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Models of Electricity Generation from Nuclear Energy in the World

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Introduction

The core competitiveness of an economy remains contingent upon finding a new energy development strategy for sustainable development and a transition towards a sustainable future. Nuclear energy is a type of energy resource that can meet the needs of industrial production; it is a comprehensive industry related to national economic development and energy security. In this chapter, we will examine the experiences of different countries in the field of nuclear energy to determine the extent to which nuclear energy has contributed to bridging the gap between energy supply and demand, as well as how it has contributed to solving environmental challenges in these countries.

This chapter will present the following points
Section One: Development Planning Trends for Nuclear Projects in China
Section Two: Evaluating the technical and economic potential for generating nuclear electricity in South Korea.

Section 1

Trends in Development Planning for Nuclear Projects in China

Introduction

China has recently resumed approving new nuclear projects, followed by the gradual maturation of next-generation nuclear reactor technology and increasingly supportive policies. This significant shift in the nuclear energy development environment will undoubtedly lead to a new phase for China.

This section explains the growth rate, development scale, and trajectory of China's nuclear energy sector by proposing economic development indicators against the backdrop of changing energy policies. These analyses also include forecasts for installed nuclear capacity, nuclear power generation, uranium imports, and other related factors.

Furthermore, the findings of this section provide the Egyptian government with suggestions for planning to promote the nuclear economy, as well as for defining a uranium procurement strategy to ensure a safe and stable nuclear energy supply. To assist developing countries in mastering and emulating the development model of China's nuclear power system.

This Section Will Present the Following Points
First: A roadmap for nuclear projects in China
Second: Current trends in China's energy needs
Third: An economic, social, and political analysis of electricity generation in China
Fourth: The current state of global supply and demand for uranium resources in China
Fifth: China's development of national capabilities and objectives related to non-fossil fuels
First Axis: A Roadmap for Nuclear Projects in China
First: The Path of Economic Development in China

China has faced serious challenges related to environmental protection, the shortage of fossil fuels, and upgrading its industrial structure, leading it to take measures to promote the use of nuclear energy. In recent years, the Chinese government has sought greener ways to develop its economy as energy shortages and environmental pollution have intensified, relying on assistance from the international community. Therefore, China has focused considerable attention on developing non-fossil fuel energy sources.

As a result, nuclear energy has attracted increasing attention from the Chinese government to reduce air pollution emissions and meet its growing energy demands, and it has begun to play a crucial role in the energy mix. With a comprehensive system of policies and institutions in place to ensure nuclear safety, public acceptance of nuclear energy technologies has garnered

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increasing attention. This high level of social acceptance within local communities contributes to the success of nuclear power projects. Consequently, China has decided to develop nuclear energy for peaceful purposes, building a local ecological society and striving for cleaner and more efficient energy to replace coal.

This underscores China's position as one of the major countries with significant potential for nuclear energy development. Faced with increasing pressure to improve the climate and meet growing electricity demand, China has, according to data published by the World Nuclear Association, 22 nuclear power units (19,095 MW) were in operation and 26 units (28,528 MW) were under construction as of December 2014. Second: The Historical Stages of Development of the Nuclear Power Industry in China

The Chinese nuclear power industry has successfully laid the foundation for rapid development and played an indelible role in national economic development and environmental protection through the construction of nuclear power plants and the development of nuclear technology in China. This development can be summarized in four stages, as shown in the following table:

Table 1: The Historical Development of Nuclear Power in China

The beginning phase From 1970 to 1993	Moderate Development Phase From 1994 to 2005	Rapid Development Phase 2006 to 2011	Safe and Efficient Development Phase From 2012 to the Present
China's first domestically designed nuclear power plant (Qinshan NPP) was built with a generating capacity of 300 MW.	A solid foundation has been laid for the rapid development of the nuclear power industry in construction, operation, and management.	In October 2007, the State Council approved the Long-Term Development Plan for Nuclear Power (2005-2020), which outlines the strategic role of nuclear power in the sustainable development of the economy and energy sector.	The State Council approved the Five-Year Plan for Nuclear and Radioactive Pollution Prevention, ushering in a new phase of safe, efficient, and steady development of nuclear power in China.
This made China the seventh country to design and build a completely new nuclear power plant independently, joining the United States, Britain, France, the former Soviet Union, Canada, and Sweden.	China has made progress in purchasing new generating capacity from France, Canada, and Russia to build two Ling'ao-type units.	By 2011, the total operational nuclear power capacity under construction reached 11,308 MW with 13 units and 29,245 MW with 26 units, respectively.	The Chinese government has taken measures to ensure the safety of the National Nuclear Protection Plan by effectively managing all stages of design, manufacturing, construction, and operation, with comprehensive quality control.
In 1982, China imported two 980 MW units from France to build the Daya Bay NPP.	By the end of 2004, China's total installed nuclear power capacity reached 4,700 MW.	The total nuclear power generation capacity in China was approximately 87.4 billion kWh, representing 1.85% of the national output.	In 2015, China had 28 operational and 26 nuclear power units under construction, with capacities of 26,374 MW and 28,976 MW respectively, accounting for 2.96% of total power generation.
Three problems emerged: 1. The lack of clear development guidelines, such as the initial location of the nuclear power plant and government financial support. 2. The absence of long-term planning. 3. A lower level of technological and scientific advancement.	International nuclear trade has been developed, and China completed the Chashma National Nuclear Power Project with a capacity of 300 MW to Pakistan. This project, which was launched in June 2000, has further boosted domestic investment through continuous technological advancements and enhanced international cooperation.	The establishment and improvement of the technical service system for the safe operation of nuclear power, the implementation of supportive conditions for the nuclear fuel cycle, and research and development efforts to enhance the technological program.	

