capacity to enforce their national plans. Such power remains with the more powerful National Development and Reform Commission (NDRC).

As observed by scholars, China's state backbone grid companies, operating under SOE structures, function within "distorted incentive structures" that reduce risk-taking, and shift focus toward short-to-medium-term commercial returns rather than long-term national energy security or system optimization (Yi-chong, 2019). In the absence of credible oversight, SOEs can initiate redundant or misaligned projects that crowd out more targeted investments.

The regulatory vacuum within energy investment has tangible consequences. Rawski finds that State Grid's vertically integrated structure enables it to pursue aggressive expansion of UHV transmission not based on systemic need, but to enlarge asset holdings and strengthen its domestic monopoly position (Rawski, 2017). The Paulson Institute similarly notes that grid firms often initiate large-scale projects to generate stable, regulated returns, regardless of broader system planning (Paulson Institute, 2015). These incentives–combined with weak regulatory oversight–have led to the rapid buildout of transmission assets that frequently exceed actual utilization needs. By 2017, many UHV lines were operating at only 60-70 percent of intended capacity, reflecting the disconnect between infrastructure expansion and system-level coordination (Energy Charter Secretariat, 2017). This overcapacity imposes long-term efficiency and cost burdens, undermining the strategic logic behind such large-scale investment.

Regional Inequality in Investment

While China's power sector strategy has emphasized large-scale infrastructure expansion to support national development and decarbonization goals, in practice, power grid investment has been highly uneven across regions–contributing to structural inefficiencies and widespread overcapacity. Inland, rural and underdeveloped provinces, many of which generate surplus electricity, particularly from coal, are often disconnected from demand-heavy coastal regions due to inadequate transmission capacity. Such disconnection has created a misallocation of capital: generation and grid assets are built in places where they cannot be fully utilized, while clean energy integration and emissions reductions stall due to weak interregional connectivity.

Yang et al. develop the Peripheral Degree Index (PDI) to quantify disparities in grid development, demonstrating that power infrastructure remains concentrated in coastal and central economic hubs. These regions benefit from dense transmission networks and high industrial demand, while inland provinces, despite producing the majority of the country's electricity, receive disproportionately low levels of grid investment. Their analysis shows that inland provinces receive just 65% of the per capita grid investment compared to coastal areas (Yang et al., 2020). Su et al. extend this critique, finding that China's power transmission investment reinforces existing spatial disparities, concentrating infrastructure in economically advanced eastern provinces while under-serving resource-rich western regions (Su et al., 2018). Despite abundant wind and solar generation potential, these inland areas face persistent limitations in transmitting power to high-demand urban centers due to lagging interregional connectivity.

Instead of being shaped by national system needs, infrastructure decisions are often driven by provincial political incentives and economic performance metrics, such as GDP growth and capital expenditures. These distorted priorities produce redundant or underutilized grid assets that exacerbate national overcapacity. Rather than enabling an efficient, decarbonized electricity system, regional inequality in grid investment constrains China's ability to meet both its economic and environmental objectives.

The Future of China's Domestic Investment in Power Generation and AI

China's artificial intelligence sector emerged from a coordinated state-led effort to build national technology capacity. The central government launched the New Generation Artificial Intelligence Development Plan in 2017, which defined AI as a strategic priority tied to long-term goals of economic modernization and digital sovereignty (Webster et al., 2017). SOEs and government-guided funds were tasked with building the infrastructure and foundational capabilities needed to scale AI development. By 2023, these funds had deployed over 912 billion USD across strategic sectors, with approximately 23 percent supporting more than 1.4 million AI-related firms (Beraja et al., 2024). SOEs and designated "national AI teams" such as Baidu, Tencent, and iFlytek were assigned leadership in key technical domains, including computer vision, autonomous driving, and language processing (Larsen, 2019). These early investments created a baseline ecosystem of computing resources, data assets, and industrial coordination.

