Examination of the Strategic Value of Nuclear Power: A U.S. Focus

by

Allison Williamson Arnold

(Under the Direction of David Gattie)

Abstract

The guiding principles of U.S. civilian nuclear power position nuclear technology as having intrinsic value for national security and global collaboration. Existing evaluation models for U.S. nuclear power primarily emphasize economic and environmental metrics while not incorporating broader competitive advantage dimensions, including geopolitical influence, export leverage, supply chain resilience, and public trust. This study addresses that gap by developing the Strategic Nuclear Competitiveness Index (SNCI), a multidimensional framework designed to assess the strategic value of U.S. nuclear power compared to its primary global competitors. This framework integrates five core domains: policy and regulatory environment, innovation and technological leadership, public perception, export capacity, and supply chain security. This analysis offers insights into U.S. nuclear power's strategic positioning in the global landscape.

INDEX WORDS: nuclear, first principles, national security, strategic, competitiveness index

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Allison Williamson Arnold

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M.A., University of Georgia, 1991

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Allison Williamson Arnold

Major Professor: David Gattie

Committee: Tim Foutz

Thomas Lawrence

Joshua Massey

Marcia Porter Campbell

Electronic Version Approved:

Ron Walcott

Dean of the Graduate School

The University of Georgia

August 2025

Dedication

To my husband Steve who made me laugh when I was ready to cry – I love you. You managed our household so I could finish this dissertation—thank you for everything you shouldered to lighten my share of "all the things." You believed in me. I am honored to be your wife.

To the family who cheered me on and patiently waited for me to "wrap this up," – your understanding is priceless. To my dearest friends – you are my chosen familial tribe, forever.

To the glory of God, through whom all things are possible (Phil 4:13), and in loving memory of my parents and brother, and other dear ones, whose love continues to guide me.

Acknowledgments

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Special thanks to my UGA Mathematics Department colleagues who cheered me on, and to department chairs Dr. Malcolm Adams, Dr. William Graham, and Dr. Michael Usher, who provided the flexibility to pursue this degree while maintaining my full-time teaching duties. To Dr. Jean Williams-Woodward, Dr. Charles Braucher, and Dr. Ruth Cline, whose expertise, support, and commitment to my success and well-being kept me moving forward.

All data visualizations, tables, and figures presented in this dissertation represent original analysis and design by the author, synthesized from the data sources cited in individual captions.

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Chapter 1

Introduction

Energy is a geopolitical weapon. History shows that nations leverage electricity generation resources as geopolitical tools of strategic influence. Most recently, Russian use of such resources, primarily natural gas, as a tool of coercion during its 2022 invasion of Ukraine served as a wake-up reminder of the strategic vulnerabilities of energy dependent nations. The inherent dual-use capabilities of nuclear energy distinctly sets it apart from fossil fuels and renewable energies.

For many years the U.S. held its position as the world leader in an evolving global civilian nuclear power system. Once a fearless advocate of nuclear power as a tool of peaceful collaboration and nonproliferation, its currently stagnated nuclear posture is challenged by those of state-owned nuclear enterprises. Russia leverages government controlled nuclear expansion for regional influence, or worse, as the aforementioned geopolitical weapon. China ambitiously expands its nuclear sector and is considered a top global leader in the realm of advanced nuclear reactor technology, further positioning itself as a significant player in the global nuclear energy market.

The competitive landscape reveals stark disparities in strategic positioning. While the United States maintains technological diversity with 30 advanced reactor designs under development, execution remains limited with only one operational advanced reactor. In contrast, China has achieved operational status with the world's first Generation IV reactor (HTR-PM), and Russia operates three advanced reactors while dominating global exports with 22 international projects currently under construction (International Atomic Energy Agency, 2025c). These deployment patterns reflect fundamental differences in how different political-economic models approach nuclear strategic competition.

Where will the United States stand in leadership, influence and strategic competition in the civilian nuclear power industry moving forward in the latter half of the 21st century and beyond?

The critical issue is not whether nuclear energy is a vital asset, but whether the U.S. will demonstrate the commitment to revive its nuclear program and reassert its leadership in the global nuclear arena.

1.1 Problem Statement

The strategic blueprint for nuclear power was intiated and promoted by the United States after World War II. This framework explicitly positioned civilian nuclear power as a national security asset and tool of international influence.

However, this strategic framing has been largely displaced by economic metrics and market-driven evaluation criteria, creating a gap between nuclear power's strategic potential and its current policy treatment.

Civilian nuclear power is growing in recognition as a strategic asset and not just an energy source that is subject to cost constraints. This competitive shift is evidenced by stark deployment trends: China connects 57 nuclear reactors since 1990 compared to only 2 in the United States, while Russia dominates global exports with 22 international projects (International Atomic Energy Agency, 2025c). Economic metrics fail to capture the broader strategic value of nuclear power in geopolitical competition involving diplomatic leverage and long-term supply chain resilience.

The emergence of nuclear tripolarity between the U.S., Russia, and China fundamentally reshapes the strategic landscape of civilian nuclear competition. This shift reveals how state-directed competitors demonstrate systematic advantages (Atlantic Council, 2023). State-directed competitors demonstrate systematic advantages in deployment speed, export competitiveness, and supply chain control that challenge traditional assumptions about market-driven approaches to strategic industries. Russia's control of global uranium enrichment capacity and China's rapid execution capabilities highlight how authoritarian governance models can achieve strategic coordination unavailable to fragmented democratic systems.

The absence of a structured framework for incorporating strategic factors such as geopolitical influence, supply chain sovereignty, and technological leadership creates a critical gap in existing research. Current assessment methodologies focus primarily on economic competitiveness such as levelized cost of electricity or narrow technical metrics, failing to capture the multi-faceted nature of global strategic competition in the civilian nuclear power construct. This analytical gap constrains United States policymakers' abilities to assess competitive positioning and develop effective strategic responses to state-directed competitors.

1.2 Purpose of Study

This study assesses the strategic value of U.S. civilian nuclear power within the context of national security and international competitiveness through systematic comparison with Russia and China. To address the analytical limitations in existing frameworks, this study develops a comprehensive evaluation methodology, denoted as the Strategic Nuclear Competitiveness Index (SNCI), to quantify the crucial dimensions of national power relevant to modern nuclear competition.

The SNCI framework provides a practical method for assessing strategic nuclear competitiveness across five domains: public opinion and societal trust, regulatory and policy frameworks, innovation and technology leadership, export capacity and international influence, and supply chain sovereignty. By examining these interconnected dimensions, the reconnects civilian nuclear capabilities with broader strategic national security imperatives while enabling systematic comparison across political-economic models.

This structured approach provides policymakers and stakeholders with evidence-based tools for strategic nuclear decision-making. The framework identifies specific competitive advantages and vulnerabilities across nuclear strategic domains. It enables strategic gap identification, policy intervention targeting, and alliance coordination support through objective assessment of competitive positioning relative to strategic rivals.

1.3 Research Questions

The following research questions guide this dissertation's systematic investigation of nuclear strategic competitiveness:

1. How has the strategic framing of U.S. nuclear power evolved since the Cold War, and what are the implications for national security today?
2. What are the comparative strengths and weaknesses of civilian nuclear strategies across the U.S., China and Russia, particularly in terms of state objectives, technological development, and global influence?
3. What are the key factors influencing the strategic value of nuclear energy, and how can they be utilized to model the intrinsic strategic value of nuclear power?

To address these research questions systematically, this study employs a hybrid comparative analysis approach to examine countries with fundamentally different political-economic models while holding nuclear power capabilities as a constant factor (Anckar, 2008). This comparative approach maximizes analytical leverage by examining how institutional differences affect strategic outcomes across similar technological contexts.

1.4 Theoretical Framework

This study is grounded in strategic competition theory, which emphasizes that nations compete across multiple dimensions beyond military power, including economic capabilities, technological leadership, and institutional effectiveness (Mearsheimer, 2001). Unlike traditional approaches that treat nuclear power primarily as an energy technology subject to market forces, this study adopts a strategic perspective, viewing civilian nuclear power as a tool of national power and international influence.

The theoretical foundation builds on nuclear policy analysis framework, which argues that nuclear power represents a national security imperative rather than a purely economic commodity (D. K. Gattie, 2019; D. K. Gattie & Hewitt, 2023). This framework demonstrates that state-directed nuclear programs gain systematic strategic advantages over market-driven systems in international competition, particularly in export markets and geopolitical influence. This framework emphasizes the innovation-execution gap where technological capabilities must translate into operational deployment to achieve strategic value.

The study integrates insights from comparative political economy to examine how different governance models affect nuclear competitive outcomes. Democratic market-driven systems emphasize transparency, innovation diversity, and regulatory independence, while authoritarian state-directed systems enable strategic coherence, resource mobilization, and execution capability. These institutional differences create systematic advantages and constraints that shape nuclear competitiveness patterns in the United States, Russia, and China.

The Strategic Nuclear Competitiveness Index translates these theoretical insights into measurable indicators across five domains that reflect different dimensions of national power. This multi-domain approach captures the complex relationship between nuclear capabilities and strategic competitiveness in contemporary great power competition, providing operational tools for policy analysis and strategic planning.

1.5 Distinctiveness of this Study

This study makes three key contributions. First, it develops a systematic framework for assessing the strategic value of nuclear power across multiple domains. Second, it provides an empirical comparison of nuclear competitiveness across different political-economic models (democratic vs. authoritarian, market-driven vs. state-directed). Third, it reconnects nuclear policy analysis with its original national security foundations, informing contemporary decision-making for stakeholders and policymakers about the role of nuclear power in strategic competition.

The research advances strategic nuclear competitiveness theory through systematic measurement methodology. While existing literature conceptualizes nuclear power as a strategic competition issue and evaluates it from a market-based perspective, the field lacked application of quantitative tools for comparative assessment across multiple domains in a theoretical framework. The Strategic Nuclear Competitiveness Index bridges this gap by integrating theoretical insights from strategic competition theory, comparative analysis methodologies, and industry indices into a comprehensive measurement framework.

The comprehensive assessment of U.S. , Russian, and Chinese nuclear competitive advantage posturing provides distinctive insights into how different governance models affect strategic outcomes. The findings demonstrate that institutional structures create systematic competitive advantages and constraints that shape nuclear strategic positioning in great power competition.

These contributions inform contemporary policy debates about the role of nuclear power in strategic competition while providing analytical tools for ongoing assessment and strategic planning. The study reconnects nuclear policy analysis with its original national security foundations, demonstrating the continued relevance of strategic approaches to civilian nuclear power in the 21st century.

1.6 Limitations and Scope

The analysis focuses on civilian nuclear power strategic competitiveness in the United States, Russia, and China during the post-Cold War period, with forecasting analysis extending to 2050 where appropriate. Military nuclear programs and weapons systems are excluded from the analysis, though the dual-use characteristics of civilian nuclear technology are acknowledged as relevant to strategic considerations.

The case selection approach that focuses on three major nuclear powers provides analytical leverage for most different systems design but limits generalization to other nuclear countries with different characteristics and strategic priorities. Future research could expand the framework to include additional countries and examine alliance patterns or regional competition dynamics.

This comparative assessment acknowledges important methodological limitations regarding data availability and transparency. Democratic and authoritarian systems provide different levels of data transparency, potentially creating systematic biases in assessment. U.S. data availability generally exceeds that of Russia and China, requiring careful attention to comparative validity and methodological consistency.

This assessment acknowledges several important limitations. The assessment period captures contemporary competition dynamics but may not fully reflect long-term trends or cyclical patterns in nuclear competitiveness. Strategic positioning can shift rapidly due to policy changes, technological breakthroughs, or geopolitical developments that extend beyond the study's temporal boundaries. Additionally, the framework uses publicly available data and equal weighting across domains due to the absence of extensive expert consultation for differential weighting.

While future geopolitical developments may shift competitive dynamics unpredictably, current trends and institutional patterns provide a robust foundation for understanding strategic positioning and policy implications. The systematic approach enables meaningful comparative insights for strategic assessment despite these limitations.

1.7 Dissertation Structure

This dissertation is organized into five chapters that progress from theoretical foundations through empirical analysis to strategic implications and policy recommendations.

This chapter establishes the research problem, theoretical framework, and strategic significance of nuclear competitiveness assessment. This chapter positions civilian nuclear power within great power competition and introduces the Strategic Nuclear Competitiveness Index as a systematic measurement approach.

Chapter 2 provides comprehensive historical context on nuclear power development from Atoms for Peace to contemporary strategic competition. The chapter synthesizes existing assessment frameworks from strategic competition theory, nuclear policy analysis, and comparative methodologies while identifying research gaps that justify the SNCI approach. Country profiles establish the contemporary competitive landscape across the United States, Russia, and China.

Chapter 3 details the research design, case selection rationale, and SNCI framework development process. This chapter explains the five-domain structure, data collection procedures, and composite index construction methodology. The approach integrates quantitative indicators with strategic qualitative strategic insights to capture both measurable performance and strategic implications.

Chapter 4 presents the empirical assessment results across all three countries and five strategic domains. Individual country analyses provide detailed evaluation of performance across public opinion, regulatory frameworks, innovation, export capacity, and supply chain sovereignty. Comparative analysis examines cross-country patterns, political-economic model effects, and strategic competition dynamics.

Chapter 5 synthesizes key findings, discusses theoretical and policy implications, and provides strategic recommendations for U.S. nuclear competitiveness. The chapter addresses study limitations, outlines future research directions, and concludes with strategic implications for nuclear competition in the 21st century.

This structure enables systematic progression from theoretical foundations through comprehensive empirical analysis to strategic implication, providing a structured assessment of nuclear strategic competitiveness and its significance for great power competition.

Chapter 2

Literature Review

This chapter provides the historical, theoretical, technical and empirical foundations for understanding nuclear strategic competitiveness. The review examines nuclear power through multiple analytical lenses: its evolution from national security imperative to market commodity, the contemporary competitive landscape among major powers, and existing frameworks for assessing strategic value. This analysis identifies critical gaps in current approaches and establishes the conceptual foundation for the Strategic Nuclear Competitiveness Index (SNCI) framework developed in this study.

2.1 Historic Foundations of Nuclear Power

2.1.1 Atoms for Peace Legacy

The origins of U.S. nuclear power lie in national defense strategy (Hewlett & Holl, 1989; National Security Council, 1955). During World War II, the

Manhattan Project established American technological leadership in nuclear science, but the transition to peacetime applications required deliberate policy frameworks connecting civilian nuclear power to national security objectives (U.S. Department of Energy, 1994).

President Eisenhower's 1953 *Atoms for Peace* address to the United Nations marked a fundamental shift in nuclear policy discourse, positioning civilian nuclear energy as both a diplomatic tool and a strategic asset (Hewlett & Holl, 1989). The vision for U.S. leadership in commercial nuclear development and global collaboration was institutionalized through the Atomic Energy Act of 1954. The National Security Council report NSC 5507/2 (1955) explicitly outlined how U.S. domestic and international leadership and safeguarding of atomic energy served national security objectives (National Security Council, 1955).

Section 123 of the Atomic Energy Act (1954) (U.S. Department of State, Bureau of International Security and Nonproliferation, 2025) established the legal framework for nuclear cooperation agreements that remain central to U.S. nuclear diplomacy today, with active agreements across forty-nine countries. These agreements formalized the connection between civilian nuclear cooperation and broader strategic relationships, establishing patterns that continue to shape international nuclear competition.

2.1.2 Cold War Competition

During the Cold War, nuclear competition encompassed both weapons and peaceful applications developments. The U.S. designed and developed experimental breeder reactor, EBR-1, was the first nuclear reactor to produce usable electricity from fission (Idaho National Laboratory, 2023). The successful U.S. deployment of the novel fast reactor design was closely followed by the world's first nuclear power plant. In 1954, the USSR (Russia) brought online Obninsk Nuclear Power Plant (International Atomic Energy Agency, 2025a), triggering a wave of global nuclear reactor development. Eisenhower's *Atoms for Peace* vision to prevent the spread of nuclear weapons and promote peaceful nuclear power applications led to the establishment of International Atomic Energy Agency (IAEA) in 1957 (International Atomic Energy Agency, 2025a).

The formation of the IAEA served to create international norms in peaceful use technology across diverse fields of study, promote nuclear diplomacy and provide safety oversight. As an example of peaceful uses of atomic energy and international nuclear leadership, the U.S. brought online its first nuclear power plant near the end of 1957, Shippingport Atomic Power Station (International Atomic Energy Agency, 2025a). By 1960, the U.S. , U.K., USSR, and France launched 17 nuclear reactors (International Atomic Energy Agency, 2025a).

The original strategic framework created by the U.S. emphasized international leadership, technological advancement, and alliance-building through export partnerships and research cooperation. The first major nuclear power reactor 1979 accident at Three Mile Island catalyzed a fundamental shift in the application of this framework, as shown in Figure 2.1 (International Atomic Energy Agency, 2025d).

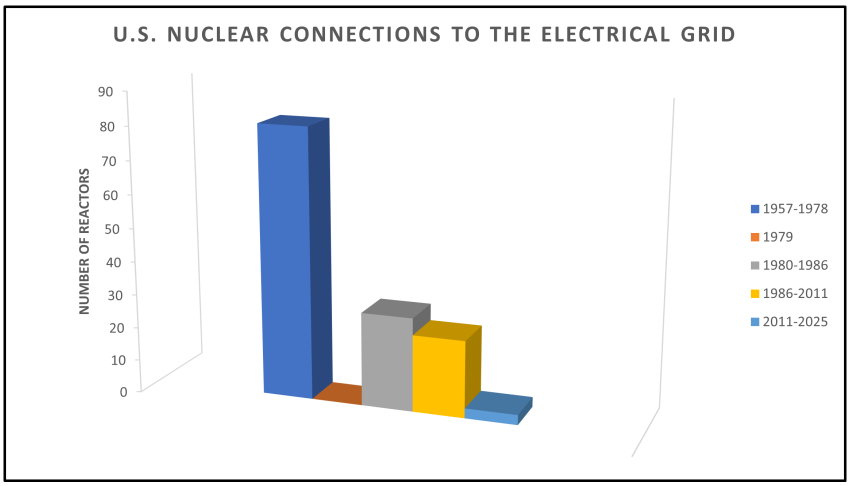

Figure 2.1: U.S. nuclear reactors connected to the electrical grid by year (1957–2025). The decline after Three Mile Island demonstrates the policy shift from strategic to economic evaluation criteria.

2.1.3 From Strategic to Economic

In the 1950s and 1960s support for nuclear power was generally high. Gallup and Harris polls conducted surveys prior to 1979 reporting the majority of respondents were in favor of more nuclear plants (Saad, 2016), and the majority of Americans did not see the threat of a nuclear accident to be likely. By 1976 general acceptance and not-in-my-backyard (NIMBY) sentiment differed with a majority of Americans opposed to siting a plant in their area (Baron & Herzog, 2020; U.S. Department of Energy, 2024).

As shown in Figure 2.2, U.S. public acceptance of nuclear power experienced its first significant shift during the aftermath of Three Mile Island (1979) and again after Chernobyl (1986). Gallup reported that American's willingness to have a nuclear power plant constructed within five miles of their homes dropped from 42% to 23% in the years surrounding Three Mile Island and Chernobyl (Reinhart, 2019). No new power plants were constructed in the U.S. after the partial meltdown at Three Mile Island until construction on Unit 3 at Alvin W. Vogtle Electric Generating Plant in March of 2013 (International Atomic Energy Agency, 2025d) .

The noted impacts in public acceptance Figure 2.2 after deregulation of U.S. electricity markets in the 1990s, combined with natural gas abundance and renewable energy growth, supported the shift in U.S. nuclear evaluation away from national security considerations toward market and emissions metrics. This transition overshadowed the original strategic framework that positioned nuclear power as a tool of national power and international influence as shown in the author-generated visualization in Figure 2.2 (Gallup, Inc., 2025; Saad, 2016).

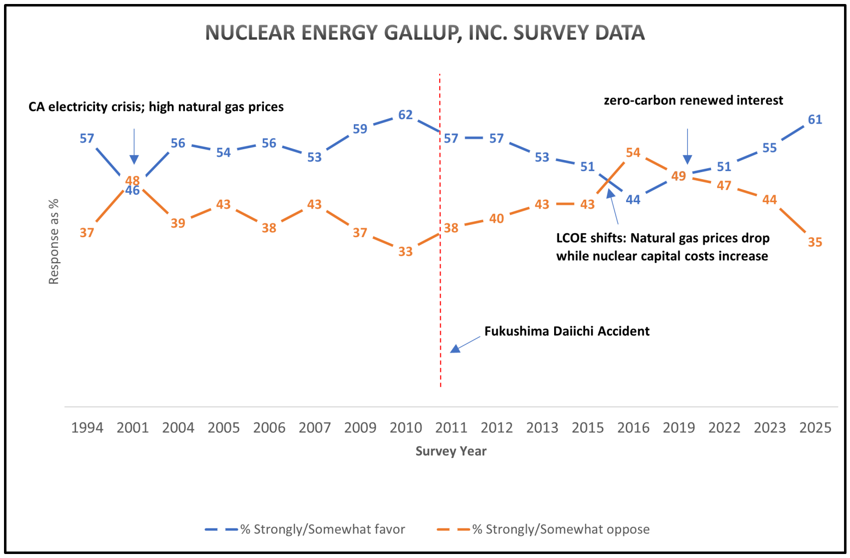

Figure 2.2: Gallup survey data for the years 1994-2025.