Source: Zeng, M., Wang, S., Duan, J., Sun, J., Zhong, P., & Zhang, Y. (2016). Review of nuclear power development in China: Environment analysis, historical stages, development status, problems and countermeasures. Renewable and Sustainable Energy Reviews, 59, 1369-1383.

Third: Investment in Nuclear Power Plants by Different Countries

Nuclear energy currently constitutes an important element of global energy security and economic development. It is a cornerstone of the world's energy needs and contributes to decarbonization, generating a tangible impact on stabilizing global climate warming. This requires a strategic action plan from an international governmental team. To achieve this goal, investments are necessary to reach an installed nuclear capacity of 930 gigawatts by 2050. Consequently, it will be necessary to invest more than US$4 trillion. Approximately half of this amount (around US$2 trillion) will be required to decommission nuclear facilities, extend the lifespan of power plants, and expand nuclear capacity in OECD countries, particularly in the United States and the European Union. China must invest nearly a quarter (US$1 trillion) of the total global amount in new nuclear capacity, thus becoming the country with the largest contribution to nuclear energy development, as illustrated in the following figure:

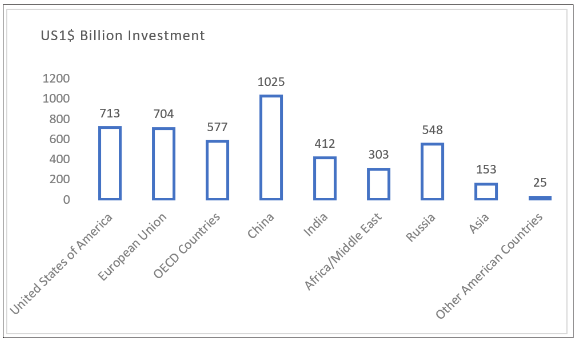

Figure 1: Shows The Contribution of Investments in Nuclear Power Plants from Different Countries.

Source: Prăvălie, R., & Bandoc, G. (2018). Nuclear energy: Between global electricity demand, worldwide decarbonisation imperativeness, and planetary environmental implications. Journal of environmental management, 209, 81-92

China will also encourage foreign investment in the construction and operation of nuclear power plants in which it has a dominant share, will continue to import advanced technology and equipment through international tenders, and the government will provide preferential investment and tax policies for nuclear power projects. China will increase its investment in research and development and in higher education in nuclear science, nuclear engineering and related materials at major universities, and intensify its research efforts on important technologies such as decommissioning nuclear facilities, reprocessing spent fuel, and processing and disposal of nuclear waste to reduce the volume of radioactive waste and make nuclear power sustainable [1-7].

Fourth: Economic Indicators of Nuclear Development in China

Power Generation Structure in China

The dry and rainy seasons lead to instability in hydroelectric power. Furthermore, the decentralized nature of solar and wind power means they cannot occupy a significant portion of installed electricity capacity in the short term. Therefore, it is essential for China to effectively improve its energy structure and diversify its supply. China's energy structure is illustrated in Figure (32).

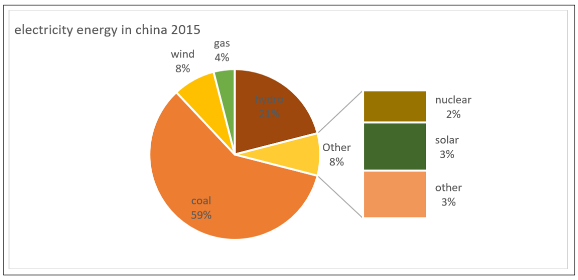

Figure 2: China's Power Generation Structure in 2015

Source: Xing, W., Wang, A., Yan, Q., & Chen, S. (2017). A study of China’s uranium resources security issues: Based on analysis of China’s nuclear power development trend. Annals of Nuclear Energy, 110, 1156-1164

Total Electricity Production from Nuclear Power in China

The traditional energy infrastructure barely meets the demand for electricity development, in addition to the scarcity of natural resources. Therefore, it became clear that nuclear power is capable of replacing fossil fuels on a large scale, fully meeting the growing electricity needs, and improving the environmental impact. As the following figure shows, the percentage of nuclear power production in China's total electricity generation increased during the period from 2000 to 2020. The total installed capacity reached 30 million kilowatts, representing 1.19% of the national energy capacity. Nuclear power plants accounted for 2.11% of China's total electricity production in 2015.

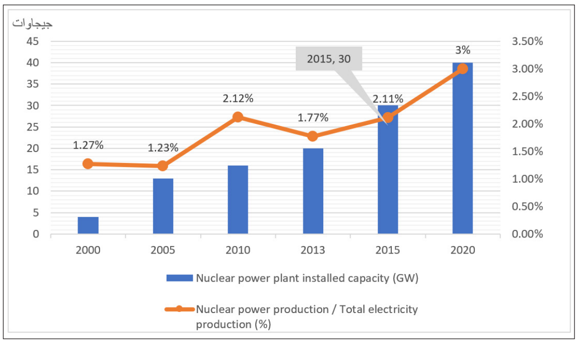

Figure 3: Nuclear Power Plant Capacity and Percentage of Nuclear Power Generation in China's Total Electricity Production

Source: Yuan, X., Zuo, J., Ma, R., & Wang, Y. (2017). How would social acceptance affect nuclear power development? A study from China. Journal of Cleaner Production, 163, 179-186.