This state-driven foundation signaled confidence to private investors and enabled rapid expansion by China's technology firms. Between 2014 and 2024, the private sector completed more than 8,000 AI investment deals, totaling approximately 85 billion USD (*China's AI Strategy and Analysis*, 2025). Companies including Alibaba, Huawei, and SenseTime built proprietary models and enterprise platforms, while also expanding R&D in AI chips, robotics, and cloud integration. Surveys suggest a strong forward trajectory: 87 percent of Chinese firms reported plans to increase AI spending in 2025, with over half indicating faster-than-expected deployment (王丹宁, 2025). Crucially, the relationship between public and private capital was not incidental–71 percent of firms that attracted both sources of investment received government funding first (Webster et al., 2025).

At the provincial level, AI investment has been uneven but strategically coordinated. Inland provinces have emerged as computing hubs under the Eastern Data, Western Computing initiative, launched in 2021. By late 2024, ten national computing zones had been built, with total investment exceeding 33 billion USD (Stokols, 2025). Guizhou, Gansu, and Ningxia now host large-scale data infrastructure, while coastal hubs like Beijing and Shenzhen continue to focus on software development, smart city applications, and public service platforms.

Despite these gains, two constraints continue to shape China's AI investment landscape. First, export controls imposed by the United States have sharply restricted access to high-end GPUs, limiting model training and hardware performance. Chinese chipmakers, including SMIC and Huawei, remain two to three generations behind global leaders in advanced fabrication (Beraja et al., 2024). In response, authorities have scaled domestic chip subsidies and introduced voucher systems that grant smaller firms access to state-managed cloud computing at reduced cost (ITIF). Second, coordination problems persist within China's investment ecosystem. Hundreds of overlapping government guidance funds have diluted capital efficiency and led to redundant or misaligned projects (Omaar, 2024). Since 2019, regulators have begun consolidating these funds and narrowing mandates to improve oversight and avoid duplication (Webster et al., 2025). These reforms signal a shift from volume-driven growth to a more selective, outcome-oriented investment strategy–an essential adjustment as AI systems grow more capital-intensive and technically complex.

Outside China

Foreign Investment

Understanding China's foreign energy investments is essential to understanding its broader geopolitical role in energy and power generation. These outbound projects reflect the same institutional logic that governs power generation inside China: centralized planning, SOE-led execution, and strategic allocation of capital. By examining how China builds and finances energy infrastructure abroad, we gain insight into how it seeks to shape global energy flows, embed its technical standards, and extend its political and industrial influence beyond its borders.

China's outbound investment in energy infrastructure has become a defining feature of the Belt and Road Initiative (BRI), Beijing's global development strategy launched in 2013. Through state-backed financing and construction, China has built pipelines, power plants, and transmission networks across Asia, Africa, the Middle East, and beyond. These investments serve multiple objectives: securing long-term access to energy resources, exporting industrial overcapacity, and strengthening China's geopolitical influence in key regions.

The scale of these energy investments is considerable, but questions remain about their efficiency, coordination, and long-term impact. Many projects operate in fragile political environments, face limited legal protections, and encounter technical or financial underperformance. As Beijing shifts toward a "high-quality BRI," understanding the structure, risks, and outcomes of these energy investments is critical.

The Belt Road Initiative and Foreign Investment Strategies

China's outbound energy investment under the BRI reflects a centralized model in which energy infrastructure serves both foreign policy and domestic industrial objectives. These investments are dominated by SOEs, including CNPC, Sinopec, and State Grid, working in coordination with China's policy banks. While formally categorized as foreign direct investment, the strategy behind these projects differs sharply from market-based investment models. The central goals are to secure long-term access to energy, support domestic industrial capacity, and embed China into the physical and regulatory infrastructure of their partner countries (Buckley et al. 2018).

Chinese energy FDI typically takes two forms: Greenfield investment, where Chinese firms build energy infrastructure from scratch, and cross-border mergers and acquisitions (M&A), where they acquire existing foreign energy assets. Milleli and Sindzingre document a consistent pattern: M&A dominates in developed economies such as Canada and Australia, where Chinese companies target upstream oil and gas assets (Sindzingre & Milelli, 2013). In contrast, Greenfield investment is more common in developing regions–including Africa and South Asia–where Chinese SOEs finance and construct power plants, hydropower dams, and long-distance transmission lines. These projects are often integrated into broader economic deals involving roads, ports, or resource concessions.