Gattie and Hewitt (D. Gattie & Hewitt, 2023), iChord (Ichord, 2019), and Atlantic Council (Atlantic Council, 2019) argue that this shift toward viewing civilian nuclear power as merely a market commodity neglects the original national security imperatives that shaped U.S. nuclear program development (D. K. Gattie & Hewitt, 2023). They contend that market-driven evaluation criteria fail to capture the strategic dimensions that make nuclear power valuable for national security and international competitiveness.

2.1.4 Current Nuclear Landscape

Leadership and innovation by the U.S. spawned impressive early growth of the nuclear power industry. By 1970, there were 90 reactors operating in 15 countries. By 1980, there were 253 nuclear reactors generating 135,000 mega-watts of electricity in 22 countries with 230 additional units on the horizon (Char &

Csik, 1987). The relative trend of early nuclear power growth across the world between 1950 and 1986 is shown in Figure 2.3.

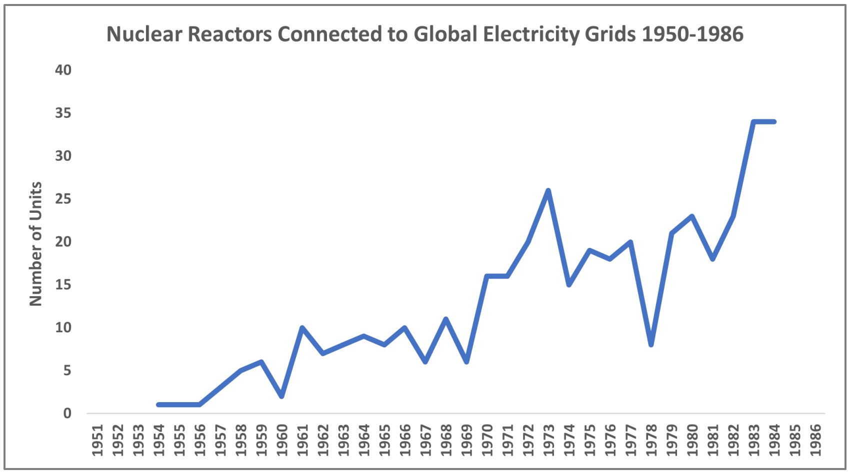

Figure 2.3: Number of nuclear reactors connected to electricity grids between 1950 and 1986 (International Atomic Energy Agency, 2025c).

The global nuclear energy landscape is increasingly defined by the divergent trajectories of the world's three largest nuclear powers: the United States, China, and Russia. While the United States pioneered commercial nuclear technology and built the world's largest nuclear fleet during the latter half of the 20th century, the 21st century has witnessed a fundamental shift in nuclear leadership dynamics.

China's rapid nuclear expansion (State Council Information Office of the People's Republic of China, 2024; World Nuclear Association, 2024e) and Russia's aggressive export strategy (Nakano, 2025; World Nuclear Association, 2024f) have challenged America's historical dominance (Third Way, 2024; Wilson Center, 2018), creating a trilateral competition that extends far beyond electricity generation to encompass geopolitical influence, technological innovation, and energy security. Understanding these shifting power dynamics requires examining not only current generation capacity but also the underlying trends that reveal each nation's nuclear trajectory and strategic priorities. Figure 2.4 illustrates these evolving nuclear generation patterns, highlighting the contrasting paths that have reshaped the global nuclear hierarchy.

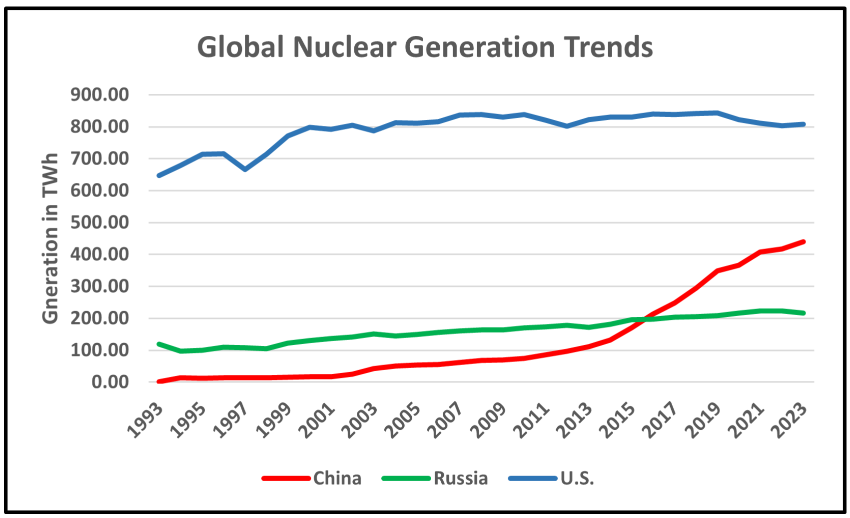

Figure 2.4: Nuclear generation trends for U.S. , China, and Russia (World Nuclear Association, 2024h).

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Understanding the divergent nuclear deployment patterns across major powers requires examining the analytical frameworks nations employ to evaluate nuclear investments. While economic competitiveness metrics guide investment decisions, application and weight given to these metrics varies significantly across different governance models and strategic priorities (International Atomic Energy Agency, 2008). International nuclear programs demonstrate varied approaches to investment evaluation, with major powers like China and Russia integrating strategic planning alongside economic analysis (World Nuclear Association, 2024e).

This integrated assessment model differs significantly from the United States' increased reliance on market-based metrics following electricity deregulation (D. K. Gattie & Hewitt, 2023), where LCOE and LACE calculations have become primary decision drivers despite their acknowledged limitations (U.S. Energy Information Administration, 2025b). Analysis of nuclear programs across major powers reveals a fundamental divergence in assessment approaches. While economic metrics like LCOE and LACE provide standardized comparison tools (U.S. Energy Information Administration, 2025b), countries employ these frameworks differently based on their governance models and strategic priorities (World Nuclear Association, 2024e).

The United States' market-driven approach increasingly emphasizes economic competitiveness (D. K. Gattie & Hewitt, 2023), contrasting with the strategic integration models employed by state-directed competitors.

China's developmental state model demonstrates systematic integration of strategic planning with economic analysis in nuclear decision-making (World Nuclear Association, 2024e). While economic factors including LCOE calculations inform Chinese nuclear planning (U.S. Energy Information Administration, 2025b), the country's centralized governance structure enables strategic priorities to override pure market considerations (World Nuclear

Association, 2024e). China's extensive nuclear expansion program, comprising 57 operating reactors with additional units under construction (State Council Information Office of the People's Republic of China, 2024), prioritizes energy security, climate objectives, and industrial competitiveness alongside economic optimization (M. Xu & Medlock, 2023). This approach contrasts with market-driven systems where economic metrics typically serve as primary decision criteria rather than strategic inputs (D. K. Gattie & Hewitt, 2023).

Russia operates through Rosatom, a state corporation that integrates nuclear development and export promotion under unified strategic direction (World Nuclear Association, 2024f). This institutional model prioritizes geopolitical influence through comprehensive nuclear export programs over pure economic optimization (World Nuclear Association, 2024f). Russian nuclear decisions emphasize maintaining industrial capacity, securing strategic leverage through international reactor projects, and advancing energy security objectives (International Atomic Energy Agency, 2019), with economic metrics serving as informational inputs rather than primary decision criteria in strategic planning processes.

The differences in assessment approaches help explain the contrasting deployment patterns evident since 1990. Countries that supplement economic analysis with systematic strategic evaluation demonstrate consistently stronger nuclear deployment capabilities compared to nations relying primarily on market-driven assessment frameworks.

Examination of contemporary nuclear competition reveals disparities in deployment capabilities and strategic approaches across major powers. Since 1990, China has connected 57 nuclear reactors to its grid with consistent five to six year construction timelines, while Russia has connected 12 reactors and maintains steady construction programs. In contrast, the United States connected only 2 nuclear reactors between 1990 and 2025, with construction timelines exceeding 10 years and a 27-year deployment gap (International Atomic Energy Agency, 2025c).

These differences in assessment approaches help explain the contrasting deployment patterns evident since 1990, as illustrated in Figure 2.5.

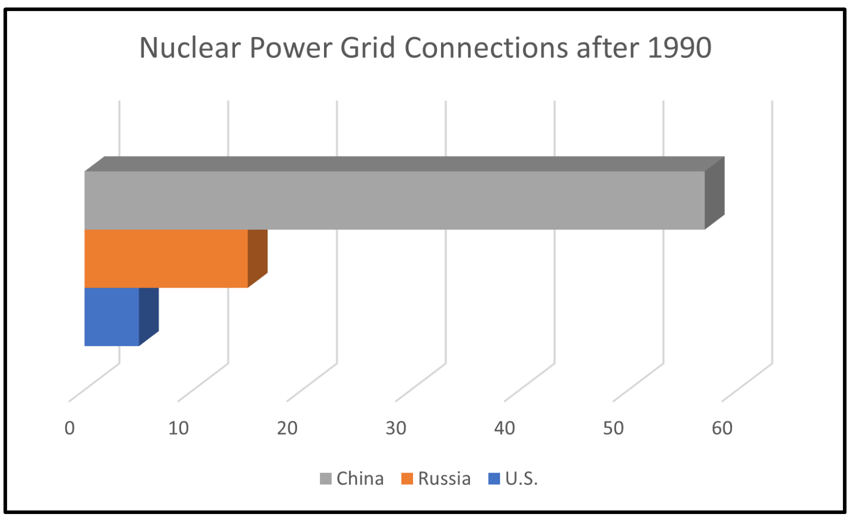

Figure 2.5: Grid-connected nuclear reactors by major powers (1990–2025), demonstrating divergent strategic and regulatory approaches to nuclear deployment (International Atomic Energy Agency, 2025c).

These deployment patterns reflect fundamental differences in governance models and their effects on nuclear strategic positioning. Examination of contemporary nuclear competition reveals disparities in deployment capabilities and strategic approaches across major powers, with China connecting 57 nuclear reactors to its grid since 1990 with consistent construction timelines, while Russia has connected 12 reactors and maintains steady construction programs. In contrast, the United States connected only 2 nuclear reactors between 1990 and 2025, with construction timelines exceeding 10 years and a 27-year deployment gap (International Atomic Energy Agency, 2025c). These differences in assessment approaches help explain the contrasting deployment patterns, reflecting divergent strategic and regulatory approaches where developmental state models (China), state-owned enterprise models (Russia), and market-driven models (United States) produce fundamentally different outcomes. A detailed comparative analysis of these deployment patterns is presented in Chapter 4.

The current global nuclear landscape reflects decades of divergent national strategies and institutional approaches. The U.S. retains its status as the leading global producer of nuclear power. As shown in Figure 2.6, nuclear electricity generation varies dramatically across major powers, with these differences reflecting underlying strategic competitiveness factors that the SNCI framework seeks to systematically measure.

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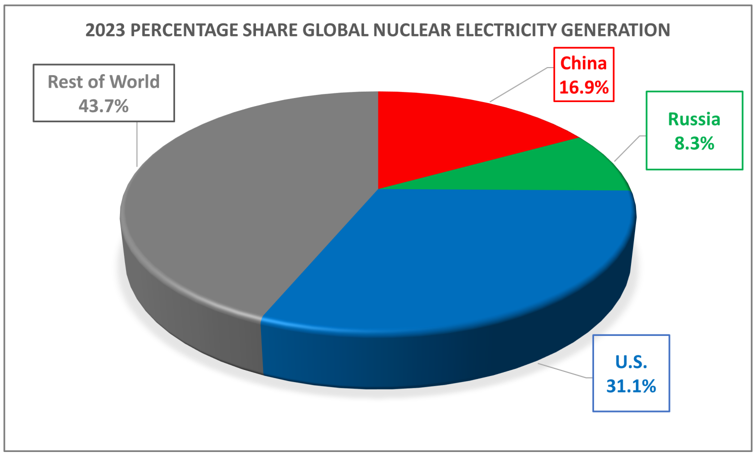

Figure 2.6: Global Nuclear Electricity Share by Country - Strategic positioning context for the U.S. , Russia, and China (International Atomic Energy Agency, 2025c).

2.2 Strategic Profile: United States

The United States has a diverse electricity generation portfolio with nuclear power steadily producing an approximately 19% percent share of net electricity generation since the 1990s. Net generation from low carbon resources including nuclear power and renewable resources is approximately 42% (U.S. Energy Information Administration, 2024e). U.S. Nuclear power remains the backbone of net-zero carbon electricity generation (U.S. Energy Information Administration, 2024e), as illustrated in Figure 2.7.

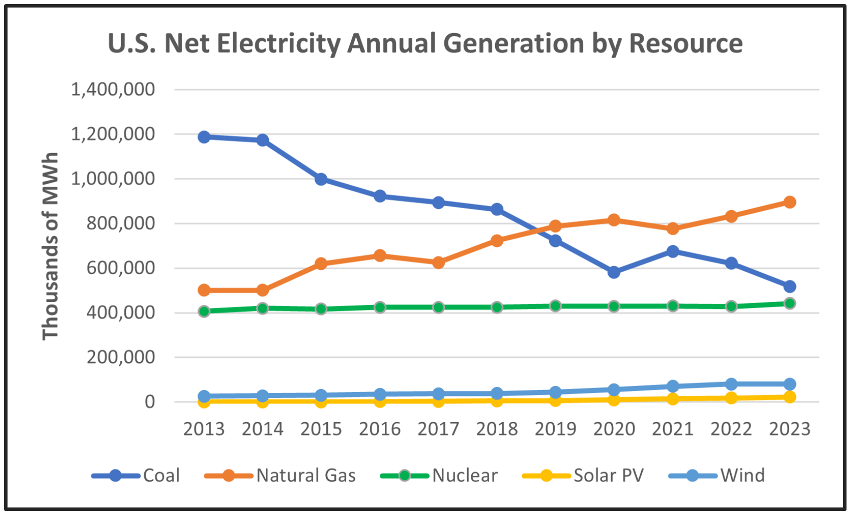

Figure 2.7: U.S. annual net generation by resource (U.S. Energy Information Administration, 2025c).

This consistent nuclear generation performance reflects the strategic importance of the existing U.S. nuclear fleet.

2.2.1 Fleet Overview and Strategic Posture

The United States operates the world's largest nuclear fleet with 94 commercial reactors across 54 nuclear plants, providing approximately 97 GWe of total capacity and 850 TWh generation annually (International Atomic Energy Agency, 2025d)–representing 18.6% of total U.S. electricity generation and 31% of global nuclear electricity production (World Nuclear Association, 2024g). This substantial generation capacity positions the U.S. as a dominant force in global nuclear energy despite recent deployment challenges. Figure 2.4 shows a decline in U.S. generation in recent years in contrast to an increase for China. Looking ahead, official projections suggest this trend may continue.

The U.S. Energy Information Administration's short-term forecasts indicate nuclear power's share of electricity generation will remain relatively stable in the near term, as shown in Figure 2.8.

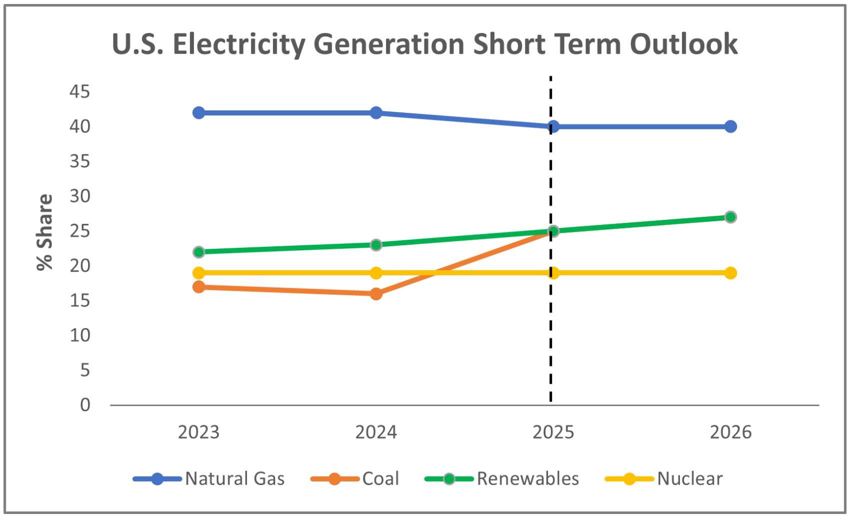

Figure 2.8: Short-Term Forecast of U.S. percentage share of electricity generation forecast using 2023-2024 data (U.S. Energy Information Administration, 2025a).

The nuclear fleet consists primarily of Generation II and III pressurized water reactors (PWR) and boiling water reactors (BWR). The U.S. has two Gen III+ reactors operating in the state of Georgia. As shown in Figure 2.9, the U.S. fleet demonstrates remarkable operational excellence with consistently high capacity factors during 2012–2025 (U.S. Energy Information Administration, 2025c), significantly outperforming other baseload electricity generation sources (U.S. Energy Information Administration, 2024e) and international nuclear capacity factors averaging 81.5% (World Nuclear Association, 2024b). China's reactors are rapidly catching up with U.S. versions in operational performance (U.S. Energy Information Administration, 2025c). These capacity factor improvements reflect technological advances in reactor

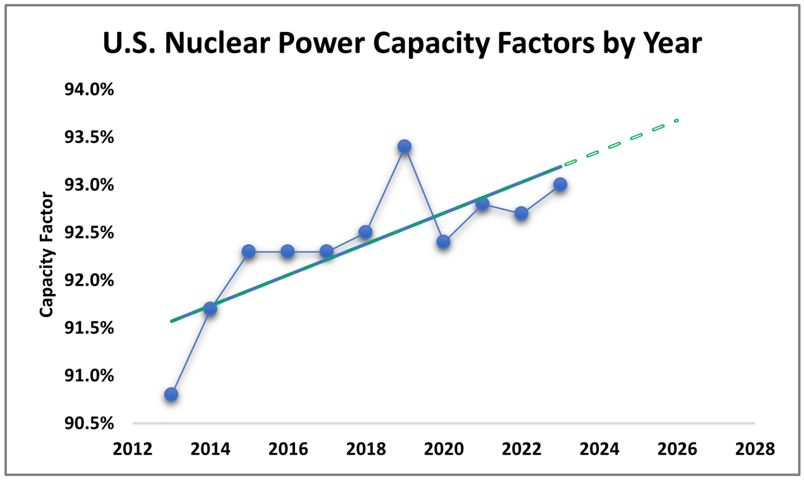

Figure 2.9: U.S. nuclear capacity factors with linear regression trendline forecast (U.S. Energy Information Administration, 2025a).

operations, maintenance scheduling optimization, and enhanced fuel utilization strategies implemented across the U.S. nuclear fleet over the past two decades. The sustained high performance levels demonstrate the maturation of nuclear technology and operational expertise.

The average reactor age of 43 years creates both modernization challenges and opportunities for advanced reactor deployment (Cleveland & Clifford, 2024) in the aging U.S. fleet. The strategic implications of fleet modernization emerge clearly when examining reactor age profiles across the three major nuclear powers. Figure 2.10 illustrates the critical modernization challenge facing the United States, where an aging fleet constrains both current performance and future strategic options (International Atomic Energy Agency, 2025d).

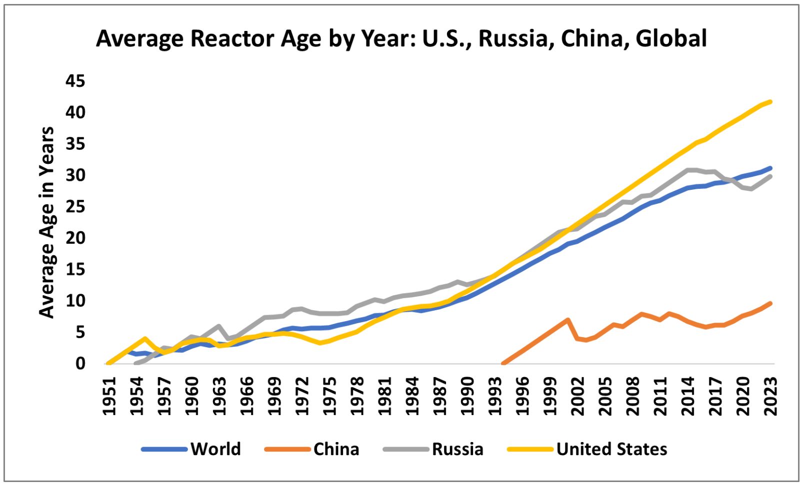

Figure 2.10: Average Reactor Age by Country - Modernization Imperatives (International Atomic Energy Agency, 2025c).