The Chinese government has made nuclear energy the backbone of its energy policy, aiming to provide a reliable, clean, safe, cost-effective, and dependable energy source for the foreseeable future. This paves the way for a new nuclear industry and a global revival of nuclear engineering, research, and manufacturing, which will have significant economic repercussions worldwide.

Fifth: Exporting Nuclear Technology

China's export of nuclear technology has contributed to international cooperation, enabling it to become a nuclear power technology powerhouse, second only to the United States, France, and Russia. Nearly 90% of the main equipment is manufactured domestically, and industry estimates indicate promising potential in international markets, enhancing its competitiveness in the energy sector. Sixth: Public Financial Support for Technology

There is a mechanism for marketing nuclear energy that is reflected in mobilizing social capital to finance this industry and using the government funding fund to support research and development, as well as financial and tax incentives. At the beginning of the repayment period, the tax should be as low as possible, and thus the cost of generating nuclear energy is very high, but after the repayment period, the cost of generation is lower than coal energy.

Second Axis: Current Trends in China's Energy Needs

Politics plays a fundamental role in the development of nuclear energy in China, as its development requires sufficient financial support; this industry is entirely dependent on government funding.

Government Policies for Planning China's Nuclear Development Program

China's nuclear energy development policy has shifted from moderate development in the past to priority development; According to the National Plan for Nuclear Energy Development, more than 30 nuclear power plants will be built in coastal provinces with high population densities and higher levels of industry by 2020. The operational nuclear power plants will reach 44 gigawatts as shown in the following table, in addition to 18 gigawatts of nuclear power that are operational and under construction. There will be about 23 gigawatts of new nuclear power plants, and the installed nuclear power capacity will constitute at least 6% of the national installed capacity. Accordingly, electricity production from nuclear power will be increased to 6% by that time.

Table 2: Government Nuclear Energy Projects in China

A period	New capabilities (gigawatts)	Operating capacity (GW)	Capacity under construction (GW)	Total operational capacity at the end of the five-year plan (GW)
Before 2000				2.268
2001-2005	3.46	4.68	5.58	6.948
2006-2010	12.44	5.58	12.44	12.528
2011-2015	20.00	12.44	20.00	24.968
2016-2020	18.00	20.00	18.00	44.968

Source: Hou, J., Tan, Z., Wang, J., & Xie, P. (2011). Government policy and future projection for nuclear power in China. Journal of Energy Engineering, 137(3), 151-158

The table shows that the operational capacity of nuclear power increased to 12,528 GW by 2010, 24,968 GW by 2015, and 44,968 GW by 2020. The Chinese government decided to accelerate the development of nuclear power so that it would become a significant component of the power generation structure.

The Government's Objectives for Nuclear Power Planning in China are as Follows:

Operational performance and safety of nuclear power: Ensuring the safe and reliable operation of nuclear power plants, the law on environmental protection and prevention and control of radioactive pollution, regulation of safety and protection of radioactive isotopes and radiation equipment.

Engineering construction: Introducing competition and implementing a tender and contract management system to improve project management and reduce project costs.

Self-reliance in nuclear energy development: establishing self-designed power plants, manufacturing equipment with local localization, setting comprehensive standards for nuclear power construction, and managing operations in accordance with international practice.

Economics: Reducing operating costs to make nuclear power competitive with coal-fired electricity generation, and providing incentive mechanisms such as government subsidies, low-interest loans, and tax reductions.

Laws and technical standards: China has established a policy and standards framework for nuclear energy in line with international standards, including safety, facility management, emergency and radiation management, as well as engineering design, manufacturing, construction and operation.

Source: Hou, J., Tan, Z., Wang, J., & Xie, P. (2011). Government policy and future projection for nuclear power in China. Journal of Energy Engineering, 137(3), 151-158.

China's Approach to Nuclear Safety

The New Global Nuclear System for Safety and Energy Security Guarantees

Nuclear safety is a crucial component of national security and a vital area for environmental protection, particularly in terms of site selection. Therefore, the country continues to improve its nuclear emergency system, standardized legal and regulatory framework, strengthen nuclear emergency infrastructure, enhance emergency training, deepen international exchanges and cooperation in nuclear emergency response, and enact the "Nuclear Safety Law."

We emphasize that nuclear safety, long-term sustainable development, and the peaceful production of nuclear energy in the local community will be achieved by adhering to the following approach:

- Focusing on both development and security; nuclear security and nuclear energy development are interdependent.
- Developing countries that develop nuclear resources should bear equal rights and obligations and fully implement Security Council resolutions.
- The international nuclear community should strive to achieve nuclear security for the entire community, and governments should improve awareness of nuclear safety and enhance their infrastructure and technological capabilities.
- Maintaining a balance between the supply and demand for nuclear materials.

China ensures nuclear safety through:

- Strengthening safety and security standards and developing a more transparent international mechanism.
- Establishing a special program to support newly established countries in building the necessary infrastructure to ensure safe and secure nuclear energy.
- Developing more effective emergency response plans and measures to protect nuclear facilities and materials.
- Implementing higher standards to ensure the effective protection of all nuclear material stockpiles and facilities.

