ISSN 2790-7139
E-ISSN 2958-082X

Journal of Aerospace & Security Studies

2024 | Volume III

CASS
CENTRE for AEROSPACE & SECURITY STUDIES

ISSN 2790-7139
E-ISSN 2958-082X

2024

All correspondence pertaining to this publication should be addressed to CASS, through post or email at the following address:

Centre for Aerospace & Security Studies

cass.editor@gmail.com/

Centre for Aerospace & Security Studies

+92 051 5405011

cassthinkers

cass.thinkers

@CassThinkers

Old Airport Road, Islamabad, Pakistan
www.casstt.com

Title Design & Layout:
Hira Mumtaz

ISSN 2790-7139
E-ISSN 2958-082X

Journal of Aerospace & Security Studies (JASS)

Volume III

EDITOR-IN-CHIEF

Dr Usman W. Chohan

EDITOR

Sarah Siddiq Aneel

CASS
CENTRE for AEROSPACE & SECURITY STUDIES

FOREWORD

The pursuit of ever greater specialisation and interdisciplinarity in new bodies of research, along with the increasingly global connectivity of researchers and institutions, necessitates the birth of new avenues to report and explain their work and results. One such promising avenue that I have seen emerge is the *Journal of Aerospace & Security Studies* (JASS), now issuing this impressive third volume. Closely tied to the Centre for Aerospace & Security Studies (CASS), JASS speaks to the broader concept of 'security studies' with respect to areas such as emerging technologies, aviation, space technologies, warfare, economics and geopolitics, and where particular interest is accorded to the aerospace domain.

This third volume of JASS remains true to that interdisciplinary commitment to security studies, following closely in the footsteps of two previous volumes that also adhered to excellent research standards, by offering a range of interesting and novel contributions to areas of scientific and social concern within the broader security studies research domain. The reader of this issue will find in the pages of this volume a cutting-edge and salient collection that warrants close examination as the world passes through a time of transformation and turbulence, when technological advancements become sharper double-edged swords for those concerned with the preservation of the utmost public value: security.

Shaheer Ahmad's article provides a thorough overview of the perils portended by an emerging domain of warfare: neural warfare or 'neurowarfare,' a battle within the adversary's most inner mind. The risks posed by the mere existence of such a domain warrant the utmost policymaker concern, and Ahmad's paper provides the necessary distillation of trends and risks in that regard. Shaza Arif addresses the changes that quantum computing augurs in the field of aviation. With the formidable computing power that quantum computers shall muster, many dimensions of aviation can achieve far greater levels of optimisation, from flight trajectories to flight paths, to aircraft design, and still more. As such, her article sits very

well within a core interest of JASS in aerospace and emerging technologies.

Shah Muhammad's study examines the concept of 'technological sovereignty' through a geoeconomic lens with China as the case study. He concludes that the acrimony in US-China technological competition shall worsen but that a total and complete separation between both superpowers in the technological sphere is unlikely due to a degree of inextricable ties across technology domains. His article thus sits well in its multidisciplinarity between geoeconomics, emerging technology, and foreign policy.

Mustafa Bilal explores Western 'securitisation' of Chinese telecommunication companies, therein comparing the developing and developed worlds attitudes towards the breakthroughs made by Chinese telecom giants. The divergent political and economic considerations of various countries points to increasing complexity in the global technology sphere. Zahra Niazi's paper focuses on the photovoltaic potential of Pakistan, where she deploys a SWOT analysis of the factors at play in advancing a larger renewables agenda in the country. Energy security and economy are two of the most important considerations for the security of any nation. Therefore, her study is valuable for those seeking a comprehensive, balanced approach to understanding the solar potential in Pakistan.

No scholar would advance their understanding of their field without a voracious reading habit. Reflecting this, JASS presents a rich book review section in its second portion, with important contemporary works by: Chad Anderson on the Space Economy, Sara Louise Miller on women's participation in air forces, Aaron Bateman on the history of space weaponisation, Andrew F. Krepinevich on disruptive military innovation, and Bohumil Doboš on the geopolitics of space colonisation. These reviews are extremely well situated to JASS' key subjects of aerospace and security and offer keen analyses of the books in question. Together, the book reviews as well as the scholarly articles evidence the thirst for scholarship imbibed by the contributors to the volume.

This volume, as with its two predecessors, would not be possible without the tireless efforts made by Sarah Siddiq Aneel who, in her capacity as editor of JASS, has ensured that the journal adheres to the highest international standards of scholarship. Through her commendable endeavour, a high-calibre of peer reviewed articles has been meticulously arranged, proofed, and presented in a manner that enriches the reader's understanding of important developments of our time and prognostications of a future time. I am privileged to support her in my humble capacity as Editor-in-Chief, to ensure that these standards persist in future volumes, which will allow JASS to bloom as an avenue of novel research that does justice to both the hard work of its contributors, as well as to CASS' reputation as a leading centre of national and international research.

Dr Usman W. Chohan

Editor-in-Chief

Journal of Aerospace & Security Studies

Table of Contents

Research Papers

Book Reviews

RESEARCH PAPERS

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 1-34

Neural Frontlines: Exploring Future Battlefield amid Rise of Neurowarfare

Shaheer Ahmad

Abstract

Advancement in neurotechnologies has led policymakers to rethink the role of human cognition in modern warfare. As neuroscience unravels the intricate facets of the cognitive puzzle, human cognition has become the centerpiece of the technological revolution. The potential of these technologies to enhance, target, and weaponise the human brain places them at the heart of modern warfare. The United States Defense Advanced Research Projects Agency and China's Central Military Commission have poured sizable funds and resources into harnessing the untapped potential of these technologies for military purposes. This study examines the strategic and doctrinal implications of deploying neurotechnologies for military purposes. It highlights the challenges posed by neurowarfare, including legal ambiguities, ethical dilemmas, and moral concerns, which demand urgent attention. The study underscores the necessity of establishing robust regulatory frameworks to mitigate potential risks and unintended consequences associated with the militarisation of neurotechnologies.