At the same time, China uses outbound energy investment to address domestic economic pressures. Chen and Galkin argue that many of these overseas projects function as industrial export mechanisms, absorbing excess capacity in construction, turbine manufacturing, and engineering services (Chen & Galkin, 2023). For example, Chinese firms have exported turnkey coal-fired power plants to South and Southeast Asia, using domestic turbine designs and environmental control systems. This model is embedded in China's broader planning apparatus, especially the 13th and 14th Five-Year Plans, which link outbound investment to national development goals such as infrastructure connectivity, industrial upgrading, and energy security (*Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China*, 2021)

In parallel, China seeks to standardize global infrastructure around its own technical systems. Chen and Galkin point to the export of UHV transmission technology as a form of soft power (Chen & Galkin, 2023). By embedding Chinese design and operating standards in partner countries, these investments increase long-term technical dependence and ensure Chinese firms retain influence over maintenance, upgrades, and regulatory adaptation.

Regional Patterns of Chinese Energy Investment

Chinese outbound energy investment varies significantly by region, with clear differences in strategy and project type. In Central Asia, Chinese firms focus on upstream oil and gas and cross-border pipelines. These investments are meant to secure stable overland energy flows and reduce dependence on maritime routes, but they often take place in weak legal environments and rely on bilateral government agreements (Boute, 2019).

In the Middle East, Chinese SOES are primary interested in the upstream oil reserves. Although recent reports note increasing Chinese involvement in solar and hydrogen projects in countries like Saudi Arabia and the UAE (Wang, 2025), fossil fuel infrastructure still dominates. In Africa, Chinese Greenfield investment is concentrated in hydropower and transmission infrastructure and is often linked to exporting Chinese construction capacity (Chen & Galkin, 2023). However, many of these projects have encountered delays, financial strain, or political backlash (Chatzky, 2023).

Elsewhere, China adjusts its approach based on local conditions. In Southeast Asia, Chinese banks and SOEs have financed coal plants in Indonesia (Custer & Gruber, 2025). While there is a push toward green initiatives, high-emission investments remain common. In South Asia, Pakistan stands out as the primary energy partner through the China-Pakistan Economic Corridor (CPEC), which includes coal, solar, and grid projects (Usmani et al., 2024). Across all these regions, the Chinese model remains consistent–leveraging SOEs, policy financing, and diplomatic tools to secure energy access, support domestic industry, and expand geopolitical reach.

The Future of China's Foreign Investment

Since 2018, China has moved away from financing large-scale coal and hydroelectric projects in politically unstable or economically vulnerable environments. This shift reflects a recognition that many high-profile outbound investments under the BRI failed to deliver reliable returns or provoked backlash from host governments and civil societies.

The case of Sri Lanka is illustrative. While the Puttalam coal-fired power plant, funded by Chinese policy banks, did reach completion, it became politically entangled with the Hambantota Port–another BRI project–and was later cited as a contributing factor to Sri Lanka's sovereign debt crisis. The literature shows that this outcome undermined public support for further Chinese energy projects, spurring Beijing to reevaluate its exposure to fragile fiscal environments (Moramudali & Panduwawala, 2024).

In response, China has announced a strategic reorientation. Beijing's new emphasis on "high-quality" BRI projects includes clearer environmental standards, smaller-scale renewables, and stricter risk assessment protocols. The Green BRI initiative, launched in 2019, formalized this approach. According to Liu et al., Chinese firms are increasingly investing in solar and wind in middle-income countries with stable institutions, such as Vietnam, Saudi Arabia, and the UAE (Liu et al., 2020). These projects aim to reduce reputational risk and shift away from the debt-heavy megaprojects that characterized early BRI lending.

Still, as the literature shows, the structural goals of China's energy FDI remain intact: to export industrial overcapacity, embed Chinese technical standards abroad, and secure long-term political relationships through energy infrastructure. While project selection has become more cautious, the underlying model continues to prioritize state-led influence over commercial efficiency.

Foreign Grid Expansion

Another strategic component of securing China's energy sector and power grid is its expansion and interconnection of the electricity grid with other countries. First proposed by State Grid Corporation in 2015, the Global Energy Interconnection (GEI) policy is labeled as a method to revolutionize renewable energy, transition, and serve as an economic opportunity for other countries, especially developing nations (Quiembre et al, 2023).