China's Low-Carbon Development Trends

China is a major source of carbon emissions and a significant player in mitigation projects. As a major energy consumer, China is responsible for approximately a quarter of global carbon dioxide emissions. Climate change is constraining economic and social development, and China faces international pressure to reduce carbon emissions, coupled with increasing domestic demand for fossil fuels. China has begun restructuring its energy management sector under new government leadership to harmonize energy pricing and policies across national and local industries.

The Chinese government has therefore embarked on sustainable program options, developing and integrating early warning systems, strengthening monitoring, planning, and implementation evaluation to mitigate global warming, and activating local community participation in climate change mitigation management within the framework of integrated governance, program oversight, and management for a sustainable environment.

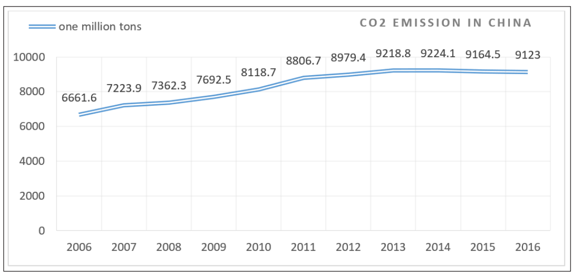

Figure 4: Shows Carbon Dioxide Emissions in China

Source: BP review of world energy 2017. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy conomics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf.

China is the largest contributor to emissions and global warming, having surpassed the United States as the world's largest emitter in 2016. As illustrated in Figure 34, emissions increased from 9,218.8 million tons in 2013 to 9,123 million tons in 2016, representing an annual growth rate of 0.24%.

The environmental impacts of fossil fuels often result in real costs to society in terms of human health, such as lost workdays, healthcare expenses, and infrastructure deterioration. However, the environmental impacts and associated economic costs are frequently included in economic comparisons between renewable and conventional energy sources.

Third Axis: Economic, Social, and Political Analysis of Electricity Generation in China

Economic Impacts on Chinese Electricity Generation Policy

Domestic electricity prices are a key factor influencing demand management and driving industrial growth. The total cost of a project does not necessarily reflect its economic viability. The relevant metric is the cost of electricity produced by the nuclear project compared to alternative electricity sources and its comparison to the market price of electricity when the nuclear power plant comes into service. It must be stated here that fuel costs constitute 30% of the total production costs of nuclear power plants, while fuel costs for coal, natural gas and oil constitute about 80% of production costs. Thus, nuclear power plants have achieved the lowest production costs among coal, natural gas and oil as shown in the following chart:

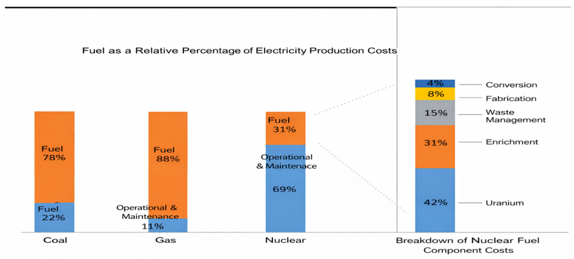

Figure 5: Percentage of Electricity Production Costs Attributed to Nuclear Fuel, Coal, Gas, and Oil.

Source: Zohuri, B., & McDaniel, P. (2015). The Economic Future of Nuclear Power. In Thermodynamics in Nuclear Power Plant Systems (pp. 561-586). Springer, Cham.

According to this view, the gradual rise in fossil fuel prices reduces the national incentive to use coal for power generation. Consequently, China strengthened its financial capacity to facilitate technological transition in the electricity sector. Thanks to its rapid economic growth and high level of government savings, it employed a two-pronged strategy:

a) Encouraging joint ventures with foreign companies to facilitate the transfer of technology and production know-how.
b) Strategically protecting key industrial sectors from direct foreign competition to allow for the establishment of robust market centers.

For example, China's first nuclear power plants were joint ventures that helped the Chinese acquire nuclear power and applied technical knowledge. As China's nuclear energy sector matured, the government adopted a policy allowing selective competition to push domestic performance levels and ensure that the Chinese had the opportunity to develop manufacturing capabilities.

For nuclear power to be a viable option, electricity prices must cover investment and operating costs and provide a sufficient profit margin. If the costs of fuel transportation and environmental pollution are properly factored into electricity generation costs, coal-fired power generation will not be as competitive as nuclear power. For example, a nuclear power plant producing one million kilowatts requires 20 to 30 tons of nuclear fuel per year, transported by only a few trucks. In contrast, a thermal power plant producing one million kilowatts requires 2-3 million tons of coal annually, transported by 100 train cars per day. Furthermore, if decarbonization costs are factored into China's power generation costs, coal-fired power generation will be significantly more expensive than nuclear power generation.

Cultural and Social Impact

China's ruling elite has provided engineering expertise as a foundation for policymakers to begin considering alternative energy sources and integrating them into the framework of economic development.

Technological Impacts on China's Electricity Generation Policy

The government has pursued a policy that encourages joint ventures with foreign nuclear energy companies to transfer technology. It has worked to establish grid connections to deliver electricity from supply centers to geographically distant demand centers to expand coverage. The government also strengthens the grid infrastructure.