Keywords: Cognitive Warfare, Neurotechnology, Neuroweapons, Brain Chips.

Introduction

In recent years, neurotechnologies have achieved significant breakthroughs, redirecting global technological focus toward a domain of unprecedented complexity and potential: the human brain. From treating causalgia during the American Civil War[1] to diagnosing shell shock in World War I and addressing Post-Traumatic Stress Disorder (PTSD) after the Vietnam War, neurotechnologies have evolved substantially since their inception in the 16th Century. Today, with technological advancements becoming the norm, neuroscientists are increasingly focused on deciphering and translating the brain's electrical activity. This is exemplified by Elon Musk's 'Neuralink', which successfully implanted a neural-invasive chip[2] capable of enabling humans to control external devices through thought, enhance cognitive abilities, and address various psychological conditions. Furthermore, these technologies hold the potential to erase traumatic memories and stimulate brain activity to improve cognitive functions, representing a transformative milestone in global technological advancement.

The United States (US) is leading advancements in neurotechnology by allocating substantial funds to Research and Development (R&D). Through agencies like the Defense Advanced Research Projects Agency (DARPA), the US has launched nearly 40 neuro-related initiatives, including the BRAIN Initiative and Next-Generation Non-Surgical Neurotechnology (N3). Militarily, these initiatives aim to enhance cognitive functions and execute complex

1 Francois Boller and Daniel Birnbaum, "Silas Weir Mitchell: Neurologists and Neurology during the American Civil War," in *War Neurology*, ed. L. Tatu and J. Bogousslavsky (Basel: Karger Publishers, 2016), 93-106.

2 Robert Hart, "Elon Musk's Neuralink Prepares to Implant Second Human Patient," *Forbes,* July 11, 2024, https://www.forbes.com/sites/roberthart/2024/07/11/elon-musks-neuralink-prepares-to-implant-second-human-patient/.

national security tasks such as controlling unmanned platforms, managing cyber-attacks, and enabling human-machine teaming. Similarly, China is heavily investing in neurotechnologies as part of its grand strategic ambition to emerge as a global leader by 2030. Initiatives like the development of New Concept Weapons (NCW) and cognitive operational concepts are integral to its broader goal of transforming the People's Liberation Army (PLA) into a world-class military by 2049.[3] These developments demonstrate a technological grail between two geopolitical competitors, each striving to avoid a critical lag in this pivotal domain.

Growing use of neurotechnologies for national security impetus also brings a minefield of ethical, legal, and privacy risks. The possible coupling of these technologies with external hardware and firmware poses the threat of information theft, improvisation, and data manipulation. Correspondingly, proliferation of neuroweapons including pharmaceuticals, Directed Energy Weapons (DEWs), microwave weapons, and laser beams could be used for cognitive sabotage, inhumane torture, and brutal interrogation. Beyond ethical dilemmas, ambiguity surrounding the current legal frameworks, particularly the Biological Weapons Convention (BWC), and the Geneva Convention, raises the issues of accountability and attribution.

The study argues that the militarisation of neurotechnologies will profoundly complicate the future battlefield landscape. The potential deployment of mind-disrupting weapons could enable precise targetting of decision-making centers, specifically the cognitive functions of military commanders and policymakers. This marks a paradigm shift in warfare, redirecting the focus to the cognitive domain—an area largely unexplored in earlier conflicts. Acknowledging the ethical and legal challenges inherent in these

[3] Caitlin Campbell, *China's Military: The People's Liberation Army (PLA)*, report (Washington, D.C.: Congressional Research Service, 2021), https://sgp.fas.org/crs/row/R46808.pdf.

technologies, the study underscores the urgent need for the international community to establish robust regulatory and governance frameworks to prevent the malicious use of neurotechnologies in military applications. While these technologies hold vast potential for civilian applications, this paper focuses specifically on their military dimensions.

The paper is divided into three sections. The first section discusses impacts of neurotechnologies on warfare by employing the conceptual framework of Revolution in Military Affairs (RMA). The second offers country-specific cases, specifically the US and China on their development and acquisition of neuroweapons. Meanwhile, the last section concludes the study by discussing legal and ethical challenges.

Methodology

The study is based on qualitative research methods. Data was collected from secondary resources involving books, journal articles, reports, dissertations, and archival records. Moreover, commentaries on media outlets, think tanks, and newspapers were incorporated to curate expert analysis on emerging trends in neurowarfare. Thematic analysis was employed to analyse the data drawn from secondary sources. To maintain credibility of the research, key themes were extracted and interpreted to uncover underlying trends in neurowarfare.

Theoretical Framework

Given the transformative potential of neuro weapons in reshaping tactical and operational dimensions of warfare, this study applies the concept of Revolution in Military Affairs (RMA) to analyse the complexities of the emerging domain of neurowarfare. RMA is broadly defined across a wide spectrum, generally referring to a paradigm shift in the nature and conduct of military operations. This shift renders obsolete or irrelevant one or more core

competencies of a dominant actor, introduces new core competencies in emerging dimensions of warfare, or achieves both simultaneously.'[4] However, analysts have also offered a more nuanced perspective by defining RMA as 'a major change in the nature of warfare brought about by the innovative application of technologies which, combined with dramatic changes in military doctrine and operational and organisational concepts, fundamentally alters the character and conduct of military operations.'[5] Typically, technological innovations are viewed as catalysts for RMA. However, technology alone is insufficient to achieve the transformative leap required for groundbreaking military advancements. Instead, it is the integration of novel operational concepts and the resulting re-organisation of military structures that fulfil the prerequisites for such progress.