Although the idea was initially proposed by State Grid, the Global Energy Interconnection Development and Cooperation Organization (GEIDCO) nonprofit was established to oversee the interconnection and collaboration between China's SOEs and the governments of other participating countries (Quiembre et al, 2023). This GEIDCO nonprofit status has additionally created a proposed governance structure that allows China to claim non-affiliation. Yet, the governing board of GEIDCO is mainly comprised of Chinese SOEs as well as CCP Chairmen or those with CCP affiliation. Additionally, due to State Grid's, the enterprise controlling the majority of the electricity grid in China, role in progressing the grid expansion and interconnectedness of numerous countries; China is at the forefront of efforts to invest, expand, and centralize electricity interconnection with a strategic China centralized focus (Quiembre et al, 2023). As the GEI expands in its efforts to enhance the interconnectivity of cross border power lines, the main corridors for electricity projects will follow those of China's BRI development, especially efforts in the energy and electricity sectors (Quiembre et al, 2023).

Prior to the official state policy of GEI and the establishment of GEIDCO, China's efforts to expand its' dominance in the electricity sector have been seen through global investments in foreign electricity companies and sectors (Quiembre et al, 2023). Reports show that between 2000 and 2017, China invested approximately $115 billion USD towards electricity sectors. These investments have helped shape Chinese firms' control over different electricity corporations globally. For example, in Brazil, China has stakes in 10% of national power generation capacity and, due to investments in UHV lines, holds 12% of investments in transmission lines. Chile's electricity sector is heavily influenced by China holding 57% of its ownership. Cambodia, due to significant Chinese BRI investment in energy generation, holds 80% of local electricity capacity.

Finally, in the Philippines, State Grid fully controls ownership of the National Grid Corporation, an entity that serves around 93% of the total population of the Philippines (Quiembre et al, 2023).

Electricity exports are also a substantial portion of China's electricity generation, as seen through their exports of 20 million GWh in 2023. These exports were mostly to the administrative zones of Hong Kong and Macao followed by Mongolia, Myanmar, and Vietnam further receiving high quantities of Chinese electricity exports (World Bank, 2023).

Although GEIDCO has not invested in UHV transmission line capabilities globally, China as the leader in UHV technology through the initiatives of State Grid has started to expand their capabilities and ownership globally as seen through development of UHV lines in Brazil. The establishment of the Belo Monte phase II UHV line by State Grid Corporation distributes power over 2,000 km with 800kV DC lines investing over $39.7 billion USD to expand the UHV lines interconnectivity across Brazil with Chinese control and investment over the electricity industry (NDRC, 2021).

Numerous concerns of the GEI include State Grid's interconnection with the Chinese government especially the relationship with the PLA through civil-military fusion and the development of advanced electricity generation and deployment technologies (Quiembre et al, 2023). The technologies that are employed through the GEI initiatives such as the use of the corporation Huawei 2.0 software and technology create concerns that due to corporations' status with the PLA, China's military will have significant control and influence over the infrastructure of certain countries if implemented through GEIDCO initiatives (Quiembre et al, 2023).

Limitations

Mistranslations can lead to inaccurate statistics and measurements. Western news outlets and academic articles often refer to translated versions of Chinese state reports and Chinese news articles – original Mandarin writings translated to English. However, China sometimes uses its own units of measurements. For example, mu (亩) is a unit of land measurement and is equivalent to 0.165 acres. Several news articles reported Xinjiang Solar Farm to span 200,000 acres, which was a mistranslation. The original source written in Mandarin said 200,000 mu, which is closer to 33,000 acres. Additionally, it is important to note that China has high capacity for research in power and emerging energy technology. In comparison to the US, China has published over 5 times the amount of research on emerging energy technology. However, when looking at China's overall research in terms of academic quality, China ranks lower as defined through Global Scientific Impact (Quiembre et al, 2023).

Conclusion

Over the past 25 years, China has undertaken extensive efforts to expand power generation capacity and enhance grid infrastructure across its vast and geographically diverse territory. Although coal remains the dominant energy source, China has made significant progress in developing renewable energy, including wind, solar, nuclear, and hydropower, as part of a broader strategy to meet rising energy demands, reduce environmental pollution, and decrease reliance on foreign energy imports. These efforts are part of a larger goal to ensure energy security.