Costs of Electricity Produced from Nuclear Power in China

Annual investment costs primarily influence the differences between alternative power systems. As illustrated in the figure, the HN-PV system requires the highest costs (US$469 billion), which is 9.39% higher than the BAU scenario, while the LN-H system requires the lowest costs (US$421 billion), which is 1.84% lower than the BAU scenario. The higher nuclear versions of the scenarios generally require more costs due to the substitution between nuclear and coal-fired power. However, the HN-H and HN-W scenarios are more economically sustainable than the LN-PV and LN-B scenarios.

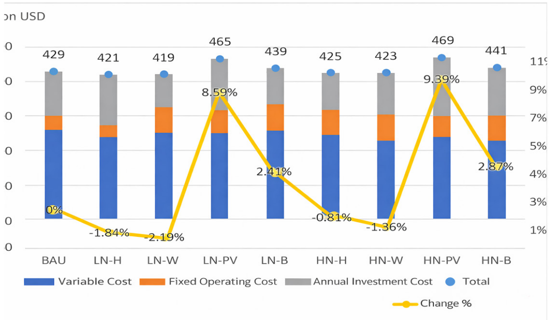

Figure 6: Shows The Total Costs for All Scenarios in 2030 Compared to the Bau Scenario

Source: Sun, X., Zhang, B., Tang, X., McLellan, B. C., & Höök, M. (2016). Sustainable energy transitions in China: Renewable options and impacts on the electricity system. Energies, 9(12), 980.

Graph shape variables

LN-B A balanced mix of low nuclear energy
HN-H High-energy nuclear – hydroelectric
HN-W Nuclear high winds
HN-PV Nuclear High – Solar
HN_B A balanced mix of high nuclear energy
BAU Usual business scenario (fossil fuels)
LN-H Low-energy nuclear – hydroelectric
L N-W Low nuclear – winds
LN-PV Low-energy solar nuclear

Combined Water and Electricity Generation System in Nuclear Power Plants

The severe shortage of fresh water, the growing consumption of local needs, the high cost of producing desalinated water using depleting fossil fuels, and the resulting environmental pollution, make the use of nuclear energy for water desalination the appropriate option in the coming decades.

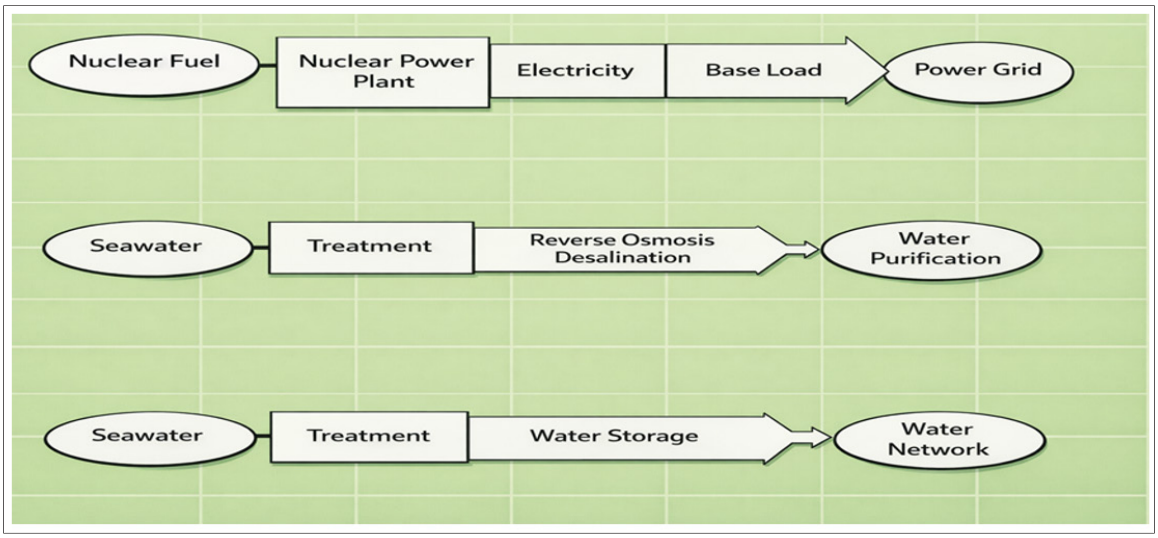

Figure 7: Shows The Combined Water and Electricity Generation System in Nuclear Power Plants

Source: Li, J., Li, C. F., Zhang, Y. X., & Yue, H. G. (2014). Study on the large-scale water/electricity cogeneration system in nuclear power plants. In Applied Mechanics and Materials (Vol. 448, pp. 1912-1915). Trans Tech Publications.

As shown in the figure, linking desalination technologies to nuclear energy will enable the utilization of resources and their adoption as a key element in serving the solutions necessary for the sustainability of water security; as the nuclear power plant systems in China work to desalinate seawater through reverse osmosis, enabling them to provide large quantities of fresh water to water-scarce areas.

Fourth Axis: The Current State of Global Supply and Demand for Uranium Resources in China

Uranium is a reliable energy resource in China, as the price of natural uranium is relatively low, along with low utility and management costs, and convenient transportation and storage.