2.2.2 Market Structure and Industry Organization

The U.S. nuclear industry operates through private utilities and some public power entities across mixed market structures—competitive markets in seventeen states and regulated markets elsewhere (U.S. Environmental Protection Agency, 2025). This private sector leadership contrasts with state-directed competitors, creating both innovation advantages and coordination challenges (Nuclear Fuel Working Group, 2020).

The completion of Vogtle Units 3 and 4 in Georgia (2023-2024) represent the first new U.S. reactors in decades (U.S. Energy Information Administration, 2023). The construction pipeline includes limited advanced reactor demonstrations, while retirement pressures continued with approximately 12 plants closed since 2010 due to the economic pressures in a stagnant electricity market with competitiveness from natural gas and renewable energies (Holt & Brown, 2022). The authors noted that several more retirements were announced forecast until the 2030s (Holt & Brown, 2022). The Levelized Cost of Electricity (LCOE) is a standardized metric that estimates the revenue required to build and operate electricity generators over a specified cost recovery period, incorporating capital costs, operating costs, fuel costs, financing, and tax impacts (Lazard, 2024; U.S. Department of Energy, 2015). The U.S. electricity sector uses LCOE as a primary metric to assess and compare the economic competitiveness of different energy technologies and resources, with nuclear power not competitive in the short-term using this metric (U.S. Energy Information Administration, 2025a).

The United States Energy Information Administration regularly incorporates LCOE calculations into its Annual Energy Outlook, recognizing the complexity of energy markets and that projections depend on net generation, actual use, laws and regulations, and behavior by producers and consumers (U.S. Energy Information Administration, 2025a). Similarly, the National Renewable Energy Laboratory treats LCOE as a key metric that synthesizes major cost and performance factors in its technology assessments (National Renewable Energy Laboratory, 2024). Regulatory bodies and energy developers utilize LCOE calculations in their decision-making processes, with influential industry analyses like Lazard's annual reports (Lazard, 2025) serving as standard references for evaluating energy technology costs across sectors.

Industry experts increasingly recognize the limitations of LCOE as a single metric and advocate for more extensive systems-level analyses (Lazard, 2024; U.S. Energy Information Administration, 2024d). The EIA incorporates additional metrics such as the Levelized Avoided Cost of Electricity (LACE) to develop a more comprehensive assessment of cost-competitiveness of electricity generation resources. LACE represents a power plant's value to the grid—the revenue available to a generator during the same period as LCOE calculation. The relationship between these metrics, expressed as a value-cost ratio (LACE-to-LCOE), provides a framework for understanding economic competitiveness, with projects considered attractive when LACE (value) exceeds LCOE (cost) (U.S. Energy Information Administration, 2024d).

2.2.3 Regulatory Framework

The United States nuclear regulatory system distributes responsibilities across multiple independent agencies, creating institutional checks and transparency advantages that enhance international credibility. The Nuclear Regulatory Commission (NRC) in particular provides independent safety oversight through a two-step licensing process (construction permit plus operating license) with public hearings and transparent decision-making (U.S. Nuclear Regulatory Commission, 2025a). This independent regulatory approach contrasts with promotional functions handled by the U.S. Department of Energy for research, development, and international cooperation (U.S. Department of Energy, n.d.). Other regulatory bodies involved in some aspect oversight of the nuclear power industry: OSHA, EPA, FERC, and NERC. The Occupational Safety and Health Administration (OSHA) enforces worker safety standards including radiation exposure limits, ensuring plant personnel protection. The Environmental Protection Agency (EPA) sets environmental radiation standards and oversees contamination cleanup, protecting public health and the environment. The Federal Energy Regulatory Commission (FERC) regulates the interstate grid transmission and commerce. The North American Electric Reliability Corporation (NERC) plays a role in grid reliability across all states and energy sectors.

The distributed electricity model used by the U.S. enhances regulatory independence that importing countries value for nuclear investments, as evidenced by the NRC's role in certifying advanced reactor designs for international deployment. However, the complexity creates licensing inefficiencies (U.S. Government Accountability Office, 2023), with new reactor approvals by the NRC requiring year 10 to 12 years, constraining deployment speed and industrial capacity maintenance. As shown in Table 2.1, the United States has the longest approval process, licensing fewer new reactors annual in comparision to Russia and China (U.S. Nuclear Regulatory Commission, 2025b). As shown in Table 2.1, the United States licenses fewer new reactors annually compared to China and Russia (U.S. Nuclear Regulatory Commission, 2025b).

Table 2.1: Nuclear licensing activity and timeline for the U.S. , Russia and China.

Country	New Licenses/Year	Notes
United States	<1 per year	Focus on renewals
China	Up to 10/year	New construction
Russia	2-3/year	Domestic & export

More recent policy developments including the the Infrastructure Investment and Jobs Act of 2021 and the ADVANCE Act of 2024 provide renewed federal support through production tax credits, loan guarantees, and streamlined licensing procedures. These measures acknowledge regulatory modernization as essential for maintaining nuclear competitiveness against state-directed competitors while preserving safety standards.

2.2.4 Supply Chain Dependencies and Vulnerabilities

Since 1977, the United States operates an open fuel cycle (once-through) without commercial reprocessing due to a policy prohibition (U.S. Government Accountability Office, 1980a), creating dependencies in multiple fuel cycle stages. As shown in Figure 2.11 uranium production remains limited while enrichment capability consists of one commercial facility (Urenco USA), requiring significant imports of uranium and enrichment services.

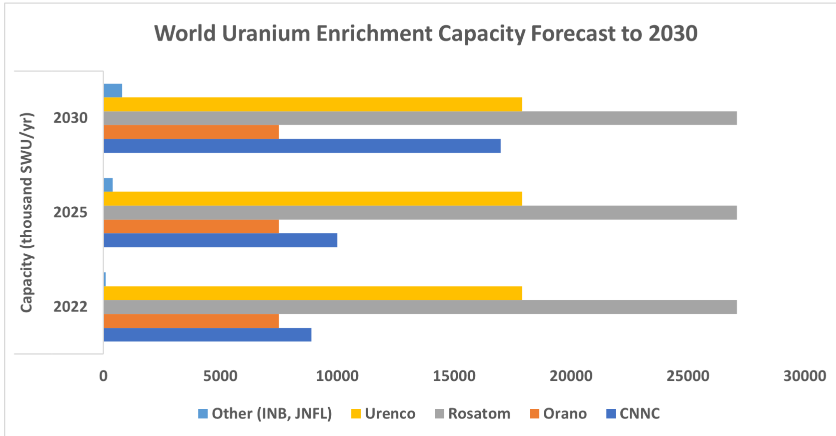

Figure 2.11: Global uranium enrichment capacity share by supplier forecast through 2030 (U.S. Energy Information Administration, 2024a). Accessed 06-01-2025.

As shown in Figure 2.12, a critical supply chain dependency is significant reliance on foreign enrichment services for the low-enriched uranium (LEU) needed to operate existing reactors (U.S. Energy Information Administration, 2024a). The EIA estimates approximately a third of U.S. purchased enriched uranium is from Russia. Figure 2.12 illustrates U.S. capacity, relative to that of foreign suppliers, to produce uranium concentrate U_3O_8, also referred to as yellowcake. This natural form of uranium is converted to a form that is ready for enrichment (U.S. Energy Information Administration, 2024a, 2024c).

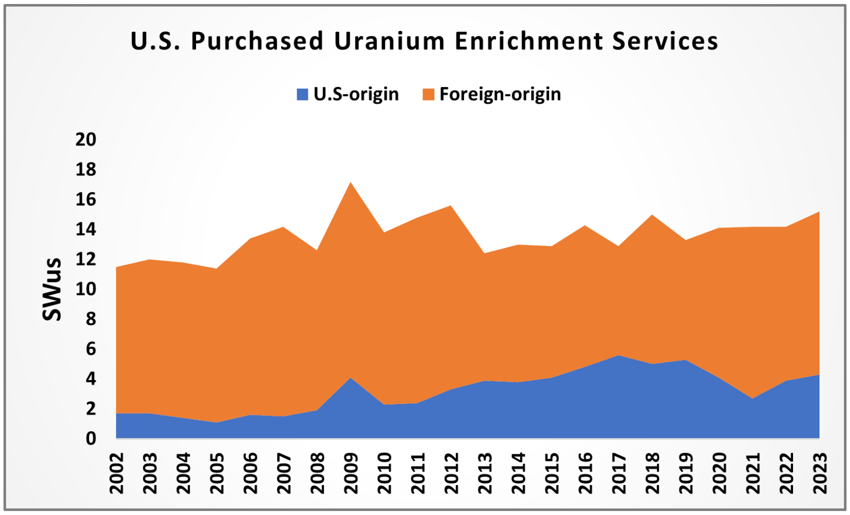

Figure 2.12: Global uranium enrichment capacity share by supplier forecast through 2030 (U.S. Energy Information Administration, 2024a). Accessed 06-01-2025.

The nuclear fuel cycle encompasses multiple specialized stages from uranium mining and enrichment to reactor fuel fabrication, followed by interim storage and potential reprocessing of spent fuel. Each stage requires dedicated infrastructure and technical expertise, creating complex supply chain dependencies (Ahn et al., 2023; U.S. Nuclear Regulatory Commission, 2024d). While most nuclear states maintain complete fuel cycle capabilities, the U.S. discontinued commercial spent fuel reprocessing, creating different strategic considerations for fuel cycle management. The 1977 ban on commercial reprocessing grew from nuclear proliferation concerns during the Carter Administration (U.S. Government Accountability Office, 1980b), with recent Congressional analysis examining policy implications for spent fuel management (Holt & Larson, 2025). However, the U.S. Department of Defense currently oversees reprocessing for military use (U.S. Nuclear Regulatory

Commission, 2024b). The strategic implications of fleet modernization emerge clearly when examining reactor age profiles across the three major nuclear powers. Of strategic importance is the sovereignty of the nuclear reactor fuel supply chain that supports power reactor operations. U.S. uranium procurement patterns reveal significant dependencies on foreign suppliers that could constrain both domestic reactor deployment and international export competitiveness.

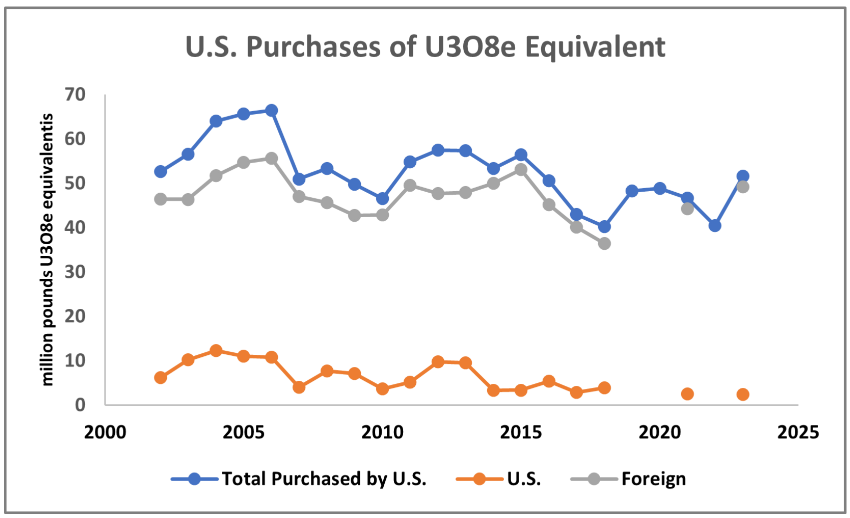

Figure 2.13: U.S. domestic uranium concentrate capacity (U.S. Energy Information Administration, 2024a). Accessed 06-10-2025.

Another emerging constraint affecting domestic advanced reactor deployment and international export credibility U.S. dependency on foreign sources to access high-assay low-enriched uranium (HALEU) needed for conceptual U.S. advanced reactor designs. Fuel fabrication capabilities through Framatome, Westinghouse, and Global Nuclear Fuel facilities provide partial domestic capacity, but spent fuel storage relies on temporary on-site storage without permanent repository solutions (U.S. Department of Energy, 2024; U.S. Nuclear Regulatory Commission, 2024d). For more details on HALEU see Appendix A. These supply chain vulnerabilities expose strategic constraints that state-directed competitors exploit through vertical integration and export leverage. Ongoing efforts to rebuild domestic enrichment capacity and HALEU production (Pir-Budagyan, 2025) represent recognition of these strategic vulnerabilities but show limited progress relative to advancing international competition.

2.2.5 Innovation Challenges

The United States leads globally in nuclear innovation diversity with at least 30 advanced reactor designs under conceptual or development phases, reflecting strong research capabilities and entrepreneurial energy by companies such as NuScale, Natrium, XTerra and others. However, this design leadership contrasts sharply with execution performance of Russia and China (International Atomic Energy Agency, 2024a). The U.S. currently has no reactors under construction (International Atomic Energy Agency, 2025c) despite operating the oldest nuclear fleet in the world (Cleveland & Clifford, 2024).

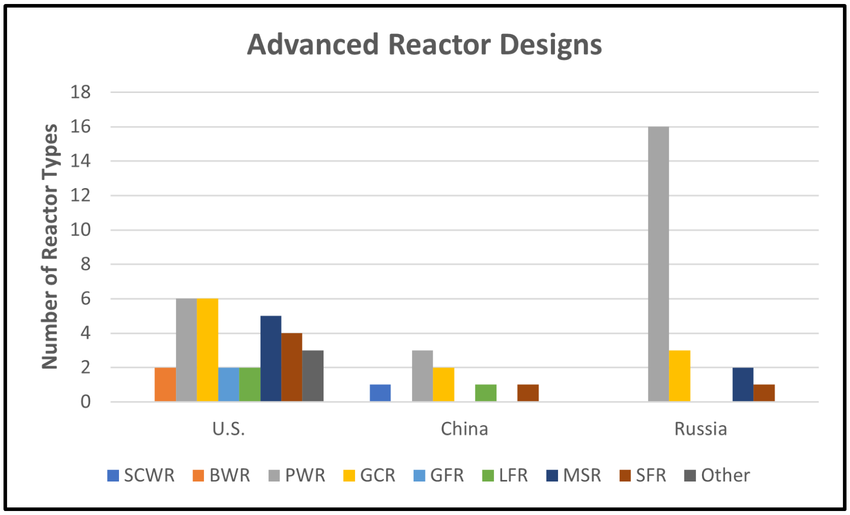

Figure 2.14: Advanced reactor design diversity by country and reactor type. The U.S. demonstrates broad technological diversity across multiple reactor categories, while China and Russia show more focused development approaches, reflecting different innovation strategies and execution capabilities (International Atomic Energy Agency, 2024a).

As illustrated in Figure 2.14, the United States pursues development across virtually all advanced reactor categories—including Small Modular Water Reactors (SCWR), Boiling Water Reactors (BWR), Pressurized Water Reactors (PWR), Gas-Cooled Reactors (GCR), Gas-Cooled Fast Reactors (GFR), Liquid Metal Fast Reactors (LFR), Molten Salt Reactors (MSR), and Sodium-Cooled Fast Reactors (SFR). This technological diversity reflects the market-driven innovation model where multiple private companies pursue different technical pathways. In contrast, China and Russia demonstrate more focused approaches, concentrating resources on specific reactor types aligned with strategic priorities and deployment capabilities.

Analysis of the IAEA's Advanced Reactors Information System logs over 60 SMR designs under development globally, with distinct national approaches to technology development and deployment (International Atomic Energy Agency, 2024a). As shown in Table 4.3, the three major nuclear powers demonstrate different strategies in advanced reactor innovation and deployment.

The innovation-execution gap represents a fundamental strategic challenge where technological superiority fails to translate into deployment advantages or export competitiveness. Recent policy developments including the ADVANCE Act of 2024 (U.S. Congress, 2024) directly address these challenges through streamlined licensing and enhanced federal support for advanced reactor deployment.

2.2.6 Export Challenges and Vulnerabilities

U.S. nuclear export competitiveness faces structural challenges stemming from limited government backing compared to state-directed competitors offering comprehensive turnkey packages. While maintaining technological advantages through advanced designs and safety standards, the fragmented export model struggles against Russia's 22 international reactor projects (International Atomic Energy Agency, 2025d) and China's Belt and Road Initiative nuclear strategy (Kim, 2023).

Critical supply chain dependencies, particularly the significant Russian dependence for low-enriched uranium (LEU) and high-assay low-enriched uranium (HALEU) constrain both domestic advanced reactor deployment and international export credibility. Ongoing efforts to rebuild domestic enrichment capacity represent recognition of these strategic vulnerabilities but show limited progress to date. In 2022, the U.S. Department of Energy awarded a milestone contract to the subsidiary of an American-owned company, Centrus, for production of amounts of HALEU for demonstration reactor projects (U.S. Department of Energy, 2023). The DOE announced this production to be "the first of its kind in the U.S. in over 70 years (U.S. Department of Energy, 2023)."

2.3 Strategic Profile: Russia

2.3.1 Fleet Overview

Russia's early development of nuclear power parallels that of the United States, with each vying to out-compete the other during the Cold War era. Russia operates 36 nuclear reactors with approximately 29.4 GWe total capacity which produce around 216 TWh of annual domestic electricity generation. The average age of operational reactors in Russia is approximately 30 years (Cleveland & Clifford, 2024), see Figure 2.10 (International Atomic Energy Agency, 2025c). Russia's thirty-six operational reactors include two primary reactor types: VVER (Pressurized Water Reactor) and RBMK (Channel-type

Boiling Water Reactor). The RBMK, also known as a Light Water Graphite Reactor (LWGR), is unique due to its use of graphite as a moderator and water as a coolant (World Nuclear Association, 2024a).

The Russian fleet demonstrates steady operational performance with capacity factors of 80-85% reported by International Atomic Energy Agency (2025c). The gradual replacement of aging RBMK units with modern VVER designs reflects ongoing fleet modernization efforts (World Nuclear Association, 2024f).

Russia is less consistent than China in terms of construction projects and timelines. However, the country currently has seven reactors under construction and is involved in the construction of at least 20 reactors in other countries (World Nuclear Association, 2024f). These regulatory differences provide the foundation for examining approaches to innovation in nuclear technology in the next domain. Russia leads the world in fast reactor technology and two BN-series operational units and the BREST demonstration under construction (World Nuclear Association, 2023).

2.3.2 State Corporation Model

Russia operates through Rosatom, a unique state corporation that integrates nuclear development, regulation, and export promotion under unified strategic direction (World Nuclear Association, 2024f).This institutional model enables strategic coherence unavailable to fragmented democratic systems, with a

Rosatom subsidiary, Rosenergoatom, serving as the primary plant operator while maintaining vertical integration across the nuclear supply chain (World Nuclear Association, 2024f).

Nuclear regulatory oversight in Russia operates through Rostechnadzor, which historically functioned with less institutional independence and weaker legal authority compared to the U.S. NRC (U.S. General Accounting Office, 1994).

2.3.3 Strategic Leverage: Global Export Dominance

Russia achieves unparalleled nuclear export competitiveness with approximately 20 international reactor projects under construction as of 2024 (World Nuclear Association, 2024f), representing the world's largest nuclear export program. The Rosatom export model leverages comprehensive state backing to offer turnkey solutions including construction financing, fuel supply agreements, operator training, and maintenance support that create strategic dependencies among importing countries (World Nuclear Association, 2024f).

Russia's nuclear activities reflect broader geopolitical dynamics in the nuclear energy sector (Nakano, 2025). Russian strategic cooperation extends to multiple partners, including technical collaboration with China, Iran, and North Korea (Bergmann et al., 2024). Nuclear cooperation agreements serve as components of broader diplomatic relationships between nations (Nakano, 2025).

2.3.4 Fuel Cycle Sovereignty and Market Control

Russia maintains extensive domestic fuel cycle capabilities including uranium production, enrichment, fuel fabrication, and waste management (World Nuclear Association, 2024f). Their comprehensive supply chain enables Russia to provide complete nuclear fuel cycle services to international customers while maintaining domestic energy security. (World Nuclear Association, 2024f). Russia dominates the global uranium enrichment market with an estimated 44% share (World Nuclear Association, 2025). Approximately 27% of U.S. imported enriched uranium comes from Russia (U.S. Energy Information Administration, 2024a).

2.4 Strategic Profile: China

2.4.1 Fleet Overview

China's approximately fifty-seven post-1990 reactors include advanced Generation III+ designs, such as the indigenous Hualong One and imported AP1000 (United States) and EPR (France) technologies (International Atomic Energy Agency, 2025c), demonstrating both the absorption of technology and indigenous innovation capabilities.

China operates nuclear energy policy through a hybrid developmental state model (Karagiannis et al., 2020) that combines authoritarian governance with strategic economic planning and rapid industrial scaling (Y.-c. Xu, 2012). This approach enables exceptional deployment capability, with 57 operating reactors representing one of the world's most ambitious nuclear expansion programs (U.S. Energy Information Administration, 2024b; World Nuclear Association, 2024e).

The centralized planning system achieves remarkable consistency in nuclear development across leadership transitions and economic cycles, demonstrating institutional capacity for sustained long-term investment. China's nuclear policy maintains strategic direction through unified government priorities that significantly outperform international averages as shown in Table 4.3.