There are three precursors for the complete realisation of RMA in any scenario— technological development, doctrinal innovation and organisational adaptation. During the First Gulf War, the success of *Operation Desert Storm* against Iraqi forces demonstrated that advanced high-tech weapon systems could serve as a decisive factor in future military operations.[6] Secondly, doctrinal innovation is essential for RMA, as it enables militaries to harness the potential of new weapons by formulating operational concepts that integrate these systems cohesively into established doctrinal frameworks. This is exemplified by the German *Wehrmacht's* innovative strategy during World War II, which concentrated artillery, armored, and mechanised infantry formations, supported by close airpower, to

4 Richard Hundley, *Past Revolutions, Future Transformations,* report (Santa Monica: RAND Corporation, 1999), 8, https://www.rand.org/pubs/monograph_reports/MR1029.html.

5 Benjamin S. Lambeth, "The Technology Revolution in Air Warfare," *Survival* 39, no.1 (1997):75.

6 Tsukamoto Katsuya, "The Gulf War as a Harbinger of a Revolution in Military Affairs," (paper presented at International Forum on War History, 2021).

penetrate enemy defences and achieve strategic surprise.[7] Lastly, a critical aspect of RMA is bureaucratic endorsement and institutional adaptation, involving changes to force structure and organisational reconfiguration to align with emerging technologies.[8]

The development of neuroweapons underscores the relevance of RMA by introducing a transformative dimension to modern warfare. Advancements in neurotechnologies, particularly cognitive weapons designed to manipulate or disorient enemy minds, have shifted war planners' focus toward the cognitive domain. These weapons reportedly possess the capability to disrupt or damage brain functions, as illustrated by the widely discussed case of Havana Syndrome. In this instance, hundreds of US officials from agencies such as the State Department, Department of Justice, and CIA, along with other diplomatic staff, were incapacitated during overseas assignments, allegedly due to exposure to non-kinetic weapons.[9] While the definitive source of these symptoms remains uncertain, experts suggest the involvement of neuroweapons intended to impair cognitive functions. This case highlights the operational precision and disruptive potential of neuroweapons, which could inflict severe losses on adversaries in crisis or conflict scenarios.

The development of neuroweapons has also demonstrated the doctrinal changes in the military strategies of great powers. China,

---

7 Rolf Hobson, "Blitizkreig, the Revolution in Military Affairs and Defense Intellectuals," *Journal of Strategic Studies* 33, no. 4 (2011): 625-643.

8 Andrew F. Krepinevich, Jr, *The Origins of Victory: How Disruptive Military Innovation Undermines the Fates of Great Powers* (London: Yale University Press, 2023), 415.

9 Lewis Regenstein, "Havana Syndrome: The History Behind the Mystery," *Foreign Policy Research Institute,* April 1, 2024, https://www.fpri.org/article/2024/04/havana-syndrome-the-history-behind-the-mystery/.

a potential contender to the US hegemony has tried to seize the 'first mover' advantage by making necessary adjustments to its military strategic guideline for the new era. The recently published 'Cognitive Warfare Doctrine' has termed human cognition as a centerpiece of PLA's future military operations.[10] Reportedly, the PLA is developing cognitive degradation technologies to achieve an element of surprise against its adversaries in future conflicts.[11] On the other hand, the US has also undertaken neuroscientific research regarding human-machine teaming, hyper-enabled operators, and developing cyborg soldiers equipped with cognitive enhancement technologies enabling them to operate in austere battle conditions.[12] These technologies are also being systemised and integrated into the doctrinal patterns of both great powers which demonstrates their anticipation and responsiveness to the changing landscape of modern warfare.

However, the organisational and bureaucratic acceptance of these technologies by modern militaries is yet to be seen. Despite their purported lethality, neuroweapons have yet to be deployed in active combat, leaving their battlefield impact confined to theoretical speculation. Likewise, their unique characteristics and mode of employment require thorough scrutiny before getting them

---

10 Nathan Beauchamp-Mustafaga, "Cognitive Domain Operations: The PLA's New Holistic Concept for Influence Operations," *Jamestown Foundation,* September 6, 2019, https://jamestown.org/program/cognitive-domain-operations-the-plas-new-holistic-concept-for-influence-operations/.

11 Yang Longxi, "Targeting Future Wars and Fighting the "Five Battles" of Cognition," *PLA Daily,* August 23, 2022, http://www.81.cn/jfjbmap/content/2022-08/23/content_322554.htm.

12 Yasim Tadjeh, "VSOFIC News: SOCOM Moving Forward with Hyper-Enabled Operator Concept," *National Defense Magazine,* May 5, 2020, https://www.nationaldefensemagazine.org/articles/2020/5/12/socom-moving-forward-with-hyper-enabled-operator-concept.

integrated into the existing operational frameworks. Furthermore, adapting force structures, implementing organisational transformations, and revising battlefield doctrines are inherently time-intensive processes, making the integration of these weapons into military culture a gradual endeavour. Consequently, the acceptance and assimilation of such technologies pose a substantial challenge for modern militaries.