First: Global Uranium Production

Global uranium production increased from 36,366 tU in 2001 to 60,496 tU in 2015, mainly due to increased production in Kazakhstan. Production is projected to reach approximately 23,800 tons per year by 2050. Uranium production is concentrated in a few countries. The three largest uranium-producing countries in the world—Kazakhstan, Canada, and Australia—accounted for 6%, 34%, and 21% of total production in 2001, respectively. Kazakhstan produced the largest share of uranium from mines (39%) in 2015, followed by Canada (22%) and Australia (9%), making it the world's largest uranium producer, as shown in the following figure:

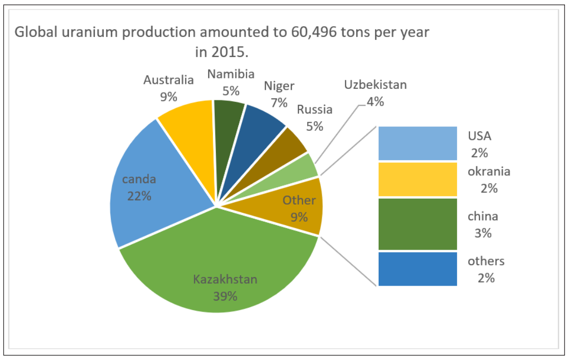

Figure 8: World Production of Uranium Resources

Source: Xing, W., Wang, A., Yan, Q., & Chen, S. (2017). A study of China's uranium resources security issues: Based on analysis of China's nuclear power development trend. Annals of Nuclear Energy, 110, 1156-1164.

Second: The Importance of Nuclear Fuel in China

Uranium is a crucial strategic mineral resource, indispensable for the development of the nuclear industry. It is a priority for many countries seeking to protect themselves against supply or price fluctuations. Therefore, the sustainability of uranium as a fuel source is a vital area of study. Since China's domestic uranium resources are limited, meeting demand through internal production is difficult. Consequently, China's dependence on external sources for uranium will persist. This situation necessitates efforts to secure an independent energy supply. As the nuclear power industry develops, the demand for uranium resources in China will grow rapidly, making the security of these resources a primary concern for Chinese scientists.

Third: Government Measures to Ensure the Safety of Uranium Resources in China

Strengthening Scientific Research and Exploration

China is increasing investment in domestic and foreign uranium resources by studying the theories and laws of uranium mineralization, as well as advanced technologies and exploration methods. At the same time, relevant research bureaus must develop new uranium mining technologies, such as extraction technologies for unconventional uranium resources. Exploration work must be expanded, especially in the northwestern and northeastern regions. Therefore, promoting scientific and technological research to improve the processing capacity for foreign fuel can increase the efficiency of nuclear fuel utilization.

Actively pursue a diversified global import source

The government is encouraging Chinese uranium companies to actively participate in the development of uranium resources globally. A comprehensive study of mineral resource conditions and investment environments revealed that countries suitable for uranium investment can be divided into three levels. The first level includes Kazakhstan, Australia, Mongolia, Canada, Russia, and Brazil. The second level includes South Africa, Namibia, Niger, Uzbekistan, Jordan, Vietnam, Colombia, Venezuela, and Morocco. Finally, the third level includes the United States, India, Ukraine, Denmark, Germany, the Czech Republic, Sweden, Mexico, and Egypt. The primary target countries for investment will be those in the first level. Serious consideration should be given to countries in the second level, and countries in the third level should be considered only as a last resort.

Accelerate the R&D rate for fourth-generation nuclear power units

Reactor technology is being improved to reduce costs to an acceptable level and to make them ready for large-scale commercial operation. Fast reactors are designed to produce 60 to 70 times more energy from uranium resources than current-generation thermal reactors. These reactors are highly efficient and produce significantly less nuclear waste through the recycling of spent fuel, which greatly reduces the demand for uranium ore.

Legal and Administrative Systems for Spent Nuclear Fuel Management in China

China has established separate inspection and management and enforcement agencies. The Ministry of Environmental Protection (National Environmental Protection Agency) is responsible for monitoring and managing work related to radioactive waste, including the regulatory work of drafting and issuing laws, regulations, and standards related to environmental protection; reviewing and approving environmental impact reports; signing and issuing construction and operation safety permits for low-level (LLW) and deep-level geological waste repositories; and supervising and inspecting environmental protection and facility safety.

The China Atomic Energy Authority is a central government department responsible for the regulatory work of preparing waste management planning in the areas of radioactive waste management and spent fuel in cooperation with the Ministry of Environmental Protection, national laws and regulations, national standards and nuclear trade standards related to radioactive waste management.

It is essential that China utilize natural uranium efficiently and expand fuel reprocessing technology to improve the efficiency of the nuclear fuel cycle. Chinese policymakers should pay greater attention to spent fuel management by supporting sustainable and sufficient funding, as well as establishing a specialized nuclear legal framework. The success of China's future nuclear fuel cycle transition will significantly shape global development trends related to nuclear energy.

Fifth Axis: China's Development of National Capabilities and Non-Fossil Fuel Targets

China's Energy Strategy Development Plan 2014-2020

China formulated a long-term and medium-term nuclear development plan (2011-2020), setting a target of increasing nuclear capacity to approximately 58 gigawatts by 2020. With 30 gigawatts (GW) of reactors under construction by 2050, nuclear power is expected to contribute 15% and 22%, respectively, to China's electricity production.

According to this vision, the roadmap for the period 2021-2030 anticipates sustainable growth in the use of a mix of renewable energy, gas, and nuclear power, and a radical reduction in the consumption of high-carbon fossil fuels.