2.4.2 Technology and Innovation Strategy

China demonstrates exceptional execution capability in nuclear innovation, achieving operational status with two advanced reactors from eight total designs (25% execution rate) that significantly exceeds U.S. performance (3% execution rate) as shown in Figure 2.15. The HTR-PM reactor represents the world's first operational Generation IV reactor connected to an electrical grid (Foro Nuclear, 2024; Reuters, 2023), establishing Chinese leadership in advanced nuclear reactor deployment.

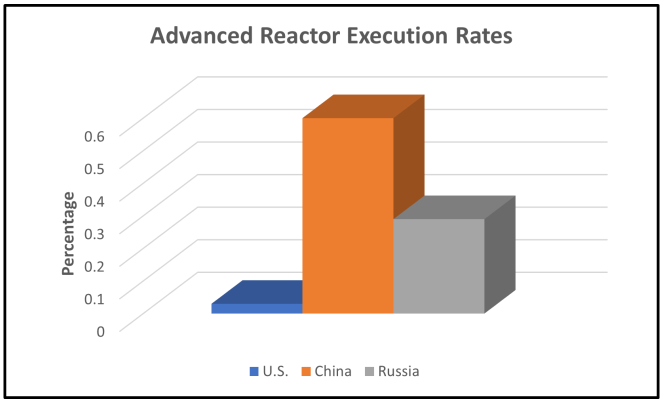

Figure 2.15: Execution rate methodology is defined in Chapter 4.

This focused innovation strategy emphasizes technology acquisition, localization, and deployment over broad research portfolios (World Nuclear Association, 2024e; Y.-c. Xu, 2012). China concentrates resources on technologies with clear deployment pathways and commercial applications, contrasting with U.S. emphasis on design diversity without comparable execution capability. The approach enables rapid capability building across nuclear fuel cycle stages within decades of program initiation.

2.4.3 Belt and Road Initiative: Nuclear Strategy

China leverages nuclear technology exports as integral components of the Belt and Road Initiative, connecting reactor projects with broader infrastructure development, financing packages, and strategic partnership building (Kim, 2023; Wilson Center, 2021). This comprehensive approach creates nuclear export opportunities while advancing broader geopolitical objectives through regional economic integration (Wilson Center, 2021). This strategy creates nuclear export opportunities while advancing broader geopolitical objectives through regional economic integration (Wilson Center, 2021).

While China's nuclear export program remains in early development stages compared to Russia's established global presence, it demonstrates rapidly growing capabilities and international interest (Nakano, 2025; Wilson Center, 2018). Current export projects focus primarily on neighboring countries and BRI participants, with state backing providing concessional financing and integrated diplomatic support (Karagiannis et al., 2020; Wilson Center, 2021).

2.4.4 Strategic Autonomy: Supply Chain Development

China pursues nuclear supply chain sovereignty through rapid capacity building and strategic resource acquisition (Nakano, 2025; World Nuclear Association, 2024e). The strategy emphasizes diversified international uranium acquisition, domestic exploration programs, and strategic stockpiling that ensures fuel supply security despite limited domestic uranium resources (Nuclear Energy Agency, 2024; U.S. Energy Information Administration, 2024a).

Domestic enrichment capacity expansion provides fuel cycle sovereignty while creating opportunities for nuclear fuel exports to regional markets (Enerdata, 2024; World Nuclear Association, 2025). Chinese nuclear capabilities include reactor construction, component fabrication, and fuel production through integrated domestic industrial base development that supports both domestic deployment and export potential (World Nuclear Association, 2024e).

2.5 Theoretical Frameworks

2.5.1 Strategic Competition Theory

Mearsheimer (2001) emphasizes that nations compete across multiple dimensions beyond military power in strategic competition theory including economic capabilities, technological leadership, and institutional effectiveness. Unlike traditional approaches that treat nuclear power primarily as an energy technology subject to market forces, this framework adopts a strategic perspective that views civilian nuclear power as a tool of national power and international influence.

Sugden (2019) developed a strategic framework for nuclear power competition. The author compares pairwise dynamics between nuclear powers (U.S. –Russia, U.S. –China). Sugden's framework is domain specific for nuclear warfare analysis. This structure is comprised of three domains: historical evolution of nuclear power programs, competitive interaction analysis, and investment balance assessment. Sugden states that nuclear energy competition between established nuclear rivals (Russia) and emerging competitors (China) occurs in two interrelated realms: markets and capabilities. Market competition is defined as reactor exports, fuels contracts, and technology partnerships. The author states that capability competition includes research and development investments, supply chain development, regulatory governance and innovation. The author also examines differences in nuclear competition across dimensions in democratic market-driven systems and authoritarian, state-directed models, emphasizing investigation of capabilities and avoidance of theoretical models absent of empirical grounding (Sugden, 2019).

Building on Mearsheimer's strategic competition theory (Mearsheimer, 2001) and Sugden's nuclear-specific framework (Sugden, 2019), competition between the United States, Russia, and China in nuclear energy demonstrates how nations compete across economic capabilities, technological leadership, and institutional effectiveness rather than military power alone (Mearsheimer, 2001; Third Way, 2024; U.S. Congress, 2018; Wilson Center, 2018).

2.5.2 Nuclear Policy Hierarchy Framework

Gattie and Hewitt provide the foundational framework connecting civilian nuclear capabilities to national security considerations (D. Gattie & Hewitt, 2023). Their nuclear policy hierarchy demonstrates that strategic nuclear assessment requires moving beyond market-driven metrics to incorporate national security dimensions that are typically dismissed as a "gray area" in U.S. policy (D. K. Gattie, 2018).

This framework identifies key weaknesses in market-based nuclear evaluation: fragmented institutional approaches, failure to monetize strategic benefits, and overlooking nuclear cooperation's role in international influence. This analysis provides the theoretical foundation for developing strategic nuclear competitiveness indicators that capture execution capabilities rather than pure innovation metrics (D. Gattie & Hewitt, 2023).

2.5.3 Social License and Trust

The Social License to Operate (SLO) framework provides a conceptual foundation for understanding how public acceptance affects nuclear strategic positioning. SLO theory emphasizes that technological deployment requires not only regulatory approval but also broader social acceptance from affected communities and stakeholders (Slovic, 2000). This framework is particularly relevant for democratic systems where public opposition can constrain nuclear deployment regardless of economic or strategic benefits.

Slovic developed a psychometric paradigm that demonstrates that public risk perception depends on qualitative characteristics in addition to quantitative risk assessments (Slovic, 2000). Slovic concluded that uclear technology exhibits characteristics that systematically increase perceived risk: involuntary exposure, potential for catastrophic consequences, and unfamiliar technology. This framework explains persistent public concerns about nuclear power despite strong safety records and helps illuminate how risk perception affects strategic nuclear competitiveness across different governance systems (Slovic, 2000).

Trust Determination Theory, developed by Peters, Covello and McCallum, identifies trust as a primary factor influencing risk-related decisions (Peters et al., 1997). The authors conducted empirical research demonstrating that perceptions of trust and credibility depend on three factors: perceptions of knowledge and expertise, perceptions of openness and honesty, and perceptions of concern and care. The study found that trust and credibility judgments are resistant to change once formed. The theory addresses how institutional trust affects public acceptance of risk management decisions.

2.5.4 Existing Nuclear Assessment Approaches

Current nuclear assessment methodologies encompass multiple analytical approaches; however, most focus primarily on economic competitiveness, safety performance, or technical characteristics without systematic integration of strategic dimensions.

Economic Models: The Levelized Cost of Electricity (LCOE) dominates nuclear economic assessment, providing standardized comparison across generation technologies but capturing only direct economic costs. System cost approaches have emerged to address LCOE limitations (Nuclear Energy Agency, 2020), with the Nuclear Energy Agency recommending system cost metrics to reflect nuclear energy's full grid value. Existing economic frameworks focus primarily on project-level cost competitiveness rather than national strategic positioning, failing to capture how broader strategic factors affect national competitiveness.

Security Assessment: The NTI Nuclear Security Index assesses nuclear security conditions across 175 countries and Taiwan using a 0-100 scoring scale (Nuclear Threat Initiative, 2023). The Index evaluates countries with weapons-grade nuclear materials across five categories: Quantities and Sites, Security and Control Measures, Global Norms, Domestic Commitments and Capacity, and Societal Factors. The 2023 edition documented regression in nuclear security conditions among countries with weapons-grade nuclear materials and nuclear facilities.

Technology Assessment: Technology Readiness Levels provide systematic assessment of technology maturity across a 1-9 scale for nuclear applications (National Aeronautics and Space Administration, 2023; Terrani et al., 2017). Socio-technical Readiness Levels integrate social and environmental considerations alongside technical readiness (Verma & Allen, 2024). International initiatives, including the Generation IV International Forum and Nuclear Innovation 2050, use these frameworks for collaborative development of advanced reactor technologies (Generation IV International Forum, 2025).

Energy Transition Assessment: The World Economic Forum's Energy Transition Index benchmarks 120 countries on energy system performance and transition readiness across equity, security, and sustainability dimensions (World Economic Forum, 2024). The framework uses 46 indicators to evaluate countries beyond economic metrics, incorporating system performance and enabling environment factors.

Assessment Gap: The predominant focus on economic metrics creates a systematic gap in evaluating the strategic dimensions of nuclear power. Nuclear power provides capabilities extending beyond electricity generation, including energy security, industrial base maintenance, technological innovation platforms, export competitiveness, and geopolitical influence tools. These strategic values resist quantification through traditional frameworks, yet represent critical considerations for national nuclear policy development. No existing framework systematically integrates the strategic dimensions that contribute to nuclear competitiveness in great power competition.

2.6 Theoretical Foundations and Key Concepts

This section establishes the conceptual foundation underlying the Strategic Nuclear Competitiveness Index (SNCI) framework by defining key strategic concepts and nuclear technology classifications that inform the analysis throughout this study.

2.6.1 Strategic Nuclear Competitiveness Conceptual Framework

Understanding nuclear strategic competitiveness requires precise definitions of key concepts drawn from national security studies and international policy literature that distinguish strategic value from purely economic considerations.

Nᴀᴛɪᴏɴᴀʟ Sᴇᴄᴜʀɪᴛʏ. National security refers to the safeguarding of a nation's sovereignty, economic interests, institutional integrity, and the welfare of its citizens from internal and external threats. It extends beyond military defense to include economic stability, infrastructure resilience, energy independence, and technological leadership (Holmes, 2014). Civilian nuclear power contributes to national security through multiple pathways including energy sovereignty, supply chain control, technological prestige, and diplomatic leverage.

Nᴀᴛɪᴏɴᴀʟ Pᴏᴡᴇʀ. National power is the capacity of a state to influence other actors and secure its interests across multiple domains—military, economic, technological, diplomatic, and informational. It encompasses both tangible capabilities and intangible elements such as legitimacy, identity, and cultural influence (Jablonsky, 1997). Nuclear competitiveness enhances national power by demonstrating technological sophistication, creating export opportunities, and establishing strategic partnerships through nuclear cooperation agreements.

Sᴛʀᴀᴛᴇɢɪᴄ Pᴏsᴛᴜʀᴇ. Strategic posture refers to a nation's orientation and readiness to pursue its objectives and respond to threats in the international system. It encompasses institutional structures, alliance commitments, technological capacity, and energy security (U.S. Department of Defense, 2022). Civilian nuclear power contributes to strategic posture by reinforcing energy sovereignty, supply chain control, and diplomatic leverage through comprehensive nuclear cooperation frameworks.

Strategic Advantage and Competitive Advantage. This distinction is central to the SNCI framework's analytical approach. Competitive advantage refers to a country's relative performance in specific measurable areas—such as innovation capacity, export volume, or regulatory efficiency. Strategic advantage, by contrast, incorporates broader considerations including national resilience, long-term sovereignty, and influence over international norms and governance structures. The SNCI framework aims to quantify both performance and strategic positioning, recognizing that nuclear competitiveness extends beyond immediate economic metrics to encompass long-term strategic value.

Zero-Sum versus Positive-Sum Competition. Nuclear competition contains elements of both competitive dynamics. Zero-sum competition (Brzezinski, 1997; Mearsheimer, 2001) refers to strategic interactions where one country's gains directly diminish another's position, creating relative advantage through the competitor's disadvantage. Examples include export market share, supply chain control, and exclusive nuclear cooperation agreements. Positive-sum competition allows multiple countries to achieve simultaneous benefits through technological advancement, market expansion, or collaborative development that creates absolute gains for all participants.

Understanding these dynamics is essential for developing effective strategic responses to nuclear competition.

2.6.2 Nuclear Technology Strategic Classifications

The evolution of nuclear reactors reflects both technological advancement and changing strategic priorities, with each generation emphasizing different aspects of nuclear capability development.

Generation I Reactors: Early prototype and demonstration reactors including Shippingport (U.S.) and Magnox designs (U.K.) established the foundational principles of commercial nuclear power (U.S. Department of Energy, 1994, n.d.). These systems demonstrated technical feasibility while serving strategic objectives of technological leadership and international prestige during the Cold War era. Most Generation I reactors are now decommissioned, having served their strategic purpose of establishing nuclear technological capabilities.

Generation II Reactors: Commercial power reactors with established safety and regulatory protocols form the backbone of current global nuclear capacity. Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs) comprise the majority of operational reactors worldwide, demonstrating proven technology and reliable performance (International Atomic Energy Agency, 2025c; World Nuclear Association, 2024h). Generation

II reactors established nuclear power as a viable commercial energy source while creating the industrial base necessary for nuclear export competitiveness.

Generation III and III+ Reactors: Enhanced safety systems, extended fuel cycles, and passive safety features characterize this generation, including designs such as the EPR, AP1000, and VVER-1200 (International Atomic Energy Agency, 2024a; World Nuclear Association, 2024a). These reactors incorporate lessons learned from decades of operational experience while addressing public safety concerns through improved design features. Generation III+ reactors represent the current frontier of commercially deployable nuclear technology, with implications for export competitiveness and technological leadership.

Generation IV Reactors: Advanced designs emphasizing sustainability, proliferation resistance, and modular deployment include technologies such as Molten Salt Reactors (MSRs), Sodium-Cooled Fast Reactors (SFRs), and High-Temperature Gas Reactors (HTGRs) (Association, 2021; Generation IV International Forum, 2025). Generation IV reactors offer strategic advantages through enhanced fuel efficiency, reduced waste production, and operational flexibility. China's achievement of the world's first operational Generation IV reactor (HTR-PM) demonstrates how advanced reactor deployment translates into strategic competitive advantages (Foro Nuclear, 2024; Reuters, 2023).

2.6.3 Strategic Nuclear Assessment Framework

The conceptual framework developed in this section provides the theoretical foundation for systematic nuclear strategic competitiveness assessment. By distinguishing strategic value from purely economic considerations and recognizing the multi-dimensional nature of nuclear competition, this framework enables comprehensive evaluation of national nuclear positioning.

The integration of strategic concepts with nuclear technology classifications demonstrates how technological advancement serves broader strategic objectives beyond electricity generation. This understanding is essential for developing assessment methodologies that capture the full spectrum of nuclear strategic value, forming the analytical foundation for the Strategic Nuclear Competitiveness Index framework developed in this study.

The conceptual distinctions established between competitive and strategic advantage inform the framework's approach to measuring nuclear competitiveness across multiple domains while recognizing that nuclear power serves national strategic objectives that resist simple quantification through traditional economic metrics.

2.7 Research Gap

Based on this literature review, existing nuclear assessment approaches encompass several established methodologies, each addressing different aspects of nuclear programs. Economic assessment models such as LCOE, LACE, VALCOE, and system cost approaches provide standardized frameworks for comparing generation technologies based on financial metrics (Lazard, 2025; Nuclear Energy Agency, 2020; U.S. Department of Energy, 2015). Security assessment models, exemplified by the Nuclear Threat Initiative's Nuclear Security Index, evaluate nuclear programs through threat mitigation and security risk lenses (Holgate et al., 2020; Nuclear Threat Initiative, 2023). Technology assessment models including Technology Readiness Levels and innovation metrics focus on technological maturity, research inputs, and development progress (National Aeronautics and Space Administration, 2023; Nuclear Energy Agency, 2015). General competitiveness frameworks such as the World Economic Forum's indices offer broad cross-sectoral comparison methodologies (World Economic Forum, 2020, 2024).

However, these existing frameworks demonstrate significant limitations in capturing the multi-dimensional strategic value of nuclear power relative to national security aims. Existing assessment methodologies operate in isolation rather than providing integrated strategic evaluation. Economic assessment models focus on cost metrics while ignoring geopolitical implications. Security assessment models emphasize threat mitigation rather than competitive advantage. Technology assessment models measure innovation inputs rather than strategic execution capability.

Current literature reveals no comprehensive framework that systematically integrates the primary strategic dimensions that contribute to nuclear competitiveness in great power competition: public legitimacy, regulatory effectiveness, innovation execution, export capacity, and supply chain sovereignty. This integration gap constrains policymakers' ability to assess competitive positioning and develop effective strategic responses to state-directed competitors.

While economic evaluations of nuclear power are well-represented in academic literature (MIT Energy Initiative, 2018; Nuclear Energy Agency, 2020), little research proposes composite scoring frameworks that capture strategic value through comparative analysis. Sources from MIT Energy Initiative, OECD-NEA, and other institutions examine deployment trends and cost comparisons but do not extend to systematic strategic assessment across multiple countries and governance models.

Public opinion research (Bisconti Research, 2024; Gallup, Inc., 2025; Leppert & Kennedy, 2024) provides valuable insights into acceptance patterns but remains disconnected from strategic policy frameworks. Similarly, innovation assessments focus on design diversity rather than execution capability, missing the critical translation from technological potential to strategic advantage.

General competitiveness frameworks (World Economic Forum, 2024) fail to capture nuclear energy's unique characteristics that distinguish it from other technologies. Nuclear power's dual-use capabilities, proliferation implications, safety requirements, and long-term infrastructure commitments create strategic dimensions absent from broader energy or technology assessment approaches.

The strategic nuclear competition between the United States, Russia, and China (Atlantic Council, 2023; Nakano, 2025) requires analytical frameworks tailored to nuclear energy's unique strategic characteristics. These include the connection between civilian nuclear capabilities and geopolitical influence, the role of state backing in export competitiveness, and the strategic implications of supply chain dependencies in uranium enrichment and advanced fuel production.

This literature review provides the theoretical foundation for the five strategic domains comprising the Strategic Nuclear Competitiveness Index (SNCI) framework, demonstrating how existing theoretical insights can be integrated into a comprehensive measurement approach for nuclear strategic competitiveness assessment.

Chapter 3

Methodology

This chapter details the research design, framework development, and analytical procedures used to assess nuclear strategic competitiveness across the United States, Russia, and China. The methodology integrates quantitative assessment with qualitative analysis to capture both measurable performance indicators and strategic implications that resist simple quantification. The Strategic Nuclear Competitiveness Index (SNCI) framework provides a systematic tool for comparative analysis across different political-economic models.

3.1 Research Design

This study employs a structured comparative analysis methodology to systematically assess nuclear competitiveness across three major nuclear powers: the United States, Russia, and China, integrating quantitative assessment with comparative analysis to capture both measurable performance indicators and strategic implications that resist simple quantification.

The gap in existing literature highlights the need for the Strategic Nuclear Competitiveness Index (SNCI), which integrates underrepresented domains like geopolitical influence, supply chain sovereignty, public trust, and technological innovation into a multidimensional evaluation model. This framework addresses limitations of current approaches that focus primarily on economic metrics such as levelized cost of electricity (LCOE) while neglecting broader strategic value dimensions.

3.1.1 Political-Economic Comparison Framework

The comparative analysis examines three major nuclear powers representing fundamentally different political-economic models. This approach investigates how different governance structures, economic systems, and strategic priorities affect nuclear competitiveness outcomes across the five strategic domains of the SNCI framework. This framework builds on comparative political economy theory to understand institutional effects on strategic performance.

The three countries selected represent distinct approaches to nuclear development that enable systematic comparison of how institutional arrangements affect strategic outcomes. The United States represents democratic governance with a market-driven nuclear industry. This approach is characterized by independent regulatory oversight, private sector leadership, competitive electricity markets, and democratic accountability mechanisms, creating advantages in regulatory credibility and innovation diversity while generating disadvantages in strategic coordination and deployment speed. The separation of powers and multiple stakeholder involvement enhances transparency and international legitimacy while constraining rapid policy implementation.

Russia exemplifies an authoritarian system with state-directed nuclear enterprise through integrated Rosatom model combining development, regulation, and export functions. The Russian model features unified state control through integrated corporations (Rosatom), centralized strategic planning, and elimination of public opposition or regulatory independence. This model enables comprehensive strategic coordination, rapid policy implementation, and turnkey export packages, but may limit innovation diversity and international credibility in democratic markets.

China demonstrates an authoritarian system with developmental state model emphasizing centralized planning, rapid execution, and strategic coordination. The Chinese model combines centralized strategic planning with rapid execution capability, technology acquisition strategies, and performance-based legitimacy. This model achieves exceptional deployment speed and technological advancement while maintaining state control over strategic direction.