Historically, China's energy sector was characterized by centralized, state-owned monopolies. However, recent decades have seen gradual market liberalization aimed at improving efficiency, diversifying energy sources, and encouraging competition. This transition has been supported by substantial government-led investments in advanced technologies, including clean coal and nuclear power, large-scale renewable, long-distance transmission lines, and energy storage solutions.

China's policy evolution reflects a tension between its ambition to lead in both AI and green energy development. AI has become a strategic national priority, with the central government aiming to position China as the global AI innovation center by 2030. However, this focus has diverted resources and attention from clean energy goals. Additionally, the decentralized implementation of central policy leads to regional overinvestment and inefficiencies. SOEs, lacking strong oversight and often operating under local political priorities, have contributed to wasteful spending, overcapacity, and uneven energy efficiency gains.

Grid infrastructure has improved through the construction of UHV transmission lines, expansion of energy storage capabilities, and development of energy management systems. Despite this, regional disparities in access, outdated local grids, and bureaucratic inefficiencies continue to hamper progress. The fragmented authoritarian model, where central authorities issue broad policy goals and local governments determine implementation, has enabled flexibility but also allows for inefficiencies.

Looking ahead, China's investment outlook remains ambitious but complex. Domestically, future investments will likely focus on smart grid technologies, integrated renewable systems, AI application development, and battery storage. Internationally, China continues to exert influence through the BRI and GEI, using energy infrastructure as a vehicle for geopolitical leverage.

In conclusion, while inefficiencies persist in governance and implementation, China's centralized strategic vision and capacity for rapid mobilization provide a strong foundation for continued advancement in both AI and clean energy. The country's ability to align investment, innovation, and policy goals will be critical in addressing the dual challenges of energy security and technological transformation.

Appendix: Technical Explanations of Key Technology Advancements

Clean Coal Technology

Supercritical and ultra-supercritical coal plants have enabled China's coal industry to become more energy efficient by producing electricity using less fuel. Supercritical coal plants utilize both high pressure and temperature to bring water to its critical point where water turns into steam instantaneously. This uses significantly less energy to vaporize the same amount of water and create electricity with an average 44% energy efficiency. Ultra-supercritical coal plants utilize even higher pressures and temperatures and have an average 50% energy efficiency (J.M.K.C. Donev et al, 2024). China's Yuhuan power plant, for example, has four 1000 MW ultra-supercritical units and achieves 45% generation efficiency.

Carbon capture, utilization, and storage technology (CCUS) captures carbon-dioxide (CO_2) emissions from coal-fired power plants by compressing the gas and transporting it through pipes into underground areas to be permanently stored (Understanding Carbon Capture and Storage, n.d.). Notable CCUS initiatives include the 500-kilotonne-per-year Taizhou Project – the largest coal power CCUS facility in Asia – and an upcoming plant by Huaneng Clean Energy Research Institute expected to triple that capacity (Yang, 2023). CCUS technology can also be integrated into various fossil fuel-based power and production plants. CCUS is key to China's energy security and reduced emissions goal. This technology has the potential to be China's greatest tool against reducing domestic carbon emissions (Sun et al., 2016).

Circulating fluidized beds (CFB) generate electricity with less carbon emissions and can use a variety of fuel sources beyond coal. The core mechanisms mimic traditional coal-fired power plants, but CFB technology burns fuel with flames by continuously circulating hot solid particles in a tall furnace structure. These solid particles can be recycled and reused to heat more fuel. CFB technology uses limestone to absorb harmful pollutant gases produced in the burning process, which enables CFB to have even emissions (Sumitomo SHI FW, 2018).

Nuclear Energy Technology

Hualong One is China's first 3rd generation nuclear reactor "developed with homegrown technology and materials" (Ezell, 2024). It is a pressurized water reactor with a 60-year design life, 18-month fuel cycle, and 1200 MW capacity (Qing, 2023). A pressurized water reactor (PWR) heats water in its core using nuclear fission, pressurizes and pumps the water through tubes to heat a separate water source, creates steam and turns a turbine to generate electricity. PWRs are the most common type of nuclear reactor, largely due to their stability and efficiency (Pressurized Water Reactors, 2023).