China's nuclear energy strategy and policy have become central to its long-term future development; to reset the energy structure, ease pressure on traditional energy supplies, and achieve the goal of reducing greenhouse gas emissions. Therefore, the Five-Year Plan for wind power development aimed to generate 200 GW, solar power 100 GW, and medium- and long-term nuclear power 58 GW by 2020. This indicated that nuclear power would be an increasingly important source of energy in China and under pressure to reduce carbon emissions, and that the government would spare no effort to promote the nuclear power industry, and accordingly it would develop in China rapidly to the point of exceeding the planning targets (installed operational capacity of 58 gigawatts) by 2020.

Table 3: China Nuclear Development Plan

Prediction	Year	Operable reactors	Annual demand	Total Demand
		GWe	tU	tU
2020		58	11836	45383
2025		80	16171	117963
2030		100	20113	210645

Source: Xing, W., Wang, A., Yan, Q., & Chen, S. (2017). A study of China’s uranium resources security issues: Based on analysis of China’s nuclear power development trend. Annals of Nuclear Energy, 110, 1156-1164.

As shown in the table above, in April 2015, the China Nuclear Power Corporation announced that by 2025, the installed nuclear power capacity would reach 80 gigawatts, providing 10% of the country's electricity. China's nuclear power capacity is expected to peak at 100 gigawatts by 2030, with uranium demand reaching 20,113 tons in 2030. The total cumulative demand from 2016 to 2030 is projected to be 210,645 tons.

Second: Financing Mechanisms for Increasing Electricity Investment in China

The financial system must align with broader requirements, shifting from a system heavily reliant on fossil fuels to one that promotes efficiency and sustainability. Potential financing sources include:

1. Public-private partnerships to meet the investment needs for electricity access.
2. Securing private sector loans to supplement domestic financing for state-owned utilities.
3. Targeted government risk guarantees and subsidies for low-income households, equity investments, mutual support, bilateral and multilateral guarantees, and concessional loans and grants through development banks.
4. Issuing green bonds, which represent a growing market segment that can meet some of the long-term capital needs of the renewable energy market.
5. Engaging international lenders to invest in strengthening the financial infrastructure that supports renewable energy.
6. Establishing national or regional green investment banks, allowing countries to collaborate in creating a regional clean energy bank (funded in proportion to a mutually agreed-upon GDP ratio with each country), with funds allocated to economically viable technologies.
7. Sovereign wealth funds are a source of stability that can facilitate capital flows associated with natural resource development (particularly fossil fuel extraction), thereby contributing to macroeconomic stability. The advantages of sovereign wealth funds include a focus on increasing wealth across generations, a flexible investment structure, and the creation of a huge capital base.

Third: Opportunities and Challenges for Nuclear Energy Development in China

Nuclear energy is an unavoidable strategic choice for China, and its power plants can generate enormous power while consuming a small amount of nuclear fuel. For example, a fossil fuel power plant producing 1000 MW burns approximately two million tons of coal annually, while a nuclear power plant of similar capacity consumes about 190 tons of natural uranium as fuel. This underscores that nuclear power generation will significantly reduce fossil fuel consumption and alleviate the environmental pressure caused by coal consumption. The challenges include:

1) Obstacles Facing Nuclear Energy Development in China

1- Ensuring reactor safety due to the diversity of nuclear technologies.

2- Disposing of nuclear waste.

3- Concerns about the proliferation of weapons-grade materials, despite strict oversight by the Chinese government.

4. Nuclear power plant construction involves relatively high investment risks and costs, significant initial investments, and a long construction period.

5. Limited domestic uranium resources.

2) Driving Factors for Nuclear Energy Development in China

1. Reducing environmental damage caused by burning fossil fuels.
2. Ensuring energy security. China's net oil imports reached 136 million tons in 2005, with import dependency at 43%, posing a significant challenge to the country's energy security.
3. Positive public acceptance.
4. Financial support for nuclear energy investment from the Chinese government.
5. Annual economic losses in China due to air pollution and acid rain amounted to US$37 billion, or about 5% of GDP.
6. Local community support, which encourages local research and development and the use of domestic designs and technologies, has been a crucial element in China's expansion of its nuclear program.

We conclude from this that China was able to localize nuclear energy technology through reactor projects designed according to unified standards, and acquire skilled technical personnel from developed countries, and then moved on to learn for itself the reasons and justifications behind the manufacture of the new generation of modern technology, which enjoys a higher level of safety and economics, in order to compete in the global market and gain a position on the international stage.

Table 4: Study Variables A- Study variables: The variables used in estimating the model can be defined as follows:

Variable Name	Definition	Unit of Measurement	Type of variable
CARBON	Carbon dioxide emissions	Million Tons	Dependent variable
ELECTRICITY_COAL	Coal-fired power generation	Terrawatt-hour	Independent variable
ELECTRICITY_GAZ	Gas-fired power generation	Terrawatt-hour	Independent variable
ELECTRICITY_OIL	Oil-fired power generation	Terrawatt-hour	Independent variable
ELECTRICITY_OTHER	Other energy sources	Terrawatt-hour	Independent variable
GENERATION	Geothermal, biomass, and other energy sources	Terrawatt-hour	Independent variable
HYDROELECTRICITY	Hydroelectric power generation	Terrawatt-hour	Independent variable
NUCLEAR	Nuclear power generation	Terrawatt-hour	Independent variable

Source: Full report – BP Statistical Review of World Energy 2018.

B-Study Population and Sample

Carbon was chosen for the sample of foreign countries as a response variable (dependent) and an indicator of environmental pollution, while electricity generation from nuclear, gas, coal, oil, renewable, geothermal, biomass and hydroelectric power was included as independent variables. The study covers the foreign countries for which data is available, representing 17 countries during the period 1990 to 2017, and thus the number of observations used in the total sample is 325 observations.