Rethinking Neurotechnologies in Warfare: Applications and Implications

What once seemed confined to the realm of science fiction is rapidly becoming a reality. Technologies such as drones piloted through human thoughts[13] and neural implants erasing traumatic war memories are no longer mere concepts.[14] While these advancements offer promising applications, they also present profound security and ethical challenges. In 2012, scientists categorised neuroscience in warfare into two primary domains: performance enhancement and performance degradation.[15]

---

13 Jason Dearen, "Drones Fly Controlled by Nothing More than People's Thoughts," *Independent,* April 22, 2016, https://www.independent.co.uk/news/science/drones-brain-thoughts-controlled-bci-braincomputer-interface-braincontrolled-interface-a6996781.html.

14 Cari Romm, "Changing Memories to Treat PTSD," *Atlantic,* August 27, 2014, https://www.theatlantic.com/health/archive/2014/08/changing-memories-to-treat-ptsd/379223/.

15 The Royal Society, *Brain Waves 3: Neuroscience, Conflict and Security,* report (London: The Royal Society, 2012), https://royalsociety.org/-/media/policy/projects/brain-waves/2012-02-06-bw3.pdf.

Performance Modulation: Enhancement and Degradation

Currently, three broad categories of neurotechnologies are employed in both military and civilian contexts to enhance cognitive abilities and address operational needs. These include:

1. Neuropharmacology
2. Neurostimulation
3. Brain Chip Interface (BCI)

Neuropharmacology

The use of drugs and amphetamines to enhance troop performance has a long history, tracing back to ancient times. Opium, hallucinogenic mushrooms, and coca leaves were reportedly consumed by ancient Greeks, Vikings, and Inca warriors to boost their combat effectiveness. During the World Wars, both Allied and Axis forces utilised performance-enhancing substances to endure the hardships of total war. Notably, the German Wehrmacht administered methamphetamine to its soldiers, helping them stay awake during prolonged missions. Among the Panzer crews, this substance became colloquially known as *Panzerschokolade* (tank chocolate), enabling soldiers to withstand harsh conditions and sustain operations for extended periods.[16] Similarly, the Royal Air Force employed Benzedrine and related stimulants to enhance the performance of airmen during prolonged periods of sleep deprivation. However, the Vietnam War, often referred to as the 'first pharmacological war,' witnessed large-scale distribution of neuromedicines. Between 1966 and 1969, approximately 225 million doses of stimulants, including codeine, Dexedrine, painkillers, and anabolic steroids, were supplied to US troops to maintain their operational effectiveness in challenging

[16] Peter Andreas, "How Methamphetamine Became a Key Part of Nazi Military Strategy," *Time,* January 7, 2020, https://time.com/5752114/nazi-military-drugs/.

combat conditions.[17] In addition to prescribed drugs, US soldiers during the Vietnam War also consumed illegal substances such as marijuana, hallucinogens, and heroin.[18] These illicit substances were often used alongside neuromedicines, reflecting the widespread reliance on both legal and illegal drugs during the conflict.

Currently, neuropharmacology focuses on developing groundbreaking drugs specifically designed to penetrate the blood-brain barrier with precision, enabling targetted interventions in brain functions and disorders.[19] Such medicines are envisioned to work in conjunction with neural implants, which would enable precise control over the release of drugs into specific areas of the brain. These advancements aim to regulate brain activity using microchips, allowing physicians to manage treatment procedures with unparalleled accuracy. Reflecting the growing interest in this field, the Pentagon has allocated USD 5.8 million under its Defense Health Program for FY 2024 to support the development of medicines targetting neurosensory injuries, psychological health, and resilience. These medicines are expected to offer remedies for a range of brain disorders, from mild to advanced, potentially fostering feelings of passion, satisfaction, and happiness among veterans. Notably, they hold the promise of erasing traumatic war flashbacks, providing effective treatment for PTSD, and addressing

17 Lukasz Kamienski, *Shooting Up: A History of Drugs in Warfare* (London: C Hurst and Company, 2017).

18 Lee N. Robins, *The Vietnam Drug User Returns,* report (Washington, D.C.: Special Action Office for Drug Abuse Prevention, 1974), https://prhome.defense.gov/Portals/52/Documents/RFM/Readiness/DDRP/docs/35%20Final%20Report.%20The%20Vietnam%20drug%20user%20returns.pdf

19 Michael Mitchell and Emily Han, "Bioengineers on the Brink of Breaching Blood-Brain Barrier," *Penn Today*, January 23, 2024, https://penntoday.upenn.edu/news/bioengineers-brink-breaching-blood-brain-barrier.

neurological conditions such as Parkinson's disease and dementia.[20]

Similar to neural enhancement, neuropharmaceuticals also present the potential for misuse, including the deliberate weakening or manipulation of adversary forces. This could involve inducing hallucinations, hypnosis, memory manipulation, or even fostering trust during interrogations by administering oxytocin to extract confessions.[21] Moreover, biological weapons such as genetically engineered bacteria, viruses, microbes, and fungi pose a severe threat by targetting the brain and central nervous system. These agents are capable of inflicting precise harm—ranging from injury and disability to death—while maintaining plausible deniability or achieving specific, tailored outcomes.[22]

Moreover, many of the neuromedicines lack credible medical research on the long-term health implications of these agents especially when used in austere battle conditions. Some of the potential downsides may be neural impairments or addiction, creating challenges for soldiers once they transition back into civilian lives. While some neuropharmaceuticals may enhance cognitive functions including memory and focus, they may also

---

20 U.S. Department of Defense, *Fiscal Year (FY) 2024 President's Budget Operation and Maintenance Procurement Research, Development, Test and Evaluation,* report (U.S. Department of Defense, 2023), https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/09_Defense_Health_Program/00-DHP_Vols_I_II_and_III_PB24.pdf.