LingLong One, a 3rd generation ACP100 model nuclear reactor, is expected to be the "world's first commercial land-based small modular PWR" with the ability to power 526,000 homes (Outer Dome Installed, 2024). **SMRs** are a category of nuclear reactors designed with smaller generation capacity – usually under 300 MW – and are transportable. The individual components can be manufactured in one location, then shipped and assembled in a separate location, making them viable options for locations that may not be able to accommodate a traditional large-scale nuclear power plant. SMRs incorporate passive systems that automatically shut down systems inside the reactor in the event of a malfunction (Liou, 2023).

HTR-PM, or High Temperature Gas-Cooled Reactor – Pebble-bed Module, is China's first 4th generation nuclear reactor and world's 2nd operable small modular reactor (SMR) (Small Modular

Reactor, 2025). It has a 200 MW capacity and was first connected to the grid in 2021 at Shidao Bay Nuclear Power Plant (Shidaowan HTR-PM 1, n.d.). China's ability to commercially operate 4th generation nuclear reactors on an industrial scale is anticipated to be 10 to 15 years ahead of the United States. Currently, China is in the process of building one of each of the six 4th generation nuclear reactor types, which are "the gas-cooled fast reactor (GFR), the lead-cooled fast reactor (LFR), the molten salt reactor (MSR), the sodium-cooled fast reactor (SFR), the supercritical-water-cooled reactor (SCWR), and the very high-temperature reactor (VHTR)" (Ezell, 2024). In 2025, China's **thorium-fueled molten salt reactor prototype** – the first of its kind – was successfully refueled during operation, marking a breakthrough in nuclear innovation. Theoretically, the technology enhances safety and reduces nuclear waste compared to conventional nuclear reactors (China Refuels Thorium Reactor, 2025).

The **Experimental Advanced Superconducting Tokamak (EAST)**, nicknamed the **"artificial sun"**, is a magnetic fusion reactor. Nuclear fusion is a growing area of focus for nuclear energy research, though it remains unfeasible due to technological limitations. Nuclear fusion involves combining two atomic nuclei together into a heavy nucleus, which releases massive amounts of energy in the process. This process mimics nuclear fusion on the sun and requires temperatures of over 100 million Celsius in a small space, which experiments have somewhat successfully replicated. Although stability remains a challenge, nuclear fusion could potentially generation four times more energy than nuclear fission, making it a highly promising energy source for the future (Chatzis & Barbarino, 2021).

Solar Energy Technology

Monocrystalline Passivated Emitter Rear Cells (PERC) are solar cells with higher efficiency and weather resistance. **Bifacial solar panels** utilize both sides of the panel to turn sunlight into energy by using reflective surroundings. Current research includes developing transparent solar modules that are ideal for urban windows because sunlight can pass through while also being turned into electrical energy. China has also pursued smart PV technologies like sensors and AI-powered monitoring systems to improve the energy efficiency of solar modules (Innovations in China's Solar, n.d.). AI applications in China's energy sector will be discussed in a later section.

Xinjiang Solar Farm is currently the largest in the world with a 3.5 GW capacity. It spans nearly 33,000 acres in the desert region of Xinjiang Province and is anticipated to annually produce over 6 billion kWh of electricity (Howe, 2024). Xinjiang and other solar farms like Junma Solar Power Station located in China's uninhabitable regions highlight strategic repurposing of land for clean energy and China's ability to build large-scale solar infrastructure in harsh environments. Sand can degrade solar panels over time, posing future maintenance challenges. Distributed solar, which is small-scale decentralized solar energy deployment, provides 41% of China's total solar capacity, with residential rooftop installations making up a significant share of that 41% (Yu et al., 2024). In late 2024, China also successfully launched the world's first and largest off-shore floating solar power station, just 8 kilometers off the eastern coast (Heynes, 2024).

The "**Solar Great Wall**" is China's most ambitious solar energy generation initiative yet and is projected to have a generating capacity of 100 GW and extend over 250 miles. The target completion date is 2030, but progress is still in the early stages as less than 6% of the 100 GW goal has been installed so far, according to Chinese officials (Voiland, 2024).