Table 5: Countries Under Study

Country	Country	Country
India-12	Germany-6	US-1
Japan-13	Netherlands-7	Canada-2
South Korea-14	United Kingdom-8	Mexico-3
South Africa-15	United States-9	Argentina-4
China-16	Russian Fede-10	Brazil-5
Taiwan-17	Ukraine-11	

Full report – BP Statistical Review of World Energy 2018.

C- Methods of Model Estimation Using Panel Tests

First, Estimation of the Pooling Regression Model, Fixed Effects Model, and Random Effects Model. To clarify, to measure the impact of nuclear power generation on carbon emissions, a longitudinal data model was used by applying three models: the Pooling Regression Model, the Fixed Effects Model, and the Random Effects Model. The results of these three models are shown in the following table:

Table 6: Stages of Panel Model Estimation and Selection of the Appropriate Model

Dependent Variable: CARBON
Sample: 1990 2017
Cross-sections included: 16
Total panel (balanced) observations: 325

Variable	Pooled Regression Model				Fixed Effects Model				Random Effects Model			
	Coefficient	Std. Error	t-Statistic	Prob	Coefficient	Std. Error	t- Statistic	Prob	Coefficient	Std. Error	t-Statistic	Prob
C	71.67	15.14	4.73	0.000	610.6248	21.72579	28.10599	0.0000	125.9657	12.196	10.32792	0.0000
ELECTRICITY_COAL	2.153	0.023	90.584	0.000	1.146685	0.038109	30.08926	0.0000	2.121395	0.0119	177.3832	0.0000
ELECTRICITY_GAZ	1.721	0.079	21.753	0.000	0.720433	0.052546	13.71044	0.0000	1.128040	0.0402	28.05148	0.0000
ELECTRICITY_OIL	1.248	0.198	6.295	0.000	1.963852	0.166056	11.82647	0.0000	2.714321	0.1260	21.53319	0.0000
ELECTRICITY_OTHER	4.658	1.770	2.631	0.008	-10.317	1.025080	-10.065	0.0000	-0.6186	0.8680	-0.712	0.476
GENERATION	-3.89	1.327	-2.93	0.003	1.980609	0.737	2.684990	0.0077	-3.094	0.5401	-5.728	0.0000
HYDROELECTRICITY	0.36	0.048	7.579	0.000	0.003660	0.020654	0.177224	0.8595	0.075215	0.0195	3.849604	0.0001
NUCLEAR	0.006	0.129	0.0498	0.960	0.190959	0.075461	2.530550	0.0119	0.191414	0.0590	3.239772	0.0013
RENEWABLE	-1.195	0.346	-3.446	0.000	-0.5801	0.169463	-3.4235	0.0007	0.218110	0.1273	1.712209	0.0878
R-square	0.991653				0.991653				0.976159			
Adjusted R-squared	0.991442				0.991442				0.975555			
F-statistic	4692.888				17005.27				1617.283			
Prob(F-statistic)	0.000000				0.000000				0.000000			

Source: Prepared by the researcher using the EViews statistical software, version 10. (See Appendices Tables 68, 69, and 70)

After evaluating the three models—the pooled regression model, the fixed effects model, and the random effects model—we compare them by selecting the most suitable model for the study using the Hausman test to determine the appropriate model for analyzing the data.

Secondly, the Hausman test for choosing between the fixed effects model and the random effects model:

To ensure the most suitable model for the data used in this study; after testing both the fixed effects and random effects models, the final decision will be based on the Hausman test.

Hausman Test Hypotheses

The random effects model is the most suitable.......................H_0
The fixed effects model is the most suitable..........................H_1
The test results are shown in the following table:

Hausman Test Table No 7

Correlated Random Effects- Hausman Test			
Test cross-section Random Effects			
Test Summary	Chi-Stat	Chi-sq. df	Prob
Cross-section	1144.970342	8	0.0000

Source: Prepared by the researcher using the EViews statistical software, version 10. (See Appendix, Table No. 17)

The statistical value is 1144.970342 = $2\chi^2$, and the critical tabulated value for this test, at a significance level of 5%, is the tabulated value in the chi-squared table (Prop = 15.51). Therefore, we reject the null hypothesis and accept the alternative hypothesis, which states that the fixed effects model is the appropriate model for this study [8-28].

Analysis of the Fixed Effects Model Test Estimation Results (Table 69 in the Appendices):

Based on the results in Table (35) and in light of the previous estimation results, the researcher observes that:

1. The model coefficients are statistically significant; we find that the probability of the coefficients for coal, gas, oil, renewable energy, and geothermal energy is (0.000), and the coefficient for nuclear electricity is 0.0119 because they are less than (0.05).
2. A probability F-statistic less than 0.05 indicates the overall significance of the model.
3. The R^2 value was 0.99, meaning that the independent variables explain 99% of the changes in carbon emissions, with the remainder attributed to other factors outside the model.
4. The value of the power generation coefficient from coal, oil, gas, geothermal energy, and biomass is positive, indicating that increased electricity generation from fossil fuels leads to increased carbon emissions.
5. The value of the power generation coefficient from other renewable energy sources is negative, indicating that increased electricity generation from renewable sources leads to decreased carbon emissions, making them cleaner and more environmentally friendly.

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