Each model creates distinct institutional capabilities that translate into competitive advantages and disadvantages across the five SNCI domains. The analysis examines these systematic differences to understand how governance structures affect nuclear strategic positioning rather than treating countries as isolated cases.

3.1.2 Comparative Analysis Matrix Framework

The comparative framework operates across three analytical dimensions that systematically capture how political-economic models translate into nuclear competitiveness outcomes:

The institutional dimension examines governance structures, decision-making processes, and regulatory frameworks that shape nuclear development capabilities. Democratic systems emphasize transparency and stakeholder engagement, while authoritarian systems enable rapid coordination and strategic planning.

The execution dimension assesses implementation capability, deployment speed, and the ability to translate policy decisions into operational outcomes. State-directed systems demonstrate advantages in resource mobilization and timeline compression, while market-driven systems may experience coordination challenges.

The strategic dimension evaluates long-term competitive positioning, international influence projection, and supply chain sovereignty. Integrated state corporations can offer comprehensive export packages, while democratic systems may provide greater regulatory credibility and technology innovation.

3.1.3 Theoretical Foundations and Strategic Integration

The SNCI framework builds on established theoretical foundations that collectively capture nuclear competitiveness as a multidimensional strategic phenomenon rather than a purely economic or technical assessment. Following Mearsheimer's framework (Mearsheimer, 2001), the analysis recognizes that nations compete across multiple dimensions beyond military power, including economic capabilities, technological leadership, and institutional effectiveness. This perspective treats civilian nuclear power as a tool of national power and international influence rather than merely an energy technology subject to market forces.

Building on Sugden's nuclear competition analysis (Sugden, 2019), the framework distinguishes between market competition (reactor exports, fuel contracts, technology partnerships) and capability competition (research and development, supply chain development, regulatory governance, innovation execution). Incorporating Gattie's framework (D. K. Gattie & Hewitt, 2023) connecting civilian nuclear capabilities to national security considerations, the analysis moves beyond market-driven metrics to incorporate strategic dimensions typically dismissed in U.S. policy evaluation.

The research design integrates quantitative assessment using established multi-criteria decision making (MCDM) approaches (Ram et al., 2011; Taherdoost & Madanchian, 2023) to capture both measurable performance indicators and strategic implications that resist quantification. Quantitative elements include nuclear capacity data, construction timelines, export statistics, public opinion polling, and technical performance metrics drawn from authoritative international databases. Qualitative insights encompass the strategic comparative analysis of policy frameworks, institutional effectiveness, innovation capabilities, and geopolitical influence patterns. This hybrid approach enables comprehensive evaluation of nuclear competitiveness that balances empirical rigor with strategic insight.

3.1.4 Temporal Scope and Focus

The core SNCI assessment focuses on the 1990-2025 period to capture contemporary strategic competition dynamics with sufficient data availability across all three countries. This time period encompasses significant developments including China's nuclear expansion acceleration (U.S. Energy Information Administration, 2024b), Russia's export offensive (World Nuclear Association, 2024f), and U.S. policy responses including the ADVANCE Act (U.S. Congress, 2024).

Where relevant the analysis incorporates longer historical time series to provide context for current competitive positioning, particularly for deployment trends and technology development trajectories that extend back to the origins of civilian nuclear power development. Different indicators use appropriate temporal coverage based on data availability and analytical relevance. Deployment analysis may extend to 1990 or earlier, while policy framework assessment focuses on the contemporary period. The temporal approach enables assessment of both current competitive positioning and emerging trends that will shape future strategic competition in the nuclear domain.

3.2 SNCI Framework Development

The Strategic Nuclear Competitiveness Index addresses analytical gaps in existing literature by providing the first systematic framework for measuring nuclear strategic competitiveness across multiple domains and countries. The SNCI framework integrates diverse strategic dimensions previously examined in isolation, enabling comprehensive assessment of nuclear competitiveness. It enables systematic comparison across different political-economic models through standardized metrics and scoring procedures, transforms strategic concepts from theoretical frameworks into measurable indicators for policy application, captures execution capability rather than focusing solely on innovation inputs or economic metrics, and provides evidence-based tools for strategic nuclear decision-making and policy intervention targeting. The Strategic Nuclear Competitiveness Index integrates five strategic domains that collectively capture nuclear competitive positioning across different political-economic models. Figure 3.1 illustrates this multi-dimensional framework that enables systematic comparison of nuclear strategic capabilities.

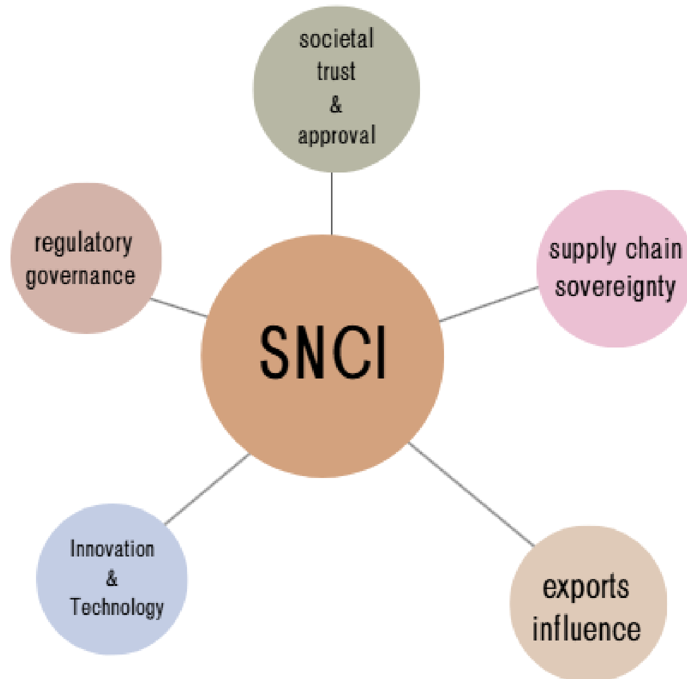

Figure 3.1: Strategic Nuclear Competitiveness Index: Five-Domain Framework

Each domain represents a critical dimension of nuclear strategic competitiveness, from domestic foundations (societal trust, regulatory governance) through technological capabilities (innovation, supply chain sovereignty) to international positioning (export capacity and influence).

3.2.1 Domain Identification and Strategic Logic

The five-domain structure of the SNCI emerged through literature synthesis combined with strategic logic derived from national security theory and comparative political economy analysis. Domain selection criteria included strategic relevance to national security objectives, measurability through available data sources, variation across different political-economic models, and impact on long-term competitive positioning.

The collection of literature was determined by searching verified academic and government databases including OpenAlex, Google Scholar, JSTOR, Science Direct (Elsevier), PubMed, Web of Science, U.S. Department of Energy (U.S. Department of Energy, n.d.), U.S. Energy Information Administration (U.S. Energy Information Administration, 2025b), U.S. Nuclear Regulatory Commission (U.S. Nuclear Regulatory Commission, 2025a), International Atomic Energy Agency (International Atomic Energy Agency, 2025c), and World Nuclear Association (World Nuclear Association, 2024h). Boolean searches progressed from general to specific terms, restricted to relevant publication years. Citation chaining broadened the scope systematically. Inclusion criteria prioritized relevance to national security and civilian nuclear power. Quality sources from reputable academic and government databases were selected based on citation strength. The approach focused on U.S. perspectives while including comparative international analysis. Strategic dimensions took precedence over purely technical or economic considerations.

3.2.2 The Five Strategic Domains

Each domain reflects distinct theoretical foundations that collectively capture nuclear competitiveness.Public Opinion and Societal Trust builds on democratic legitimacy theory and social license concepts. The Regulatory and Policy

Framework draws from institutional effectiveness and state capacity theory. Innovation and Technology incorporates national innovation systems and technological competitiveness theory. Export Capacity and International Influence reflects economic statecraft and soft power theory. Finally, Supply Chain Security and Sovereignty applies strategic autonomy and economic security theory.

Public Opinion and Societal Trust captures the social and political foundations necessary for sustained nuclear development (Peters et al., 1997; Slovic, 2000). In democratic systems, public acceptance enables policy continuity and siting approval, while in authoritarian systems, performance legitimacy supports state nuclear programs. Key indicators include public opinion polling data, NIMBY sentiment analysis, and trust in nuclear institutions.

Regulatory and Policy Framework assesses institutional effectiveness and policy coherence in nuclear governance. It examines regulatory independence, licensing efficiency, policy predictability, and international cooperation frameworks. Indicators include licensing timelines, regulatory structure analysis, policy consistency measures, and international agreement participation.

Innovation and Technology evaluates technological capabilities and execution performance in nuclear innovation. Beyond traditional research and development metrics, it emphasizes the innovation-execution gap and operational deployment (National Aeronautics and Space Administration, 2023). The execution rate methodology measures the proportion of advanced reactor designs progressing to operational status, providing systematic assessment of countries' ability to translate research into deployed technologies. Key indicators include advanced reactor development, execution rates, operational experience, and technology transfer capabilities.

Export Capacity and International Influence measures the ability to project nuclear technological leadership internationally through exports and cooperation. It captures both commercial export performance and strategic influence through nuclear partnerships. Indicators include reactor export projects, market share analysis, financing capabilities, and diplomatic nuclear cooperation.

Supply Chain Security and Sovereignty assesses control over critical nuclear supply chains and vulnerability to external dependencies. It examines uranium resources (Nuclear Energy Agency, 2024), enrichment capacity (Enerdata, 2024), fuel fabrication, and component manufacturing capabilities. Key indicators include domestic production capacity, import dependencies, strategic stockpiling, and supply chain diversification.

3.2.3 Indicator Development and Validation

Primary indicators were selected based on data availability, reliability, and strategic relevance. Sources include IAEA databases (PRIS, ARIS), national regulatory agencies, international organizations, and polling organizations. Metrics emphasize outcomes rather than inputs where possible. Qualitative indicators capture strategic dimensions that resist quantification, including policy coherence, institutional effectiveness, and international influence patterns. Assessment criteria were developed through comparative case study methodology and analysis of strategic literature.

Selected indicators underwent validation through cross-referencing across multiple authoritative sources, consultation with domain-specific literature, logical consistency checks with theoretical frameworks, and sensitivity analysis to ensure robustness. The baseline SNCI employs equal weighting across all five domains, reflecting the assumption that each represents a critical dimension of strategic nuclear competitiveness. This approach avoids arbitrary prioritization while enabling sensitivity analysis of alternative weighting schemes.

While the SNCI framework provides the foundation for systematic quantitative assessment, this study employs qualitative comparative assessment rather than numerical scoring due to research constraints. The demonstration of the SNCI relies on qualitative rankings and strategic analysis rather than precise numerical scores. Expert consultation through Delphi or other survey methodology is recommended to establish robust weighting schemes and validate numerical scoring approaches (Avella, 2016). The current qualitative implementation provides proof-of-concept for the framework while acknowledging the need for expert validation in future applications.

Multiple weighting scenarios test the robustness of comparative assessments. The comparisons include innovation-heavy weighting reflecting technological competition emphasis, export-focused weighting emphasizing geopolitical influence, and supply chain-heavy weighting reflecting economic security priorities.

3.3 Case Selection and Data Collection

3.3.1 Case Justification and Data Sources

The U.S. represents the archetypal democratic market economy approach to nuclear development, with independent regulatory oversight, private sector leadership, and competitive electricity markets. This case enables examination of how democratic governance and market mechanisms affect nuclear competitiveness.

Russia exemplifies the authoritarian state-directed approach through Rosatom's integrated model combining regulatory oversight, industrial development, and export promotion (World Nuclear Association, 2024f). This case demonstrates how centralized state control affects nuclear strategic positioning.

China represents the developmental state approach (Karagiannis et al., 2020), combining authoritarian governance with strategic economic planning and rapid industrial scaling (World Nuclear Association, 2024e). This case illustrates how state-directed development can achieve rapid nuclear expansion and technological advancement.

Data collection draws from multiple source categories to ensure comprehensive coverage and reliability. Government documents and official sources include national energy policies and nuclear strategies, regulatory agency reports and statistical databases, and official export and cooperation agreements. International databases and organizations provide data from IAEA Power Reactor Information System (PRIS) (International Atomic Energy Agency, 2025c), IAEA Advanced Reactor Information System (ARIS) (International Atomic Energy Agency, 2024a), International Energy Agency (IEA) databases (International Energy Agency, 2019), World Nuclear Association statistical resources (World Nuclear Association, 2024h), and OECD Nuclear Energy Agency reports (Nuclear Energy Agency, 2020).

Expert analysis and secondary sources include think tank reports and policy analyses, academic research and peer-reviewed studies, industry association publications, and specialist consulting firm assessments. Public opinion and survey data comes from Gallup, Pew Research, and Bisconti Research polling (Bisconti Research, 2024; Gallup, Inc., 2025; Leppert & Kennedy, 2024), academic survey research on nuclear attitudes (Baron & Herzog, 2020), government-sponsored public opinion studies (U.S. Department of Energy, 2024), and cross-national comparative polling data (OECD Nuclear Energy Agency, 2010).

3.3.2 Data Quality and Reliability

Multiple sources were consulted for each key data point to ensure accuracy and identify potential discrepancies. Government sources were cross-referenced with international organization data and independent analyses. Data collection focused on the primary assessment period with consistent temporal coverage across cases to enable valid comparisons and trend analysis. Some nuclear data involves classification restrictions, particularly regarding advanced technologies and supply chain details. The analysis acknowledges these limitations and relies on publicly available sources and expert assessments rather than classified information.

3.4 Composite Index Construction

3.4.1 Normalization and Aggregation Methodology

Raw indicators across diverse measurement scales (capacity in GW, survey percentages, qualitative assessments) require normalization for aggregation. The study employs standard min-max normalization to convert all indicators to 0-100 scales, preserving relative performance differences while enabling cross-domain comparison. The normalization formula applied is:

$$\text{Normalized Score} = \frac{\text{Raw Value} - \text{Minimum Value}}{\text{Maximum Value} - \text{Minimum Value}} \times 100 \qquad (3.1)$$

Missing data points are addressed through interpolation using available trend data, assessment based on available information, or sensitivity analysis examining impact of alternative assumptions. Within each domain, normalized indicators are aggregated using weighted averages based on indicator reliability and strategic importance. Domain scores represent composite assessments of performance across multiple dimensions.

The overall SNCI score combines domain scores using equal weighting as the baseline methodology. The composite SNCI score employs a two-stage aggregation process following standard international index construction practices. Within-domain aggregation sees individual indicators normalized (0-100 scale) and aggregated to domain scores using weighted averages based on indicator reliability. Cross-domain aggregation combines domain scores using equal weighting via arithmetic mean. The composite SNCI score is calculated as:

$$\text{SNCI Score} = \frac{1}{5}\sum_{i=1}^{5} \text{Domain Score}_i \tag{3.2}$$

This methodology follows established practices used by major international competitiveness indices such as the World Economic Forum Global Competitiveness Index (World Economic Forum, 2024), and similar composite assessment frameworks.

3.4.2 Sensitivity Analysis

Alternative weighting schemes test robustness of comparative rankings, including scenarios emphasizing innovation, exports, or supply chain security. Results examine whether core findings persist across different priority assumptions. Individual indicator impacts are assessed through systematic removal and substitution procedures to identify drivers of overall scores and ensure robustness of comparative assessments. Snapshot comparisons are supplemented with trend analysis to capture dynamic competitive positioning and identify trajectory changes over the assessment period.

3.5 Strategic Scenario Analysis

Strategic scenario analysis enables examination of how different policy trajectories and competitive dynamics might affect nuclear competitiveness over time. This section develops three strategic scenarios based on current trends and explores how the SNCI framework could be enhanced to analyze future developments.

3.5.1 Scenario Development and Growth Trajectory Analysis

The analysis develops strategic scenarios based on policy trajectories and competitive dynamics. Table 3.1 examines three potential competitive trajectories across the strategic competitors.

Table 3.1: Strategic Nuclear Competitiveness Scenarios (2025-2040)

Scenario	Country	Strategic Trajectory
Status Quo	U.S.	Market approach, limited ADVANCE Act execution, relative decline as retirements exceed construction
	Russia	Export dominance via integrated Rosatom, 25+ international projects, steady domestic growth
	China	6-8% annual growth via developmental state model, 180-200 GWe by 2035
Innovation Success	U.S.	ADVANCE Act success, domestic HALEU production, execution rates improve 3% to 15%, enhanced export financing
	Russia	Export expansion despite geopolitical constraints, maintains technological leadership
	China	Accelerated deployment for carbon neutrality, 250-300 GWe by 2040, deepened international cooperation
State Dominance	U.S.	Hybrid state-market coordination, nuclear as national security priority, alliance-based cooperation framework
	Russia	Adaptation to Western sanctions, China/Global South focus, strategic supply chain leverage
	China	Sustained high growth despite technology restrictions, leadership in technology bifurcation dynamics

Each scenario demonstrates how different political-economic models respond to strategic pressures. The Status Quo scenario shows institutional inertia effects, with democratic systems struggling against state-directed competitors. The Rapid Innovation scenario illustrates potential for institutional reform to alter competitive trajectories. The State-led Eastern Dominance scenario demonstrates how geopolitical tensions could expose democratic vulnerabilities while reinforcing authoritarian advantages in supply chain sovereignty.

Nuclear generation forecasting employs trend analysis combined with policy assessment to project future competitive trajectories. Key parameters include construction pipeline (reactors under construction and firmly planned projects), retirement schedule (aging fleet analysis and expected shutdowns), policy framework (government nuclear commitments and strategic plans), growth rate analysis (historical deployment patterns and acceleration potential), and completion probability (risk assessment for projects under development).

Each scenario examines how different trajectories would affect relative competitive positioning across the five SNCI domains, competitive dynamics in export markets and supply chain control, alliance coordination opportunities for democratic nuclear cooperation, and technology leadership implications for advanced reactor deployment. Each scenario undergoes consistency analysis ensuring institutional coherence across domains. For example, improvements in U.S. domestic deployment should enhance export capability and international influence. Supply chain capacity aligns with projected deployment rates, while strategic partnerships correspond to diplomatic relationship trajectories.

3.5.2 Future Methodological Enhancements

While this study employs qualitative scenario analysis due to resource constraints, future research integrating quantitative analysis and and qualitative modeling approaches. The application of Monte Carlo simulation, Delphi expert elicitation, and multi-criteria decision analysis (MCDM) (Avella, 2016; Ram et al., 2011) enhance forecasting rigor. The SNCI framework provides the conceptual foundation for such enhanced methodological approaches. Future iterations could incorporate expert panels for domain weighting determination, probabilistic modeling for scenario likelihood assessment, and policy lever sensitivity analysis for strategic intervention prioritization. This methodological road map ensures the framework's continued development and relevance.

3.6 Limitations and Constraints

3.6.1 Data and Assessment Limitations

Democratic and authoritarian systems provide different levels of data transparency, potentially creating systematic biases in assessment. U.S. data availability generally exceeds that of Russia and China, requiring careful attention to comparative validity. Some strategically relevant nuclear information remains classified, particularly regarding advanced technologies, supply chain vulnerabilities, and strategic planning. The analysis acknowledges these gaps while relying on available public sources and expert assessments. Private sector nuclear data often involves commercial confidentiality, limiting access to detailed financial and operational information. This constraint particularly affects assessment of market-driven systems like the United States.

Some strategic dimensions, particularly institutional effectiveness and international influence, resist precise quantification and require expert judgment based on available literature and strategic analysis. These assessments introduce potential researcher bias despite efforts at objectivity. Comparing governance effectiveness and public trust across different political systems involves normative assumptions about democratic versus authoritarian legitimacy that may affect analytical neutrality.

3.6.2 Scoring and Validation Limitations

The current study employs systematic qualitative assessment using comparative case study methodology and established strategic analysis criteria rather than numerical SNCI scoring due to methodological constraints. The qualitative approach applies consistent evaluation frameworks derived from strategic competition theory and comparative political economy literature, enabling systematic cross-country comparison through standardized assessment criteria. However, robust quantitative scoring would require expert panels using Delphi methodology (Avella, 2016) to establish domain weightings, indicator reliability assessments, and cross-country validation. The qualitative implementation provides proof-of-concept for the SNCI framework while demonstrating systematic comparative methodology that reduces researcher interpretation through established theoretical criteria. This approach acknowledges limitations in numerical precision and statistical replicability compared to expert-validated quantitative approaches, while maintaining analytical rigor through consistent application of strategic assessment frameworks.

Future research should incorporate structured expert consultation, quantitative indicator validation, and sensitivity analysis across multiple weighting schemes to enhance methodological precision. The current systematic qualitative approach provides robust comparative framework while establishing the foundation for enhanced quantitative validation methodologies.

3.6.3 Temporal and Methodological Constraints

Nuclear competitiveness involves long-term trends and cyclical patterns that may not be fully captured in the primary assessment period. Strategic positioning can shift rapidly due to policy changes, technological breakthroughs, or geopolitical developments. While the analysis attempts to identify emerging trends, predicting future competitive trajectories involves uncertainty about technological development, policy evolution, and international relations dynamics. Current competitive positioning reflects decades of prior investment and policy decisions. The analysis acknowledges this historical dependence while focusing on contemporary strategic implications.