21 Jason Koebler, "Oxytocin, the 'Trust Hormone,' Could Become New Interrogation Tool," *US News and World Report,* May 15, 2015, https://www.usnews.com/news/articles/2012/05/15/oxytocin-the-trust-hormone-could-become-new-interrogation-tool.

22 Armin Krishnan, *Military Neuroscience and the Coming Age of Neurowarfare* (London: Routledge, 2017), 106.

damage other cognitive functions including decision-making, judgment, and emotional control.[23]

Therefore, it is imperative for modern militaries to carefully adopt these technologies to ensure the mental and physical well-being of the combatants.

Neurostimulation

Neurostimulation is another type of performance enhancement that is capable of fluctuating the central nervous system's activity to improve mental functioning. Unlike neuro-optimisation, these technologies amplify individual or team performance beyond their threshold and allow the brain to process large amounts of information. Notable among them are transcranial direct current stimulation and transcranial magnetic stimulation. The former deals with emitting constant and low-frequency currents bombarded via electrodes on the head. While the latter utilises electromagnetic waves to generate a potent electrical field to stimulate nerve cells in the brain.[24] These two technologies are believed to target medial brain regions responsible for cognitive functions including the insula, medial prefrontal cortex, and anterior cingulate cortex to alter cortical activity which modulates the combatant's decision-making process and regulates emotional condition under stressors.

With the help of neurostimulation, military commanders may be able to stimulate cognitive functions of their troops, enhance decision-making, and suppress emotions under frantic stress. From infantry soldiers to pilots, neurostimulation appears as a promising agent to boost cognitive functioning and battlefield

---

23 Armin Krishnan, "Attack on the Brain: Neurowars and Neurowarfare," *Space and Defense* 9, no. 4 (2016): 16.

24 James Giordano, *Neurotechnology in National Security and Defense: Practical Considerations, Neuroethical Concerns* (New York: CRC Press, 2015), 171-172.

aptitude. Even if tailored more specifically, this technology can bolster command and control (C2) by maximising efficiency through improved decision-making in a complex landscape.[25]

Nonetheless, neurostimulation faces its own set of challenges, particularly with the existence of sonic and ultrasonic weapons. Devices such as sound cannons, noise bazookas, hailing devices, and sonic bullets are examples of performance degradation techniques. These weapons are designed to project high-pitched audible waves over long distances, potentially disrupting cognitive functions and impairing performance in targetted individuals. Likewise, radio frequency (RF) weapons including tasers, laser guns, microwave weapons, and particle beams deploy intense energy to cause damage and destruction to human and physical infrastructure.[26]

Moreover, the incompatibility of neurostimulation technologies with established military culture may discourage generals and field commanders from adopting these advancements for combat formations. Similarly, concerns related to accountability, monitoring, health, and safety pose significant barriers to the integration of neurotechnologies into doctrinal and strategic frameworks. Ethical challenges surrounding informed consent and individual autonomy further complicate the deployment of neurostimulation techniques by modern militaries, raising questions about their practicality and acceptance within operational contexts.

Brain Chip Interfaces (BCI)

BCI is an emerging and potentially disruptive domain of technology that enables man-machine neural communication. It refers to a system that measures and traces the activity of the central nervous

25 Krishnan, "Attack on the Brain": 7.
26 Krishnan, *Military Neuroscience and the Coming Age of Neurowarfare,* 117.

system and generates synthetic output that augments functioning of the nervous system and improves its interaction with the external and internal environment.[27] In other words, the BCI enables a human to interact with external gadgets using his/her thoughts. As a great leap forward in neurotechnological research, BCI aims to make human brains immune from corporeal margins and allow humans seamless interaction with machines.

Although initially developed for civilian applications, military planners are increasingly considering the adoption of these minute neural chips to achieve cognitive superiority on future battlefields. The U.S. Defense Advanced Research Projects Agency (DARPA)[28] and China's Military Brain Project[29] are actively researching brain-computer interfaces (BCI) for a range of applications. These include human-machine teaming supported by cloud infrastructure, development of advanced cybernetic organisms (cyborgs), and assisting soldiers in erasing traumatic memories as they reintegrate into civilian life.

Similar to its potential for cognitive enhancement, BCIs could also emerge as one of the most dangerous mechanisms for performance degradation by manipulating the information stored or transmitted by the user's brain, reprogramming invasive implants, and interfering with the neural functions of individuals

27 Brooke Becher, "Brain Computer Interfaces, Explained," *Built In,* July 24, 2024, https://builtin.com/hardware/brain-computer-interface-bci.

28 Defense Advanced Research Projects Agency, "N3: Next Generation Nonsurgical Neurotechnology," *Defense Advanced Research Projects Agency*, https://www.darpa.mil/research/programs/next-generation-nonsurgical-neurotechnology.

29 Mu-Ming Poo et al., "China Brain Project: Basic Neuroscience, Brain Diseases, and Brain-Inspired Computing," *Neuron* 92, no. 3 (2016): 591-96.

equipped with such enhancements.[30] As the adoption of invasive BCIs approaches mainstream use, these systems would also become an enticing target for exploitation by hackers and even tech corporations, raising serious concerns about security, privacy, and ethical misuse.[31] The possible bonding of the BCI with the Apples and IOs might allow the hackers to inflict damage on the neutrally implanted people.