However, a study conducted by an international team of researchers found that many Chinese solar farms are operating at just 1/3 of their technical potential. The study attributes this shortcoming primarily to technological issues like solar cell inefficiencies. Additionally, solar farms require significantly more land than coal-fired power plants, which contributes to inefficient land usage (From Potential to Reality, 2024). These issues collectively work against China's energy efficiency goals and present challenges to China's heavy investment and future reliance on solar energy generation.

Wind Energy Technology

China's wind energy technology developments largely involve increasing individual turbine generation capacity and expanding large-scale wind farm projects. In 2024, Mingyang Smart Energy developed the **world's largest offshore wind turbine** with a generation capacity of 20 MW (Ghoshal, 2024). That same year, China's Dongfang Electric Corporation beat that record by constructing an offshore wind turbine with a 26 MW generation capacity. Theoretically, the annual electricity output could supply power to 55,000 homes (Hale, 2025). In terms of large-scale projects, **Gansu Wind Farm**, located in an arid region of Gansu Province of China, is the world's largest operational onshore wind farm, with a current generation capacity of nearly 10 GW. China plans to increase the capacity to 20 GW. However, the project faces challenges because of lower electricity demand in the surrounding region. The wind farm is far from major urban areas where energy consumption is much higher (Jessen, 2025).

Electricity Transmission Technology

The **Changji-Guquan UHVDC link**, connecting Xinjiang to eastern China, hosts the world's longest HVDC lines. Connected to the grid in 2019, the line "is rated at 1,100-kV, spans 3,000 km in length, and provides 12 GW of transmission capacity" (U.S. Department of Energy, 2020).

The **Zhangbei-Shengli UHVAC project** connects regions of inner Mongolia with areas densely populated eastern areas like Beijing. Put into operation in 2024, the line is rated at 1000 kV and expected to annually generate over 70 billion kWh of electricity (Xinhua, 2024).

Smart grids are still in the pilot phase. Smart grids theoretically use advanced technology to monitor the entire electricity grid in real time and can adjust according to demand and supply. This enhances network stability and efficiency. Smart grids would also enable easier integration of renewable energy sources into the grid. Moving forward, smart grid technology will be vital to China's ability to meet its energy goals.

Energy Storage Technology

In 2025, China began operation for the **world's largest CAES facility** in Hubei province with a 300 MW capacity (Maisch, 2025). CAES facilities store excess energy in the form of cold compressed air underground. Once electricity is needed, the air is released into a system that heats and expands the compressed air. This expanding air turns internal turbines, which generate electricity (OurFuture.Energy, 2019).

China's **sodium-ion battery energy storage system project** in Hubei province has a 50 MW storage capacity and is the largest of its kind. Developers aim to double the capacity to 100 MW in the future (Murray, 2024). A sodium-ion battery stores electricity from an external source through the movement of sodium ions from the positive side to the negative side of the battery. When the battery is being discharged (used), the sodium ions move back to the positive side. Sodium-ion batteries are cheaper to manufacture but have lower efficiency than their lithium-ion counterparts, making them ideal for cheaper short-range electric vehicles or large-scale electricity storage (Sivaram et al., 2024). Lithium-ion batteries, on the other hand, are highly efficient and have a long lifespan, which is why they are widely used in household electronic devices and in electric vehicles like Tesla (Wang & Xue, 2025).

Dalian Flow Battery Energy Storage Peak-shaving Power Station was connected to the grid in 2022 and has a 100 MW capacity. It uses vanadium flow redox battery technology to store excess electricity from renewables and produce electricity during peak demand hours. A vanadium flow battery has a positive and negative side, each with an electrode submerged in a solution. To charge the battery, a redox reaction causes electrons from vanadium ions to flow from the positive side to the negative side. To discharge the battery, the opposite process occurs. Vanadium flow redox technology provides stable and reliable energy storage (Zhang, 2022).

Dinglun Flywheel Energy Storage Power Station was connected to the grid in 2024 and has a 30 MW capacity. The pilot project uses 120 magnetic flywheels to store electricity. A flywheel uses a motor and large heavy wheel to store electricity as mechanical energy. When charged, the motor rotates the flywheel at extremely high speeds and continues to spin due to is rotational inertia. When discharged, the spinning flywheel connects to a generator and provides electricity. Although flywheels can store energy quickly, they also lose energy quickly due to friction, making long-term storage difficult (Undecided with Matt Ferrell, 2024).

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