Any composite index involves aggregation assumptions that may obscure important nuances in individual domain performance. The SNCI provides systematic comparison while acknowledging the complexity of multidimensional competitiveness. Focusing on three major nuclear powers provides analytical leverage but limits generalizability to other nuclear countries with different characteristics and strategic priorities. The study focuses on civilian nuclear power while acknowledging but not systematically analyzing military nuclear dimensions. This boundary may underestimate some strategic interactions between civilian and military nuclear programs.

3.7 Conclusion

This methodology chapter establishes the systematic foundation for assessing nuclear competitiveness across different political-economic models. The structured comparative analysis design enables examination of how governance structures affect strategic nuclear positioning while the SNCI framework provides a comprehensive tool for multidimensional assessment. This hybrid approach balances empirical rigor with strategic insight, while acknowledged limitations provide context for interpreting findings. The following chapter applies this methodology to conduct comprehensive assessments of nuclear strategic competitiveness across the United States, Russia, and China.

Chapter 4

Analysis and Findings

4.1 SNCI Methodology Application

The Strategic Nuclear Competitiveness Index (SNCI) employs a systematic scoring methodology that converts diverse indicators into standardized 0-100 scales for each domain, enabling cross-domain aggregation and international comparison. The assessment balances quantitative data with strategic qualitative observations to capture both measurable performance and strategic implications that resist simple quantification.

The analysis focuses on the 1990-2025 period to capture contemporary strategic competition dynamics while providing sufficient temporal depth for trend analysis. This timeframe encompasses significant developments including China's nuclear expansion acceleration, Russia's export offensive, and U.S. policy responses including the ADVANCE Act. Data sources include IAEA Power Reactor Information System (PRIS) (International

Atomic Energy Agency, 2025c) for deployment and capacity data, IAEA Advanced Reactor Information System (ARIS) (International Atomic Energy Agency, 2024a) for innovation metrics, national regulatory agencies (NRC (U.S. Nuclear Regulatory Commission, 2025a), NNSA, Rostechnadzor) for policy assessment, Gallup, Pew Research, and Bisconti Research (Bisconti Research, 2024; Gallup, Inc., 2025; Leppert & Kennedy, 2024) for public opinion analysis, and government reports and official statistics for supply chain and export data.

Table 4.1: SNCI Domain Indicators and Data Sources

Domain	Key Indicators	Primary Data Sources
Public Opinion	Public support levels, knowledge gaps, NIMBY sentiment	Gallup, Pew Research, Bisconti Research
Regulatory/Policy	Licensing timelines, policy coherence, institutional effectiveness	NRC, NNSA, Rostechnadzor reports
Innovation	Design diversity, execution rates, operational experience	IAEA ARIS, national agencies
Export Capacity	International projects, market share, financing capabilities	IAEA PRIS, industry reports
Supply Chain	Domestic capacity, import dependencies, strategic stockpiling	Government statistics, industry analysis

Each domain receives a composite score (0-100) based on weighted aggregation of constituent indicators, with equal weighting providing the baseline assessment across all five strategic domains.

4.2 United States Assessment

The United States represents the archetypal democratic market-driven approach to nuclear development, characterized by independent regulatory oversight, private sector leadership, and competitive electricity markets. This model creates advantages in regulatory credibility and innovation diversity while generating disadvantages in strategic coordination and deployment speed. The democratic governance structure emphasizes transparency, stakeholder engagement, and institutional independence that enhance international legitimacy but constrain rapid policy implementation. This assessment examines how the U.S. political-economic model affects nuclear competitiveness across the five SNCI domains, revealing both the strengths and limitations of market-driven nuclear development in strategic competition. As this assessment reveals, the U.S. demonstrates mixed performance across the five SNCI domains, with particular strengths in innovation potential undermined by critical execution gaps and supply chain vulnerabilities that constrain competitive positioning against state-directed rivals.

4.2.1 Public Opinion and Societal Trust

Recent polling demonstrates significant recovery in American nuclear support, with 61% favoring nuclear power for electricity generation—approaching record-high levels (Gallup, Inc., 2025). This resurgence reflects growing recognition of nuclear energy's strategic value amid climate concerns and energy security priorities, suggesting potential for expanded social license supporting nuclear deployment.

However, this headline support masks persistent knowledge gaps that represent strategic vulnerabilities. Survey research reveals that 30% of Americans find basic facts about nuclear energy—such as its 24/7 reliability and clean energy contribution—"highly new or unexpected" (Bisconti Research, 2024). These knowledge deficits constrain the strategic value of public support, as informed populations consistently demonstrate higher nuclear acceptance across multiple studies (Bisconti, 2018; Slovic, 2000).

Public opinion analysis reveals significant variation across demographics, with education levels, proximity to nuclear facilities, and political affiliation affecting support patterns. While knowledge remains the strongest predictor of support across all groups, NIMBY sentiment persists—many supporters of nuclear energy oppose local siting, constraining deployment despite general approval. Risk perception and NIMBY analysis builds on established frameworks (Slovic, 2000) and environmental risk communication theory (Peters et al., 1997). This represents moderate-to-strong performance with recovery potential, though knowledge gaps and siting constraints continue to limit the strategic value of public support. This foundation of recovering but constrained public support intersects with regulatory framework challenges that further complicate U.S. competitive positioning.

4.2.2 Regulatory and Policy Framework

The U.S. nuclear regulatory framework, centered on the Nuclear Regulatory Commission, provides strong (U.S. Nuclear Regulatory Commission, 2025a) international credibility through independent oversight and transparent processes. This institutional independence enhances export competitiveness and international cooperation opportunities, as importing countries seek regulatory assurance for nuclear investments.

However, regulatory complexity results in extended licensing timelines averaging 10 to 12 years compared to China's 5 to 7, creating competitive disadvantages in deployment speed. The over 30-year construction hiatus from Three Mile Island (U.S. Nuclear Regulatory Commission, 2024a; Walker, 2004) to Vogtle (U.S. Energy Information Administration, 2023) illustrates how regulatory uncertainty can undermine industrial capacity and strategic positioning. However, regulatory complexity results in extended licensing timelines averaging 10 to 12 years compared to China's 5 to 7, creating competitive disadvantages in deployment speed. The construction hiatus between Three Mile Island (U.S. Nuclear Regulatory Commission, 2024a; Walker, 2004) and Vogtle (U.S. Energy Information Administration, 2023) illustrates how regulatory uncertainty can undermine industrial capacity and strategic positioning. Table 4.2 demonstrates these comparative timeline

Table 4.2: Nuclear licensing timeline comparison (U.S. Nuclear Regulatory Commission, 2025b).

Process Stage	United States	Russia	China
Design Certification	3-5 years	2-3 years	18-24 months
Site Permit	2-3 years	1-2 years	6-12 months
Construction Authorization	2-4 years	1-2 years	6-12 months
Operating License	2-3 years	1-2 years	6-12 months
Total Timeline	9-15 years	5-9 years	3-5 years

disadvantages across all stages of the licensing process (U.S. Nuclear Regulatory Commission, 2025b).

The ADVANCE Act (U.S. Congress, 2024) represents the most significant U.S. nuclear policy legislation in decades, directly addressing regulatory competitiveness challenges through streamlined licensing processes, advanced reactor support, and enhanced international cooperation frameworks. This legislation acknowledges regulatory modernization as essential for maintaining nuclear competitiveness against state-directed competitors.

The strong international credibility of the U.S. is offset by domestic licensing inefficiencies; ADVANCE Act provides modernization to the existing framework. While regulatory modernization efforts show promise, the innovation domain reveals a more complex paradox of American nuclear competitiveness.

4.2.3 Innovation and Technology

The United States leads globally in advanced reactor design diversity with 30 concepts under development across multiple technology pathways. However, this design leadership contrasts sharply with execution performance.

The Execution Rate (ER) measures the proportion of advanced reactor designs progressing to operational status or active construction:

$$ER = \frac{O}{O + UC + D} \tag{4.1}$$

where O = operational reactors, UC = under construction, D = designs in development. Technology deployment analysis incorporates established readiness level frameworks (National Aeronautics and Space Administration, 2023) to assess progression from research to operational status. This metric captures whether countries can translate research investments into deployable technologies that provide competitive advantages.

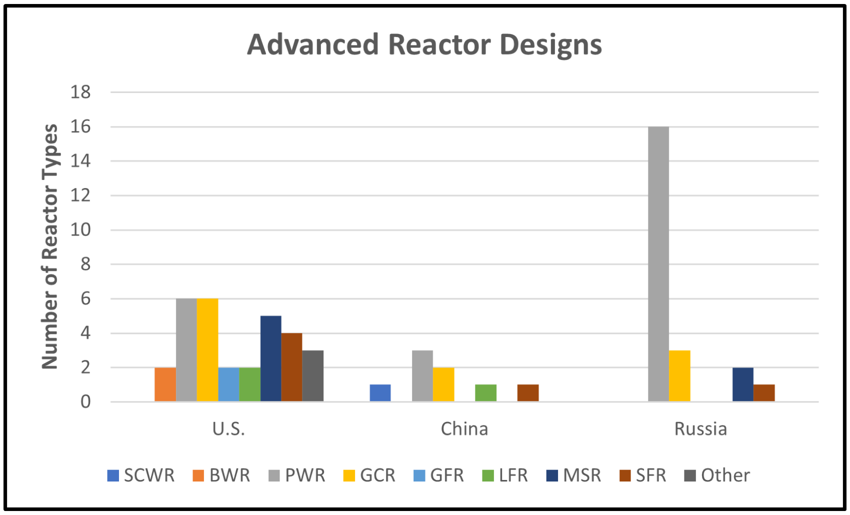

Figure 4.1: Advanced reactor development versus operational deployment by country (International Atomic Energy Agency, 2024a).

The execution rate disparities illustrated in Figure 4.1 reflect fundamental differences in institutional capacity to bridge the gap between innovation and deployment. China achieves 25% execution rate (2 operational from 8 designs), Russia achieves 14% (3 operational from 22 designs), and the United States achieves 3% (1 operational design from 30 designs). The execution rate demonstrates superior Chinese capability in translating innovation into operational deployment. Table 4.3 provides additional comparative metrics that illustrate these execution disparities across the three countries.

Table 4.3 summarizes key deployment trends for China, Russia, and the United States from 1990 to 2025, based on forecasting data downloaded from the IAEA PRIS database (International Atomic Energy Agency, 2025b).

Table 4.3: Deployment comparison of commercial nuclear reactors (1990–2025) by country.

Metric	China	Russia	United States
Reactors Connected	57	12	2
Construction	5 to 6 years	7 to 9 years	10+ years
Gap	None	Low	27 years
Rate	High	Moderate	Low

Table 4.3 summarizes the strategic implications of these divergent approaches across the broader nuclear development timeline, reflecting fundamental differences in governance models and their effects on nuclear strategic positioning.

The United States operates the world's largest nuclear fleet with key characteristics that affect strategic positioning: 94 commercial nuclear power reactors (U.S. Nuclear Regulatory Commission, 2024c), 54 nuclear plants across 28 states, technology mix of 63 PWRs and 31 BWRs, average capacity factor of 92.7% (2022) and 93.1% (2023) (U.S. Energy Information Administration, 2024e), and average fleet age of approximately 43 years, creating modernization challenges.

In sharp contrast to China's rapid execution (57 reactors) and Russia's consistent deployment, the U.S. connected only two reactors between 1990-2025 with construction timelines exceeding 10 years (International Atomic Energy Agency, 2025c). This execution gap limits the ability to translate innovation into strategic advantage and export competitiveness. This assessment reveals that leading design diversity is systematically undermined by execution challenges. However, the aging U.S. fleet creates both modernization imperatives and opportunities for advanced reactor deployment. These domestic execution challenges extend into international markets, where structural limitations further constrain U.S. competitive positioning.

4.2.4 Export Capacity and International Influence

The United States faces significant challenges in nuclear export competitiveness, with limited active international projects compared to Russia's 22 reactors under construction globally. While maintaining technological advantages through advanced designs and safety standards, structural limitations in the U.S. export model constrain the translation of capabilities into export success.

The U.S. export model relies primarily on private sector capabilities with limited government backing, contrasting with state-directed competitors offering turnkey packages including construction financing, fuel supply agreements, and operational support. This creates competitive disadvantages in international markets where importing countries seek comprehensive, government-backed partnerships. Limited export financing capabilities and fragmented government support constrain U.S. competitiveness against integrated state models. Recent policy developments including the ADVANCE

Act suggest recognition of these challenges, though implementation effectiveness remains to be demonstrated.

The United States maintains nuclear cooperation agreements with 49 countries through 25 Section 123 agreements under the Atomic Energy Act (Kerr & Nikitin, 2025; U.S. Department of State, Bureau of International Security and Nonproliferation, 2025), providing extensive institutional foundation for export competitiveness that remains underutilized due to structural limitations in government coordination and financing. These agreements establish legal frameworks for nuclear technology transfer, fuel supply relationships, and technical cooperation that create competitive advantages over countries lacking equivalent international agreements.

The current nuclear cooperation portfolio includes 25 bilateral Section 123 agreements covering 49 countries plus IAEA, international memberships in IAEA (founding member), NPT (recognized nuclear weapon state), and Nuclear Suppliers Group (48 members), and multilateral frameworks including co-chair of Global Initiative to Combat Nuclear Terrorism (U.S. Department of Defense, 2022).

Despite this extensive cooperation framework, the United States struggles to translate institutional advantages into commercial export success due to limited government backing, fragmented coordination across agencies, and inability to offer comprehensive financing packages comparable to state-directed competitors. Recent policy developments including enhanced export promotion authority suggest recognition of these coordination challenges. While this represents limited export performance due to structural challenges in financing and government coordination, the extensive institutional foundation provides underutilized competitive advantages that could be leveraged through enhanced policy coordination.

4.2.5 Supply Chain Security and Sovereignty

The United States faces significant supply chain dependencies, particularly in uranium enrichment and advanced fuel production. Strategic vulnerability assessment incorporates nuclear security frameworks (Nuclear Threat Initiative, 2023). Prior to the Ukraine conflict, Russia supplied 27% of U.S. enrichment services (U.S. Energy Information Administration, 2024a), creating strategic vulnerabilities (U.S. Department of Defense, 2022) exposed by geopolitical tensions.

High-assay low-enriched uranium (HALEU) represents a critical strategic vulnerability, with 90% of U.S. HALEU historically imported from Russia (Goff, 2024; World Nuclear Association, 2024c). This dependency constrains advanced reactor deployment and undermines export credibility.

Advanced reactor deployment requires diverse fuel types beyond conventional uranium, with different countries demonstrating significant capability gaps in advanced fuel production. Table 4.4 illustrates the strategic disadvantage facing the United States in advanced fuel technologies critical for next-generation reactor deployment.

Table 4.4: Advanced Fuel Technology Capabilities by Country

Fuel Type	United States	Russia	China
HALEU (5-20% U-235)	DEMO/Limited	OPS	OPS
TRISO Fuel	DEV	Limited	DEMO
Metal Fuel	R&D	OPS	DEV
MOX Fuel	R&D	OPS	DEV

These technological capability gaps demonstrate systematic disadvantages in fuel cycle sovereignty that extend beyond HALEU to encompass multiple advanced fuel categories essential for competitive nuclear deployment. The operational status gaps particularly affect export competitiveness, as international customers seek proven fuel supply chains rather than developmental capabilities.

Table 4.5: U.S. supply chain risk assessment

Category	U.S. Risk Summary
HALEU Supply	Pilot-scale. Delays deployment.
Enrichment Capacity	Lack of fuel cycle assurance.
Fuel Fabrication	Limited domestic ability.
Export Risk	Lack of global turnkey deals.

Recent policy analysis emphasizes that HALEU represents a strategic asset, not merely a commercial commodity (Ahn et al., 2023; Pir-Budagyan, 2025).

Without a sovereign HALEU supply chain, the U.S. nuclear industry faces insurmountable barriers to achieving successful commercial deployment of next-generation reactors. U.S. vendors cannot compete internationally without this necessary fuel infrastructure.

Federal investment to establish domestic enrichment and fuel fabrication capacity is essential for nuclear export credibility and long-term geopolitical influence. These critical dependencies create strategic vulnerabilities that expose U.S. competitive positioning. Ongoing efforts to rebuild domestic capacity demonstrate policy recognition of these challenges but with limited progress to date.

4.2.6 U.S. Assessment and Strategic Implications

The United States demonstrates mixed performance across strategic nuclear competitiveness domains, reflecting the complex dynamics of democratic market-driven nuclear development. Strengths in regulatory credibility and innovation potential are offset by critical weaknesses in execution, export capacity, and supply chain sovereignty.

The U.S. system emphasizes transparency, technological diversity, and democratic legitimacy—providing long-term competitive advantages but creating short-term disadvantages in deployment speed and strategic coordination. The independent regulatory model enhances international credibility while constraining rapid deployment capability.

Recent policy and other developments including the ADVANCE Act, Vogtle completion, and growing recognition of nuclear energy's strategic importance suggest potential for competitive recovery. However, sustained improvement requires addressing fundamental challenges in execution capability, supply chain sovereignty, and export coordination.

This assessment reveals a fundamental paradox in U.S. nuclear competitiveness: strong regulatory credibility and innovation potential are systematically undermined by execution gaps and supply chain vulnerabilities. While the democratic model provides legitimacy advantages that enhance long-term credibility, it simultaneously creates deployment challenges that constrain competitive positioning against state-directed rivals. Although significant policy modernization efforts are underway, their effectiveness in addressing these structural limitations remains unproven, leaving the United States' competitive trajectory uncertain.

4.3 Russia Assessment

Russia's nuclear competitiveness reflects the advantages of an integrated state corporation model that combines regulatory oversight, industrial development, and export promotion under unified strategic direction. The Rosatom state corporation achieves strategic coherence unavailable to fragmented democratic systems, enabling coordinated nuclear development across domestic and international markets. This assessment examines how Russia's authoritarian governance structure creates systematic competitive advantages across the five SNCI domains.

4.3.1 Public Opinion and Societal Trust

Russia operates under fundamentally different public opinion dynamics than democratic systems, where nuclear energy acceptance derives from performance legitimacy rather than social license. The Russian government's approach to nuclear policy emphasizes technological achievement, economic development, and national prestige rather than transparent public engagement and consent-based decision-making.

Public support for nuclear energy in Russia reflects broader patterns of authoritarian legitimacy, where citizens evaluate government performance based on outcomes rather than processes. Nuclear energy serves as a symbol of technological prowess and national strength, reinforcing state narratives about Russian scientific and industrial capabilities.

Russian nuclear policy benefits from strong elite consensus across political, industrial, and scientific communities. The network of nuclear cities (closed administrative-territorial formations) creates concentrated constituencies with strong material interests in nuclear program success, providing stable political support and skilled workforce. Russian nuclear communication operates through state-controlled media that emphasizes achievements while limiting discussion of risks or failures. State information control enables consistent messaging about nuclear benefits without the adversarial coverage that constrains nuclear support in democratic countries. This system creates strong authoritarian advantages in managing public opinion, though these benefits remain fundamentally dependent on continued program success and effective information control.

4.3.2 Regulatory and Policy Framework

Russia operates through a centralized nuclear regulatory system that achieves strategic coherence unavailable to fragmented democratic systems. The Rosatom state corporation model (World Nuclear Association, 2024f) integrates promotional and operational functions under unified strategic direction, enabling coordinated nuclear development across domestic and international markets.

While Rosatom dominates nuclear development and exports, Rostechnadzor provides separate safety oversight through the Federal Service for Environmental, Technological and Nuclear Supervision (International Atomic Energy Agency, 2013). This structure maintains some separation between promotional and regulatory functions while preserving strategic coordination under state direction.

Russian nuclear policy demonstrates remarkable consistency compared to democratic alternatives, maintaining strategic direction across leadership transitions and international pressures. The 12 reactors connected to the grid since 1990 demonstrate steady policy execution (International Atomic Energy Agency, 2025c), while 7 reactors currently under construction indicate continued commitment to nuclear expansion. This record illustrates the strategic coherence advantages achievable through state direction, where unified command structure enables sustained policy implementation while maintaining effective technical oversight and safety standards.

4.3.3 Innovation and Technology

Russia demonstrates exceptional balance between innovation breadth and execution capability, achieving operational status with 3 advanced reactors while maintaining a diverse portfolio of 22 reactor designs under development. The 27% share of global operational advanced reactors provides Russia with crucial operational experience that enhances export credibility.

Russia leads globally in fast reactor technology through the operational BN-600 and BN-800 reactors (World Nuclear Association, 2023), with the BN-1200 under development. This technological leadership in advanced reactor categories provides strategic advantages in both domestic fuel cycle optimization and international technology exports.

With approximately 14% execution rate (3 operational of 22 designs), Russia significantly exceeds US execution performance (3% - 1 operational of 30 designs) while maintaining broader innovation portfolios than China's focused approach. This balanced performance demonstrates institutional capability to translate research into operational technologies, creating a strategic position that combines innovation breadth with strong execution capability and valuable operational experience advantages that enhance export credibility.