Great Power Competition in Neurotechnologies

The contemporary security landscape is dominated by Sino-US great power rivalry. The ongoing Ukraine war and hovering concerns of the 'fourth Taiwan Strait crisis' are signaling a shift in geopolitical tectonics. To maintain dominance on the global geopolitical landscape, both states are utilising political, economic, and military means to achieve a competitive overmatch. Against this backdrop, neuroweapons can be juxtaposed with other military means to achieve a cutting-edge ascendancy over adversaries. The following section discusses the efforts of the US and China in utilising neurotechnologies for military purposes.

United States and Neurocompetition

The US government has prioritised neurotechnologies as a national security interest to maintain a competitive edge over its adversaries. In 2013, former President Barack Obama launched an ambitious initiative titled *Brain Research Through Advancing Innovative Neurotechnologies (BRAIN)*, aimed at addressing neurological and communication disorders, improving cognitive

30 Urpi Armengol et al., "Brain-Hack: Remotely Injecting False Brain-Waves with RF to Take Control of a Brain-Computer Interface," (Proceedings of the 5th Workshop on CPS&IoT Security and Privacy, 2023).

31 Shaza Arif, "Neuralink Implant: Scrolling via Thoughts," *Centre for Aerospace & Security Studies,* April 4, 2024, https://casstt.com/neuralink-implant-scrolling-via-thoughts/.

health, and advancing the understanding of brain functions. Overseen by the National Institutes of Health (NIH), the initiative initially received USD 100 million in federal funding, supplemented by USD 200 million in private investments.[32] To date, the NIH has awarded approximately 1,469 research grants to support various brain-related studies.[33] For the current fiscal year, the US government has allocated USD 402 million to the BRAIN initiative, underscoring its continued commitment to advancing neuroscience research and innovation.[34] In addition to the NIH, several public organisations have partnered in the BRAIN initiative, including the National Science Foundation (NSF), DARPA, the military services, the Intelligence Advanced Research Projects Activity (IARPA), and the Food and Drug Administration (FDA).

The likelihood of civilian-developed technologies permeating military applications is significant, with DARPA playing a pivotal role as a mentor to the U.S. Department of Defense as discussed further.

DARPA's Role in Military Neuroscientific Research

In the realm of military neuroscientific research, DARPA plays a leading role in advancing innovative solutions for the US military.

---

32 Tim Requarth, "This is Your Brain. This is Your Brain as a Weapon," *Foreign Policy,* September 14, 2015, https://foreignpolicy.com/2015/09/14/this-is-your-brain-this-is-your-brain-as-a-weapon-darpa-dual-use-neuroscience/.

33 BRAIN Initiative, "Funded Awards," *BRAIN Initiative*, Accessed September 18, 2024, https://braininitiative.nih.gov/funding/funded-awards?page=0.

34 BRAIN Initiative, "Understanding BRAIN Initiative Budget," *BRAIN Initiative*, Accessed September 18, 2024, https://braininitiative.nih.gov/funding/understanding-brain-initiative-budget.

With an annual budget of USD 4.122 billion,[35] the agency is engaged in multiple initiatives focused on biotechnology, brain amplification, and human-machine interfaces. Neurotechnologies, in particular, have been prioritised due to their potential utility in shaping future combat scenarios.

DARPA has a longstanding history of advancing neurotechnologies for military applications. In 1974, it launched the *Closed Coupled Man Program*, leveraging electroencephalography to explore direct communication between humans and machines by monitoring neural states such as fatigue, panic, and decision-making.[36] By 2003, DARPA initiated a strategic plan to translate human thoughts into actionable outcomes, laying the foundation for modern human-machine teaming.

This vision continued with the 2012 Cognitive Technology Threat Warning System (CT2WS)—a soldier-portable device integrating AI, cameras, and brain signals to reduce cognitive burdens and enhance threat detection.[37] These developments indicate US preparation for future conflicts where humans and machines may be able to think seamlessly through cortically attached AI systems, brain-to-brain communication, and direct information processing through the brain. In other words, it will transform the existing

35 Defense Advanced Research Projects Agency, "Budgets and Finance," *Defense Advanced Research Projects Agency*, Accessed September 20, 2024, https://www.darpa.mil/about-us/budget-and-finance#:~:text=The%20President's%20FY2025%20budget%20request,Congressional%20testimony%20by%20DARPA%20leadership.

36 Robbin A. Miranda et al., "DARPA-Funded Efforts in the Development of Novel Brain-Computer Interface Technologies," *Journal of Neuroscience Methods* 244 (2015): 52-67.

37 Bruce Sterling, "Augmented Reality: DARPA Cognitive Technology Threat Warning System," *Wired,* September 19, 2012, https://www.wired.com/2012/09/augmented-reality-darpa-cognitive-technology-threat-warning-system/.

Observe, Orient, Decide, Act (OODA) loops of the US military through human-machine teaming.

In recent years, DARPA has shifted focus to non-invasive solutions. The *Next-Generation Nonsurgical Neurotechnology (N3)* programme aims to develop high-performance, bi-directional brain-machine interfaces (BMIs) that do not require surgical intervention. These interfaces are intended to enable complex tasks such as controlling unmanned systems, active cyber defence, and advanced human-machine teaming during intricate military missions. The N3 explores both completely noninvasive interfaces, which are entirely external to the body, and minimally invasive systems that involve nanotransducers temporarily and nonsurgically delivered to the brain to enhance signal resolution. These approaches utilise modalities such as optics, acoustics, and electromagnetics to record neural activity and transmit signals back to the brain with high speed and precision. By removing the need for surgery, N3 systems seek to expand the pool of individuals who can benefit from neural interface technologies, including able-bodied service members and clinical populations requiring treatments like deep brain stimulation for neurological conditions.[38] Meanwhile, *Project ElectRX*, backed by USD 78 million, employs light, sound, and magnetic waves to address PTSD and chronic pain in post-conflict scenarios.[39]

These initiatives highlight DARPA's role in revolutionising future warfare, particularly through seamless integration of human cognition and machine intelligence to enhance decision-making

---

38 Eliza Strickland, "DARPA Wants Brain Interfaces for Able-Bodied Warfighters," *IEEE Spectrum,* September 10, 2018, https://spectrum.ieee.org/darpa-wants-brain-interfaces-for-able-bodied-warfighters.