4.3.4 Export Capacity and International Influence

Russia achieves unparalleled export competitiveness through Rosatom's integrated state corporation model, which combines reactor construction, fuel supply, financing, training, and long-term operational support into comprehensive turnkey packages. With 22 international reactor projects under construction globally (International Atomic Energy Agency, 2025c), Russia dominates the international nuclear market.

The Russian export model creates sustained strategic relationships rather than simple commercial transactions. Each export project establishes decades-long partnerships encompassing fuel supply, operator training, maintenance support, and technology transfer that create enduring influence relationships with importing countries.

Russia leverages nuclear exports for geopolitical influence, using reactor projects to strengthen bilateral relationships, create strategic dependencies, and expand spheres of influence. Nuclear cooperation agreements often coincide with broader diplomatic initiatives. Russia's control of global uranium enrichment capacity provides unmatched competitive advantages in export markets. Importing countries receive fuel supply security unavailable from competitors who depend on Russian enrichment services. This combination of the integrated state corporation model with supply chain dominance establishes Russia's global export leadership, creating strategic leverage that extends far beyond commercial nuclear transactions.

4.3.5 Supply Chain Security and Sovereignty

Russia achieves unprecedented strategic advantages through Rosatom's control of global uranium enrichment capacity, maintaining dominant market position through 2030 (Enerdata, 2024) according to industry forecasts. This control creates both domestic supply chain sovereignty and international strategic leverage unavailable to any other nuclear power.

Russia's enrichment capacity dominance represents perhaps the most significant strategic asset in global nuclear competition. Rosatom maintains controlling market share through 2030, enabling both domestic fuel cycle sovereignty and strategic leverage over international competitors and customers.

Russian nuclear supply chain integration contrasts sharply with US dependencies on foreign suppliers and Chinese efforts to build domestic capabilities. Rosatom's comprehensive control eliminates external vulnerabilities while maximizing strategic value extraction from nuclear industry activities. This vertical integration, combined with enrichment market control, establishes global supply chain dominance that provides Russia with unparalleled strategic leverage in nuclear competition.

4.3.6 Overall Russia Assessment

Russia demonstrates exceptional performance across nuclear competitiveness domains through the integrated Rosatom state corporation model. The comparative assessment reveals Russia's superior positioning across most domains: strong authoritarian legitimacy advantages in public opinion management, strategic coherence through state-directed regulatory systems, balanced innovation execution with operational experience, global market leadership through turnkey export models, and vertical integration advantages in supply chain control. Russia's nuclear competitiveness stems from institutional advantages unavailable to democratic market systems.

State corporation control enables long-term strategic planning, comprehensive resource coordination, and risk assumption capabilities that create sustained competitive advantages in international markets. This exceptional performance through the integrated state corporation model manifests in global export leadership via turnkey approaches, while supply chain dominance creates strategic leverage that, combined with authoritarian governance enabling consistent execution, establishes Russia as the leading nuclear competitor.

4.4 China Assessment

China demonstrates the developmental state model of nuclear competitiveness, combining authoritarian governance with strategic economic planning and rapid industrial scaling to achieve exceptional execution capability. This approach emphasizes centralized coordination, technology acquisition, and performance-based legitimacy to deliver the world's fastest nuclear expansion and breakthrough achievements like the first operational Generation IV reactor. The Chinese model achieves superior deployment speed and technological advancement through unified state planning while maintaining strict control over strategic direction and public discourse. This assessment examines how China's developmental state approach creates systematic advantages in nuclear competitiveness through rapid capability building, strategic resource mobilization, and coordinated execution across the five SNCI domains.

4.4.1 Public Opinion and Societal Trust

China operates nuclear energy policy within an authoritarian governance system where public acceptance derives from performance legitimacy and economic development rather than democratic consent. Nuclear energy serves as both a practical energy solution and a symbol of technological advancement supporting broader narratives of national development and modernization. Chinese nuclear communication operates through state-controlled information systems that emphasize technological achievements, economic benefits, and safety performance while limiting discussion of risks or controversies. The Chinese government leverages technocratic authority and scientific expertise to legitimize nuclear policy decisions.

Nuclear facility siting in China benefits from state authority to override local opposition while providing substantial economic development incentives for host communities. The integration of nuclear projects with broader regional development plans creates stakeholder communities with material interests in nuclear success. This approach establishes strong performance legitimacy and information control that sustains public acceptance through demonstrated economic benefits rather than requiring democratic deliberation.

4.4.2 Regulatory and Policy Framework

China operates through a highly centralized nuclear regulatory system that achieves exceptional strategic coordination through unified state planning and integrated policy implementation. The National Nuclear Safety Administration (NNSA) (World Nuclear Association, 2024e) provides technical oversight while broader nuclear policy reflects centralized government priorities and long-term strategic planning. The NNSA provides technical nuclear safety oversight while operating within the broader state planning framework that prioritizes rapid nuclear expansion. Chinese regulatory processes emphasize technical competence and construction efficiency rather than extensive public participation or environmental review procedures.

Chinese nuclear policy maintains strategic coherence across leadership transitions and economic cycles, demonstrating institutional capacity for sustained long-term planning and investment. The consistency of nuclear development programs across decades reflects institutional advantages of centralized planning systems that deliver exceptional policy coherence and implementation capability through centralized coordination and strategic planning.

4.4.3 Innovation and Technology

China demonstrates an exceptional execution capability in nuclear innovation that significantly exceeds U.S. performance (International Atomic Energy Agency, 2025c). This execution advantage reflects strategic emphasis on deployment over pure research. China's HTR-PM reactor represents the world's first operational Generation IV reactor connected to an electrical grid (Foro Nuclear, 2024; Reuters, 2023), marking a technological milestone establishing Chinese leadership in advanced nuclear reactor deployment. This achievement provides substantial advantages in future export markets seeking proven advanced reactor technologies.

China's nuclear innovation strategy emphasizes focused execution over broad research portfolios, concentrating resources on technologies with clear deployment pathways and commercial applications. This focused approach contrasts with US emphasis on design diversity without comparable execution capability, demonstrating exceptional execution capability with global technology leadership in advanced reactor deployment and effective technology acquisition strategy.

4.4.4 Export Capacity and International Influence

China leverages nuclear technology exports as integral components of the Belt and Road Initiative (Kim, 2023; Wilson Center, 2021), connecting nuclear projects with broader infrastructure development, financing packages, and strategic partnership building. This comprehensive approach creates nuclear export opportunities while advancing broader geopolitical objectives.

China's nuclear export program remains in early development stages compared to Russia's established global presence, but demonstrates rapidly growing capabilities and international interest. Current export projects focus primarily on neighboring countries and BRI participants.

Chinese nuclear exports benefit from comprehensive state backing including concessional financing, government guarantees, and integrated diplomatic support that enables competitive positioning against market-driven alternatives. China's achievement of the world's first operational Generation IV reactor (HTR-PM) creates significant export potential for countries seeking advanced nuclear technologies with demonstrated operational experience. This combination represents emerging export capabilities with strong government backing and advanced technology advantages, though China maintains limited current international presence compared to established competitors like Russia.

4.4.5 Supply Chain Security and Sovereignty

China demonstrates exceptional capability in rapid nuclear supply chain development, achieving domestic production capabilities across most nuclear fuel cycle stages within decades of nuclear program initiation. The strategy emphasizes technology acquisition, localization, and indigenous capability development.

China pursues uranium resource security through diversified international acquisition strategies (Nuclear Energy Agency, 2024), domestic exploration programs, and strategic stockpiling that ensures fuel supply security despite limited domestic uranium resources.

China rapidly develops domestic uranium enrichment capabilities to reduce dependence on foreign enrichment services (Enerdata, 2024) while building potential export capacity for regional markets. Domestic enrichment capacity provides fuel cycle sovereignty while creating opportunities for nuclear fuel exports.

Chinese nuclear manufacturing capabilities span reactor construction, component fabrication, and fuel production through integrated domestic industrial base development that supports both domestic deployment and export potential. This comprehensive approach establishes strong supply chain sovereignty through rapid capacity building and strategic resource acquisition, with growing domestic capabilities and export potential that position China for future competitive advantage.

4.4.6 Overall China Assessment

China demonstrates strong performance across strategic nuclear competitiveness domains through centralized planning, rapid execution capability, and strategic coordination. The comparative assessment reveals China's strong positioning across most domains: performance legitimacy and information control in public opinion management, exceptional centralized coordination in regulatory and policy frameworks, superior execution with global technology leadership in innovation, emerging but rapidly growing export capabilities integrated with Belt and Road Initiative, and strong supply chain sovereignty through rapid capacity building and strategic resource acquisition.

China occupies a strong competitive position, achieving superior performance to the United States across all domains while approaching competitive levels with Russia through different strategic approaches emphasizing rapid development and technological advancement. This positioning reflects exceptional execution capability through the developmental state model, manifested in global technology leadership via the HTR-PM achievement and rapid capability building across all domains that establishes a strong foundation for future competitive advancement.

4.5 Comparative Analysis

The preceding individual assessments enable systematic comparison of nuclear competitiveness across different political-economic models and analysis of broader strategic implications for nuclear competition dynamics.

4.5.1 Strategic Positioning Across Political-Economic Models

The Strategic Nuclear Competitiveness analysis reveals significant variations in nuclear competitiveness across different political-economic models, with Russia achieving superior strategic positioning, followed by China, and the United States facing competitive challenges despite innovation advantages. Table 4.6 summarizes these strategic rankings and competitive approaches based on SNCI methodology.

Table 4.6: Strategic positioning and competitive approaches

Export Leader: Russia	
Model	Authoritarian/State-Directed
Approach	Global export dominance
Advantages	Turnkey packages, supply chain control
Technology Pioneer: China	
Model	Authoritarian/Developmental
Approach	Rapid execution & technology leadership
Advantages	HTR-PM breakthrough, centralized planning
Innovation Hub: United States	
Model	Democratic/Market-Driven
Approach	Innovation diversity with execution challenges
Advantages	Regulatory credibility, design leadership

This strategic hierarchy reflects distinct performance patterns across the five competitiveness domains, with authoritarian systems demonstrating systematic advantages over democratic market-driven approaches in most areas of nuclear competition. Table 4.7 details these comparative performance patterns and strategic insights derived from the assessment methodology.

Table 4.7: Comparative performance patterns across strategic domains

Domain	Russia	China	U.S.	Strategic Insights
Public Opinion	Strong	Strong	Moderate	Authoritarian control advantages
Regulatory/Policy	Exceptional	Exceptional	Limited	Centralized planning superiority
Innovation	Strong	Exceptional	Strong	Execution capability dependencies
Export Capacity	Exceptional	Limited	Limited	State backing creates dominance
Supply Chain	Exceptional	Strong	Limited	Vertical integration advantages

4.5.2 Political-Economic Model Effects and Strategic Competition Dynamics

The analysis demonstrates fundamental differences between democratic and authoritarian approaches to nuclear competitiveness (Anckar, 2008), with each system creating distinct advantages and constraints.

Democratic Model Characteristics (United States) include transparency advantages through independent regulatory oversight that enhances international credibility, innovation diversity through multiple stakeholders driving technological creativity, public legitimacy where social license creates sustainable political foundations when achieved, implementation constraints where democratic processes create delays and fragmentation, and policy volatility where leadership transitions disrupt long-term planning.

Authoritarian Model Characteristics (Russia/China) include strategic coherence where unified command enables consistent long-term planning, resource mobilization where state control facilitates sustained investment, execution capability where centralized authority accelerates implementation, international leverage where state backing enables comprehensive export packages, and potential innovation constraints where centralized systems may limit diversity. The comparative analysis reveals distinct strategic characteristics across countries and domains, as synthesized in Table 4.8.

Table 4.8: Strategic Nuclear Competitiveness - Key Characteristics

Country	Domain	Key Characteristic
Russia	Public Opinion	State information control
	Regulatory	Strategic coherence
	Innovation	Balanced portfolio
	Export	Global dominance
	Supply Chain	Vertical integration
China	Public Opinion	Performance legitimacy
	Regulatory	Centralized efficiency
	Innovation	Exceptional execution
	Export	Emerging capabilities
	Supply Chain	Rapid development
United States	Public Opinion	Knowledge gaps limit potential
	Regulatory	Independence vs. speed trade-off
	Innovation	Innovation without deployment
	Export	Structural limitations
	Supply Chain	Critical dependencies

Nuclear competition contains both elements where one country's gains directly constrain others, and elements where multiple countries can achieve simultaneous benefits through technological advancement and market expansion (Mearsheimer, 2001). Competitive elements include export market share where international reactor projects represent direct competition, supply chain control where dominance in enrichment or fuel fabrication creates strategic leverage (Brzezinski, 1997), technological leadership where first-mover advantages in advanced reactor deployment create operational experience gaps, and strategic partnerships where exclusive nuclear cooperation agreements limit alternative suppliers.

Cooperative elements include technology advancement where innovation spillovers benefit global nuclear development regardless of origin, market expansion where growing global nuclear demand creates opportunities for multiple suppliers, safety improvements where enhanced safety standards benefit all nuclear operators through improved public acceptance, and climate benefits where nuclear expansion contributes to global decarbonization regardless of supplier nationality.

Current trends toward competitive dynamics reflect geopolitical tensions and strategic rivalry that emphasize relative gains over absolute benefits. State-directed systems appear better positioned for competitive dynamics through integrated strategic planning and government backing. Market-driven systems may achieve advantages in cooperative elements through innovation diversity and efficiency optimization.

4.5.3 Fuel Cycle Strategic Positioning

National fuel cycle strategies represent fundamental strategic choices that reflect broader political-economic model differences in risk tolerance, technological complexity, and long-term planning capabilities. These choices affect supply chain sovereignty, waste management approaches, and proliferation concerns that shape competitive positioning in international nuclear markets.

Table 4.9 demonstrates how different governance models approach fuel cycle decisions, with each strategy reflecting institutional capabilities and strategic priorities discussed throughout the SNCI analysis.

Table 4.9: Fuel Cycle Strategic Approaches by Political-Economic Model

Strategic Element	Country	Approach
Primary Fuel Cycle	United States Russia China	Open Mixed/Closed Developing Closed
Reprocessing Strategy	United States Russia China	No commercial Operational (RT-1) Under development
Waste Management	United States Russia China	Long-term storage Reprocessing + storage Strategic planning
Plutonium Utilization	United States Russia China	Limited research MOX fuel operational BN-800 demonstration
Resource Efficiency	United States Russia China	Standard burnup Extended through reprocessing Increasingly optimized
Strategic Autonomy	United States Russia China	Import-dependent Self-sufficient Rapid self-sufficiency
International Leverage	United States Russia China	Limited High (enrichment control) Growing (technology export)
Proliferation Profile	United States Russia China	Lower risk Higher complexity Managed development

These strategic differences reflect broader institutional patterns identified in the SNCI assessment. The United States maintains simpler open-cycle approaches that align with democratic oversight requirements and proliferation concerns, but limit resource efficiency and strategic autonomy. Russia leverages complex closed-cycle capabilities to maximize both domestic resource utilization and international strategic leverage through enrichment services and reprocessing technologies. China pursues rapid development of closed-cycle capabilities that support long-term resource security while maintaining state control over proliferation-sensitive technologies.

The fuel cycle positioning analysis reveals how technical choices reflect political-economic model characteristics. Democratic systems emphasize transparency and proliferation resistance through simpler fuel cycles, while authoritarian systems accept greater technological complexity to achieve strategic autonomy and international leverage. These choices demonstrate the interconnection between governance structures and nuclear competitive outcomes across the strategic domains examined in this analysis.

4.6 Strategic Scenario Analysis

The forecasting analysis reveals divergent trajectories across the three countries. China maintains rapid expansion (6.8% annual growth targeting 200 GWe by 2035 (U.S. Energy Information Administration, 2024b; M. Xu & Medlock, 2023)) through continued state investment and consistent deployment capability. Russia achieves steady growth through state-directed programs (2.1% annually) with emphasis on both domestic expansion and international export projects. The United States faces potential stagnation with retirements offsetting limited new construction unless advanced reactor deployment accelerates significantly through ADVANCE Act implementation. The forecasting analysis reveals divergent trajectories across the three countries based on IAEA data (International Atomic Energy Agency, 2025c). China maintains rapid expansion (6.8% annual growth targeting 200 GWe by 2035) through continued state investment and consistent deployment capability, as shown in Table 4.10.

Table 4.10: Detailed Forecasting Parameters and Assumptions

Parameter	China	Russia	United States
Current Net Capacity (2024)	55.32 GWe	26.8 GWe	96.95 GWe
Under Construction	29 reactors	4 reactors	0 reactors
Planned Projects	200 GWe by	28 GWe by 2042	DOE - triple by 2050
Annual Growth Rate	6.8%	2.1%	0%
Completion Probability	85%	70%	50%
Expected Retirements (by 2040)	0 GWe	5 GWe	15 GWe
Policy Support Level	High	Moderate	Limited

Accelerated advanced reactor deployment could improve US competitive positioning, particularly if execution capabilities improve through ADVANCE Act implementation and private sector innovation. Further geopolitical tensions could expose U.S. vulnerabilities while reinforcing advantages for countries with domestic supply chain sovereignty like Russia and China.

Enhanced democratic nuclear cooperation could create collective competitive advantages against state-directed competitors through coordinated export financing and technology sharing.

This assessment demonstrates that institutional structures fundamentally determine nuclear competitive outcomes, with state-directed systems achieving superior performance across most domains while democratic market-driven systems maintain specific advantages in regulatory credibility and innovation diversity.

Chapter 5

Discussion and Conclusions

5.1 Key Findings Summary

This study developed and applied the Strategic Nuclear Competitiveness Index (SNCI) to systematically assess nuclear strategic competitiveness across the United States, Russia, and China. The findings reveal significant competitive disparities that reflect fundamental differences in political-economic models and their effects on nuclear strategic positioning.

Nuclear competitiveness can be systematically measured and compared across different political-economic models through a multi-domain framework that captures strategic dimensions beyond economic metrics. The SNCI demonstrates that institutional structures fundamentally affect nuclear competitive outcomes, with state-directed systems currently achieving superior performance across most strategic domains.

The study establishes that Russia leads global nuclear competitiveness through an integrated state corporation model that combines export dominance, supply chain control, and strategic coherence unavailable to market-driven alternatives. China achieves strong second position through exceptional execution capability and rapid technological advancement, demonstrating how developmental state approaches can quickly build comprehensive nuclear capabilities. The United States ranks third despite innovation leadership, constrained by execution challenges, supply chain vulnerabilities, and structural limitations in export competitiveness. Political-economic models create systematic competitive advantages, with authoritarian/state-directed systems demonstrating superior performance in execution, export capacity, and supply chain sovereignty, while democratic/market-driven systems show advantages in innovation diversity and regulatory credibility.

The analysis reveals a critical innovation-execution gap where the U.S. leads in design diversity (30 advanced reactor concepts (International Atomic Energy Agency, 2024a)) but struggles with deployment (3% execution rate), while China achieves superior execution (25% execution rate) through focused strategic approaches. Russia's global dominance (22 international projects (International Atomic Energy Agency, 2025c)) stems from comprehensive state backing and turnkey service models that private sector competitors cannot match, demonstrating how government support translates directly into geopolitical influence. Russia's control of global uranium enrichment capacity creates both domestic sovereignty and international leverage, while U.S. dependencies (historically 27% Russian enrichment (U.S. Energy Information Administration, 2024a)) expose strategic vulnerabilities that constrain policy flexibility. Centralized planning systems achieve superior policy coherence and implementation speed, though democratic systems maintain advantages in transparency and international credibility that support long-term strategic relationships.

5.2 Contributions to Knowledge

This research advances strategic nuclear competitiveness theory through the Strategic Nuclear Competitiveness Index (SNCI), the novel systematic framework for measuring nuclear strategic performance across multiple domains and countries. While existing literature established nuclear power as a strategic competition issue, previous work lacked quantitative tools for comparative assessment. The SNCI bridges this gap by integrating insights from strategic competition theory (Mearsheimer, 2001; Sugden, 2019), comparative political economy, and nuclear policy analysis into a comprehensive measurement framework.

The methodology combines quantitative indicators and strategic comparative analysis, enabling cross-country comparison through standardized metrics.

The analysis demonstrates how different governance models create systematic advantages and constraints in nuclear strategic positioning (Anckar, 2008).

The study provides policymakers with evidence-based tools for strategic decision-making by identifying competitive advantages and vulnerabilities, enabling gap identification, supporting targeted policy interventions, and establishing an objective basis for democratic nuclear cooperation.

5.3 Limitations and Future Research

Democratic and authoritarian systems provide different levels of data transparency, potentially creating systematic biases in assessment. U.S. data availability generally exceeds that of Russia and China, requiring careful attention to comparative validity. The 2015-2025 assessment period captures contemporary competition dynamics but may not fully reflect long-term trends or cyclical patterns in nuclear competitiveness. Strategic positioning can shift rapidly due to policy changes, technological breakthroughs, or geopolitical developments.