39 Shaheer Ahmad, "Shifting Dynamics: Brain Chips as the Next Battlefield," *Centre for Aerospace & Security Studies,* August 15, 2024, https://casstt.com/shifting-dynamics-brain-chips-as-the-next-battlefield/.

and combat capabilities. Once fully developed, DARPA's initiatives in BMIs and neurotechnologies are poised to transform the nature of warfare by seamlessly integrating human cognition with external systems. This advancement could lead to the widespread deployment of remote-controlled platforms, significantly reducing human exposure to combat risks. Neural implants also have the potential to enhance the cognitive capabilities of future soldiers, enabling accelerated decision-making, integration with memory-enhancing systems, and access to vast informational resources through thought alone.

Such innovations will necessitate a fundamental shift in military strategies, doctrinal frameworks, and tactical planning to accommodate these enhanced capabilities. As DARPA continues to achieve breakthroughs in neuroscience and neurotechnology, the implications for future warfare will compel military planners and policymakers to reassess the utility, ethics, and operational integration of these technologies in shaping combat scenarios and strategic objectives.

Miscellaneous Private Sector Actors

Besides DARPA, the US military is also working on several other projects to enhance cognitive warfare capabilities. The U.S. Special Operations Command (USSOCOM) is working on a Hyper-enabled Operator (HEO), a tactical AI assistant which utilises sensors, communications, and human-machine interface to augment troops' performance in the saturated war zones.[40] Similarly, the US Army Combat Capabilities Development Command (DEVCOM) envisions the future 'super soldiers' marching on the battlefield furnished with visual and neural enhancement equipment to bolster

[40] Shannon Houck et al., "Changing Hearts and Brains: SOF Must Prepare Now for Neurowarfare," *Small War Journals,* December 12, 2021, https://smallwarsjournal.com/jrnl/art/changing-hearts-and-brains-sof-must-prepare-now-neurowarfare.

operational capability.[41] These efforts demonstrate US interest in developing and integrating neurotechnologies to enhance situational awareness, minimise casualties, and improve operational efficiency in future battles.

China's Advancement in Neurotechnologies for Strategic Dominance

China, positioned as a potential challenger to US hegemony, is strategically positioning itself to achieve dominance on the global geopolitical stage. Beyond its objectives of reclaiming disputed territories and maintaining a favourable regional balance of power, China's grand strategy is about technological advancement. With a stated goal of becoming a global leader in innovation by 2030, this strategy underscores its commitment to leveraging cutting-edge developments to enhance its geopolitical influence and military capabilities.[42] The domain of neurotechnologies, with its rapidly evolving advancements, has also become a focal point of China's strategic investments, driven by the imperative to maintain technological parity and avoid falling behind the US.

In 2016, China initiated its national brain project, mirroring the US BRAIN initiative, to explore the complexities of the human brain and advance its understanding of neurotechnologies. To date, the project has received USD 746 million in funding, reflecting China's commitment to keeping pace with its American counterparts.[43] In

41 Peter Emanuel et al., *Cyborg Soldier 2050: Human/Machine Fusion and the Implications for the Future of the DOD,* report (Washington, D.C.: US Army DEVCOM Chemical Biological Center, 2019), https://apps.dtic.mil/sti/pdfs/AD1083010.pdf.

42 Pablo Robels, "China Plans to be a World Leader in Artificial Intelligence by 2030," *South China Morning Post,* October 1, 2018, https://multimedia.scmp.com/news/china/article/2166148/china-2025-artificial-intelligence/index.html.

43 Dennis Normile, "China Bets Big On Brain Research with Massive Cash Infusion and Openness to Monkey Studies," *Science Insider,*

parallel, the Central Military Commission, which oversees China's military affairs, has launched a dedicated military brain project to evaluate and develop applications of neuroscience for defence purposes. This initiative aligns with President Xi Jinping's broader military modernisation agenda, aimed at transforming the People's Liberation Army (PLA) into a 'world-class' military force by 2049.[44] By integrating advancements in neurotechnologies, China seeks to enhance its military capabilities and secure a competitive edge in future conflicts.

Cognitive Warfare in China's Military Strategy

Since the era of Mao Zedong, China's military strategy has continuously evolved to align with shifting battlefield dynamics. Transitioning from the concept of the 'people's war' to modern information warfare, the PLA has now adopted a strategy centred on 'intelligentized wars.' [45] This strategy integrates several key elements, including advanced information processing, accelerated decision-making enabled by cloud control and Artificial Intelligence (AI), and the synergy of AI, cybersecurity, and unmanned systems to execute swarm offensives against adversaries in future conflicts.

Cognitive warfare, incorporating the use of neurotechnologies, is a critical component of this approach, extending the battlefield from traditional domains such as air, sea, land, and space into the cognitive domain. This shift underscores China's focus on cutting-

September 20, 2022, https://www.science.org/content/article/china-bets-big-brain-research-massive-cash-infusion-and-openness-monkey-studies.