Some strategic dimensions, particularly institutional effectiveness and international influence, resist precise quantification and require qualitative assessment based on established analytical frameworks from comparative political economy and strategic studies literature. These evaluations apply consistent criteria systematically across all cases, though expert validation through structured methodology would enhance objectivity and reduce interpretive variation in future applications. Focusing on three major nuclear powers provides analytical leverage but limits generalizability to other nuclear countries with different characteristics and strategic priorities.

Future research could expand the framework to include additional countries, enabling analysis of alliance patterns, regional competition dynamics, and the effectiveness of competitive strategies across diverse political-economic contexts. Extended temporal analysis could examine how nuclear competitiveness evolves over time, identify cyclical patterns, and assess the durability of competitive advantages under changing technological and geopolitical conditions. The emergence of artificial intelligence and advanced analytics presents opportunities for enhanced nuclear competitiveness assessment through automated data collection, sentiment analysis of public opinion, and predictive modeling of technological development trajectories. Future studies to examine the effectiveness of specific policy interventions on nuclear competitiveness outcomes can provide empirical evidence for strategic reform priorities and implementation approaches.

The growing power demands of artificial intelligence infrastructure create new opportunities for nuclear energy strategic positioning. Recent analysis suggests that AI data centers require reliable, carbon-free baseload power that nuclear energy uniquely provides, potentially reshaping nuclear competitiveness dynamics as countries compete for AI technological leadership. Future research could examine how AI-nuclear synergies affect strategic positioning, whether countries with strong nuclear capabilities gain advantages in AI development, and how nuclear competitiveness frameworks can incorporate AI-related demand scenarios.

5.4 U.S. Strategic Nuclear Competitiveness

Regulatory modernization requires accelerating ADVANCE Act implementation to reduce licensing uncertainties and establish clear timelines, while strengthening NRC capabilities for advanced reactor review and creating technology-neutral frameworks to support innovation while maintaining safety standards. Export financing and coordination improvements should establish government-backed export financing comparable to state-directed competitors (Atlantic Council, 2019; Gordon, 2020), create whole-of-government coordination mechanisms for international nuclear projects, and develop comprehensive technology packages including fuel supply and training components. Supply chain resilience building must accelerate domestic HALEU production capabilities through public-private partnerships, rebuild uranium enrichment capacity to reduce foreign dependencies, and establish strategic uranium reserves and supply chain diversification programs.

Medium-term strategic development should strengthen innovation ecosystems by increasing federal R&D investment in advanced nuclear technologies (Nuclear Fuel Working Group, 2020; U.S. Department of Energy, n.d.) with deployment focus, creating demonstration programs that link innovation to commercial deployment, and establishing public-private partnerships for technology development and risk sharing. Allied nuclear coordination requires developing coordinated democratic nuclear export strategies with key allies, creating joint financing mechanisms for nuclear infrastructure projects, and establishing shared advanced reactor development programs with strategic partners. Industrial capacity rebuilding must support domestic nuclear manufacturing capabilities through targeted investment, develop skilled workforce programs for nuclear construction and operation, and create sustained domestic demand through federal procurement and policy support.

Long-term competitive positioning demands technology leadership consolidation through achieving operational deployment of multiple advanced reactor technologies, establishing U.S. leadership in key technology categories (SMRs, advanced fuels, digital systems), and creating technology export advantages through demonstrated operational success. Global influence expansion requires building comprehensive international nuclear partnership networks, establishing the U.S. as preferred partner for democratic and allied countries, and creating viable alternatives to state-directed nuclear suppliers through superior technology and reliable partnerships. Sustainable competitive model development must develop hybrid approaches combining market efficiency with strategic coordination, create institutional mechanisms for sustained nuclear investment and planning, and establish competitive nuclear enterprise capable of sustained rivalry with state-directed alternatives.

Successful implementation requires unprecedented coordination across government agencies, private sector stakeholders, and allied countries. The scale of required investment and institutional reform exceeds typical policy initiatives, demanding sustained political commitment across multiple electoral cycles. Critical success factors include bipartisan political support for sustained nuclear competitiveness investment, industry coordination between traditional utilities, advanced reactor developers, and manufacturing companies, allied cooperation for coordinated democratic response to state-directed competition, and public support for nuclear energy as national security priority rather than purely commercial commodity. The window for effective U.S. competitive response may be limited, as state-directed competitors consolidate advantages through operational experience, export relationships, and supply chain control that become increasingly difficult to challenge over time.

These comprehensive reforms represent a fundamental shift from market-driven approaches toward hybrid coordination models that combine democratic legitimacy with strategic coherence. The scope of institutional change required to address identified competitive gaps extends beyond typical policy adjustments to encompass basic assumptions about government roles in strategic industries. The effectiveness of these recommendations depends critically on sustained political commitment and coordinated implementation across multiple domains simultaneously. Unlike incremental policy reforms, nuclear competitiveness requires synchronized improvements in regulatory frameworks, supply chain capabilities, export coordination, and innovation execution that challenge existing institutional boundaries.

5.5 Strategic Scenarios

The forecasting analysis based on current deployment patterns and policy commitments reveals three potential competitive trajectories. The Current Trajectory scenario, based on existing policies and deployment patterns, shows China continuing rapid expansion while the U.S. faces potential decline due to retirement pressures and limited new construction. Under this scenario, the United States faces strategic marginalization as state-directed competitors consolidate advantages through sustained deployment and export success. China's capacity expansion to 180-200 GWe by 2035, combined with Russia's continued export dominance, would establish a bipolar nuclear market dominated by authoritarian systems. U.S. influence declines as aging infrastructure and execution challenges constrain both domestic capabilities and international competitiveness.

The Policy Acceleration scenario examines successful implementation of announced commitments (U.S. ADVANCE Act, China's carbon neutrality goals, Russia's export expansion) that potentially alter competitive dynamics significantly. This scenario demonstrates potential for democratic nuclear recovery through institutional reform and strategic coordination. Successful ADVANCE Act implementation could improve U.S. execution rates from

3% to 15%, while enhanced democratic cooperation creates viable alternatives to state-directed suppliers. However, this scenario requires unprecedented political commitment and coordination across multiple electoral cycles.

The Strategic Competition scenario involves intensified great power competition driving accelerated nuclear development through increased government support and strategic coordination. This scenario reveals fundamental advantages of state-directed coordination in strategic industries, with implications extending beyond nuclear power to broader technological competition. Democratic systems face inherent challenges in sustained strategic investment and rapid resource mobilization, requiring hybrid approaches combining market efficiency with state coordination to compete effectively against integrated authoritarian models.

5.6 Conceptual Framework and Definitions

This study employs key conceptual definitions that underpin the analytical framework, drawn from national security studies and international policy literature. National security refers to the safeguarding of a nation's sovereignty, economic interests, institutional integrity, and the welfare of its citizens from internal and external threats (Holmes, 2014). It extends beyond military defense to include economic stability, infrastructure resilience, energy independence, and technological leadership. National power is the capacity of a state to influence other actors and secure its interests across multiple domains—military, economic, technological, diplomatic, and informational (Jablonsky, 1997). It encompasses both tangible capabilities and intangible elements such as legitimacy, identity, and cultural influence.

Strategic posture refers to a nation's orientation and readiness to pursue its objectives and respond to threats in the international system. It encompasses institutional structures, alliance commitments, technological capacity, and energy security. Civilian nuclear power contributes to strategic posture by reinforcing energy sovereignty, supply chain control, and diplomatic leverage. The distinction between strategic advantage and competitive advantage is central to the SNCI framework. Competitive advantage refers to a country's relative performance in specific measurable areas—such as innovation capacity, export volume, or regulatory efficiency. Strategic advantage, by contrast, incorporates broader considerations including national resilience, long-term sovereignty, and influence over international norms and governance structures.

5.7 Conclusion

This study demonstrates that nuclear strategic competitiveness represents a critical dimension of great power competition that requires systematic assessment and strategic response. The Strategic Nuclear Competitiveness Index is a framework for measuring and comparing nuclear competitiveness across the different political-economic models with a focus on the United States, Russia, and China. The analysis reveals significant competitive disparities that have important implications for national security and international relations. The research establishes that institutional structures fundamentally affect nuclear competitive outcomes, with state-directed systems currently achieving superior performance across most strategic domains. This finding challenges assumptions about market-driven approaches to strategic industries and suggests that democratic countries may require hybrid approaches combining market efficiency with strategic coordination to compete effectively.

This study reveals important implications for understanding contemporary great power competition and the role of civilian nuclear power in strategic rivalry (Atlantic Council, 2023; Mearsheimer, 2001). Nuclear competitiveness affects energy security, geopolitical influence, technological leadership, and alliance relationships that collectively shape international order. Nuclear strategic competitiveness provides countries with multiple advantages: innovation prestige, export revenues, geopolitical influence through nuclear cooperation, and strategic autonomy through supply chain sovereignty. The current competitive dynamics suggest that nuclear leadership may increasingly determine broader patterns of international influence and strategic positioning (D. K. Gattie & Massey, 2020; Ichord, 2019).

The Strategic Nuclear Competitiveness Index represents both an analytical tool and a strategic imperative for the United States. As nuclear competition intensifies among great powers, systematic assessment of competitive positioning becomes essential for effective strategic planning and policy development.

The framework developed in this study provides a foundation for ongoing analysis and policy guidance, but its ultimate value depends on effective implementation of strategic reforms that address identified competitive gaps. The United States retains significant advantages in nuclear competitiveness, but realizing this potential requires sustained commitment to institutional reform, strategic coordination, and long-term investment in nuclear capabilities. These advantages include established regulatory frameworks, advanced research infrastructure, and extensive operational experience that provide competitive foundations for strategic renewal. However, translating these assets into competitive outcomes requires coordinated action across government, industry, and research institutions.

The stakes of nuclear strategic competition extend beyond energy policy to encompass technological leadership, geopolitical influence, and international order. Success in nuclear competitiveness may well determine which countries and governance models shape the future of global energy systems and the broader geopolitical landscape.

Appendices

Appendix A

Nuclear Technology Specifications

This appendix provides comprehensive technical specifications and classifications for nuclear reactor technologies, fuel systems, and advanced reactor designs discussed throughout the dissertation. These materials support the technical analysis in Chapters 2-4 and provide reference information for the Strategic Nuclear Competitiveness Index (SNCI) framework.

A.1 Reactor Generations and Classifications

The classification of nuclear reactors into Generations I through IV is based on technological maturity, design purpose, and safety enhancements over time. Each generation reflects shifts in both strategic goals and commercial deployment models.

- Generation I: Early prototype and demonstration reactors (e.g., Shippingport, Magnox). Most are decommissioned.
- Generation II: Commercial power reactors with established safety and regulatory protocols (e.g., PWRs, BWRs).
- Generation III / III+: Enhanced safety systems, extended fuel cycles, passive safety features (e.g., EPR, AP1000, VVER-1200).
- Generation IV: Advanced designs emphasizing sustainability, proliferation resistance, and modular deployment (e.g., MSRs, SFRs, HTGRs).

A.2 Advanced Reactor Technology

Pressurized Water Reactors (PWR): Advanced PWR designs include small modular reactor configurations that maintain water cooling and thermal neutron spectra. These designs incorporate passive safety systems and operate at smaller scales than conventional PWR units.

Gas-Cooled Reactors (GCR): High-temperature gas-cooled reactors use helium as coolant and graphite as moderator. Gas-cooled reactor technology has operational examples and designs under development.

Sodium-Cooled Fast Reactors (SFR): Fast reactor designs use liquid sodium coolant and operate without moderators. Russia and China have fast reactor facilities, with additional units under development.

Lead-Cooled Fast Reactors (LFR): These designs use liquid lead or lead-bismuth eutectic as coolant in fast neutron spectrum configurations. Russia has development programs in this technology pathway.

Molten Salt Reactors (MSR): MSR designs use liquid fluoride or chloride salts as both coolant and fuel medium. Current MSR designs remain in development phases.

Very High Temperature Reactors (VHTR): These gas-cooled designs target elevated operating temperatures for industrial process heat applications. VHTR technology designs incorporate the fundamentals of gas-cooled reactors.

Supercritical Water-Cooled Reactors (SCWR): SCWR designs operate above the critical point of water. The technology is still in the research and development phases.

Microreactors: Microreactor designs target small-scale applications with factory-manufactured configurations. These designs emphasize passive safety and deployment flexibility.

A.3 Nuclear Fuel Cycle Systems

A.3.1 Advanced Reactor Fuel Classifications

Advanced reactor designs utilize diverse fuel types beyond conventional low-enriched uranium, each with distinct technical characteristics and applications. Table A.1 categorizes fuel types by enrichment level and structural characteristics.These fuel types represent the technical diversity required for advanced reactor deployment across different technology pathways.

Table A.1: Advanced Reactor Fuel Type Classifications

Fuel Type	Description
LEU	<5% U-235; standard reactor fuel
HALEU	5–20% U-235; required for many advanced reactor types
TRISO	Coated particle fuel enhanced structural integrity and safety characteristics
Metal	Uranium alloy fuel, compact and high-density, used in fast reactor applications
Liquid	Fuel dissolved in molten salt coolant, enabling unique reactor design approaches
MOX	Mixed uranium-plutonium oxide fuel, enables plutonium recycling

A.3.2 Uranium Enrichment Requirements by Reactor Type

Current reactor technologies demonstrate varying uranium enrichment requirements that directly impact fuel cycle sovereignty and supply chain dependencies discussed in Chapter 4. Table A.2 provides enrichment specifications and operational fleet sizes based on IAEA data (International Atomic Energy Agency, 2024a, 2025c).

Table A.2: Uranium enrichment requirements and operational fleet size by reactor type (2024)

Reactor Type	Enrichment (% U-235)	Units in Operation
PWR	3–5%	307
BWR	3–5%	60
GCR	2.5–3.5%	8
LWGR (RBMK)	2–3%	11
PHWR	Natural uranium (unenriched)	47
HGTR	Up to 8.5%	1
FNR	17–26%	1

The concentration of operational units in PWR and BWR categories reflects the commercial nuclear industry's standardization around these technologies, while advanced designs with higher enrichment requirements remain limited in deployment.

A.3.3 Fuel Cycle Architectures

Nuclear fuel cycle approaches represent fundamental strategic choices that affect supply chain sovereignty, waste management, and proliferation risks. These approaches illustrate the structural differences between open and closed fuel cycle systems.

The choice between open and closed fuel cycles reflects broader strategic priorities regarding resource utilization, waste management, and technological complexity.

Table A.3 compares key characteristics of these approaches based on technical specifications and country practice examples (U.S. Nuclear Regulatory Commission, 2020; World Nuclear Association, 2024d).

Table A.3: Comprehensive Nuclear Fuel Cycle Comparison

Feature	Open Fuel Cycle	Closed Fuel Cycle
Definition	Once-through cycle; spent fuel stored as waste	Reprocessed to separate usable materials
Spent Fuel Use	Stored in cooling pools or dry casks	Reprocessed to recover fissile material
Uranium Utilization	Low—small fraction of energy potential used	High—greater energy extraction via recycling
Waste Volume	High—spent fuel becomes direct waste	Lower—high-level waste volume reduced
Infrastructure	Simpler—no reprocessing facilities needed	Complex—requires reprocessing plants, MOX fabrication
Proliferation Risk	Lower—no separated plutonium	Higher—handling of separated fissile materials
Economic Considerations	Lower upfront cost	Higher cost due to advanced facilities
Adoption Examples	USA, Canada, Sweden	France, Russia, Japan (partial), China (hybrid)

These technical differences have strategic implications for nuclear competitiveness regarding supply chain independence and long-term sustainability discussed in the SNCI framework analysis.

A.4 Data Sources and Validation

Technical specifications and operational data are sourced from the International Atomic Energy Agency databases (International Atomic Energy Agency, 2024a, 2025c), World Nuclear Association technical resources (World Nuclear Association, 2024d, 2024h), and national regulatory agency specifications (U.S. Nuclear Regulatory Commission, 2020). All data current as of 2024 assessment period.

Appendix B

Country Fleet Data and Profiles

This appendix provides comprehensive fleet inventories and operational data for the three countries analyzed in this study, supporting the strategic assessments in Chapter 4. Fleet operational data and facility specifications are sourced from the International Atomic Energy Agency Power Reactor Information System (International Atomic Energy Agency, 2025c), national regulatory agencies including the U.S. Nuclear Regulatory Commission (U.S. Nuclear Regulatory Commission, 2024c), and World Nuclear Association country profiles (World Nuclear Association, 2024e, 2024f). Chinese development targets are based on official policy statements and energy planning documents (U.S. Energy Information Administration, 2024b; M. Xu & Medlock, 2023). Capacity factor data from U.S. Energy Information Administration

(U.S. Energy Information Administration, 2024e). All data current as of 2024-2025 assessment period. Data tables in this appendix are author visualized and synthesized.

B.1 United States: Fleet Profile

B.1.1 Fleet Characteristics Summary

- Total Operating Reactors: 94 commercial nuclear power reactors
- Plant Distribution: 54 nuclear plants across 28 states
- Reactor Configuration: 19 single-unit, 31 two-unit, 3 three-unit, 1 four-unit plants
- Technology Mix: 63 PWRs, 31 BWRs
- Average Capacity Factor: 92.7% (2022), 93.1% (2023)
- Permanently Shutdown: 41 reactors in varying decommissioning stages

B.1.2 United States: Development Timeline

United States nuclear expansion targets (International Atomic Energy Agency, 2024b; Trump, 2025) and IAEA operational capacity data (International Atomic Energy Agency, 2025c) are shown in Table B.1.

Table B.1: U.S. Nuclear Development Timeline and Targets

Timeline	Capacity Target (GWe)	Strategic Goals
2025 (Current)	97	94 reactors
2025 (target)	Not stated	stalled
2030	105-112	Mid-term target
2040	110-128	Long-term goal
2050	135-156	Carbon neutrality

B.2 Russia: Fleet Profile

B.2.1 Fleet Characteristics Summary

Itemized reactor summary data was extracted from IAEA PRIS (International Atomic Energy Agency, 2025c), U.S. Nuclear Regulatory Commission (U.S. Nuclear Regulatory Commission, 2024c) reactor databases. Capacity factor data was sourced from (U.S. Energy Information Administration, 2024e).

- Total Operating Reactors: 36 commercial nuclear power reactors
- Plant Distribution: 10 domestic nuclear plants
- Reactor Configuration: 2 - two unit, 2 - three unit, 5 - four unit, 1 - six unit

- Technology Mix: 24 VVERs (PWRs), 11 LWGRs, 2 FNRs
- Average Capacity Factor: 80+% (2022), 93.1% (2023)
- Permanently Shutdown: 11 reactors permanently shutdown, 4 in various stages of decommissioning

B.2.2 Russia: Export Projects

Russian export projects are illustrated in Table B.2 with data extracted from international nuclear databases (International Atomic Energy Agency, 2025c; World Nuclear Association, 2024f).

Table B.2: Russian Nuclear Export Projects

Country	Project	Reactor Type	Units
Turkey	Akkuyu	VVER-1200	4
Bangladesh	Rooppur	VVER-1200	2
Egypt	El Dabaa	VVER-1200	4
India	Kudankulam	VVER-1000	6
China	Tianwan/Xudabao	VVER-1200	4

B.2.3 Russia: Development Timeline

Russian nuclear expansion targets sourced from IAEA's database (International Atomic Energy Agency, 2024b). IAEA operational capacity data extracted from IAEA PRIS database (International Atomic Energy Agency, 2025c).

Table B.3: Russia: Nuclear Development Timeline and Targets

Timeline	Capacity Target (GWe)	Strategic Goals
2025 (Current)	26.8	36 reactors
2025 (target)	40	Continued expansion
2030	35+	Mid-term target
2040	45+	Long-term goal
2050	60+	Carbon neutrality

B.3 China: Fleet Profile

B.3.1 Fleet Characteristics Summary

Itemized summary data for China sourced from the IAEA nuclear power reactor database (International Atomic Energy Agency, 2025c) Capacity factor data sources from the U.S. Energy Information Administration's website (U.S. Energy Information Administration, 2024b).

- Total Operating Reactors: 57 commercial nuclear power reactors
- Plant Distribution: 58 domestic nuclear plants
- Reactor Configuration: 3 - two-unit, 2 - four unit, 2 - 6 unit, demo reactors
- Technology Mix: 54 PWRs, 2 PHWRs, 1 HTGR

- **Average Capacity Factor**: 89+% (2022), 90.5% (2023)
- **Permanently Shutdown**: none permanently shutdown, 1 in suspended operation according to IAEA

B.3.2 China: Development Timeline

China nuclear expansion targets shown in Table B.4 extracted from international databases and academic papers. Operational capacity data sourced from IAEA PRIS (International Atomic Energy Agency, 2025c).

Table B.4: China: Nuclear Development Timeline and Targets

Timeline	Capacity Target (GWe)	Strategic Goals
2025 (Current)	55.3	57 reactors
2025 (target)	70+	Continued rapid expansion
2030	120+	Mid-term target
2040	200	Long-term expansion
2050	240	Carbon neutrality

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