44 M. Taylor Fravel, "China's "World-Class Military" Ambitions: Origins and Implications," *The Washington Quarterly* 43, no. 1 (2020): 85-99.

45 Yatsuzuka Masaaki, "PLA's Intelligentized Warfare: The Politics on China's Military Strategy," *Security and Strategy* 2, (2022): 17-36.

edge technologies to gain an advantage in both conventional and unconventional military operations.

Chinese military strategists believe that human cognition lies at the centre of 'intelligentized war' and that strategic objectives may be achieved by directly manipulating human cognition.[46] It has been argued that the cognitive domain will be the ultimate domain of great power competition[47] and tampering with the enemy's mind or subconsciously controlling it will induce panic and hallucinations, forcing surrender.[48] According to General Qi Jianguo, former Chief of Staff of the PLA, nations that achieve dominance in next-generation AI capabilities will hold the key to securing national salvation by controlling the critical domain of human cognition.[49]

China has developed a structured cognitive warfare doctrine that integrates various technologies and capabilities, broadly categorised into *Cognition* and *Subliminal Cognition*.

---

46 Li Dapeng, "How to Fight Intelligent Warfare," *China Youth Daily Group,* July 11, 2019, https://zqb.cyol.com/html/2019-07/11/nw.D110000zgqnb_20190711_3-12.htm.

47 Guo Yunfei, "Fighting for Brain Control, How Can We Win The Future War Without Fighting?," *China Military Network-People's Liberation Army Daily,* June 2, 2020, http://www.81.cn/xxqj_207719/xxjt/ll/9826822.html.

48 Zhu Xueling Zeng Huafeng "Brain Control Warfare: A New Model of Future War Competition," *PLA Daily*, October 18, 2017, https://www.sohu.com/a/198597081_778557.

49 Qi Jianguo, "Seize the Commanding Heights of Artificial Intelligence Technology Development," *China Military Network Ministry of National Defense Network,* July 25, 2019, http://www.81.cn/jfjbmap/content/2019-07/25/content_239260.htm.

Cognition encompasses technologies such as:

- Cognitive surveys,
- Cognitive interference, and
- Cognitive strengthening.[50]

Cognitive survey technology specifically focuses on collecting and analysing brain signals, enabling the extraction of neural data to better understand and potentially influence cognitive processes.[51] Theoretically, if the physiological signals are quantified, they will likely consolidate external and internal brain control. Similarly, it is also crucial for human-machine teaming in war settings, allowing warfighters to directly access and exercise seamless control over sophisticated weaponry.

Cognitive interference technology is potentially disruptive. It includes tools which are intended to inflict harm or damage to the human brain through a certain distance. This technology could be used against adversary's political officials, theatre commanders, and tactical groups operating on the ground. Meanwhile, *cognitive strengthening technology* is aimed at enhancing mood, bolstering resilience under stressors, and enabling soldiers to fight in austere conditions.[52]

Subliminal Cognition capabilities include integration of technologies and methodologies that are applied comprehensively to paralyse the adversary's C2. To create a cognitive fog of war, it employs the use of propaganda, deep fakes, and disinformation

---

50 Zhang Guangsheng, Li Yongli and Wang Haoxian, "A Brief Analysis of the Basic Essence of Cognitive Domain Warfare," *PLA Daily,* September 8, 2022, http://www.81.cn/jfjbmap/content/2022-09/08/content_323692.htm.

51 Guangsheng et al., "A Brief Analysis of the Basic Essence of Cognitive Domain Warfare."

52 Guangsheng et al., "A Brief Analysis of the Basic Essence of Cognitive Domain Warfare."

campaigns to create a favourable environment and delay international response due to the shrouded ambiguity. These tactics are likely combined with PLA's *Neurostrike* Programme.[53]

Pursuit of Neuroweapons

To gain a strategic advantage in cognitive warfare, China has announced the development of neurological weapons and established operational concepts to maximise their battlefield utility. Referred to as *New Concept Weapons (NCWs)*, these include DEWs, information-based weapons, and biological and chemical weapons, designed to achieve cognitive superiority against adversaries, particularly the US.[54] Among these, DEWs are reportedly intended to 'disorient enemy minds' and diminish their will to fight. Reports from sources suggest that China is also exploring mind-controlling weapons capable of influencing human cognition during conflicts.[55] The PLA's gradual shift toward cognitive warfare underscores the significance of NCWs in its evolving military strategy. The development of new operational frameworks, such as *Cognitive Domain Operations*, is likely to integrate NCWs into active combat scenarios.[56] These

---

53 Ryan Clarke, Xiaxou Sean Lin and LJ Eads, *"Enumerating, Targeting and Collapsing the Chinese Communist Party's Neurostrike Program, Aggregating Intelligence Fragments and the Power of Network Graphs,* report (Washington, D.C.: CCP BioThreats Initiative), Accessed 30 October 2024, https://shorturl.at/tDe6t.

54 Marcus Clay, "New Concept Weapons: China Explores New Mechanisms to Win War," *Jamestown Foundation,* April 23, 2021, https://jamestown.org/program/new-concept-weapons-china-explores-new-mechanisms-to-win-war/.

55 Bill Gertz, "Chinese Brain Warfare includes Sleep Weapons, Thought Control," *Washington Times,* December 20, 2023, https://www.washingtontimes.com/news/2023/dec/20/inside-ring-chinese-brain-warfare-includes-sleep-w/.

56 Beauchamp-Mustafaga, "Cognitive Domain Operations: The PLA's New Holistic Concept for Influence Operations."

advancements are expected to play a pivotal role in the PLA's grey zone operations and ongoing disputes in the South China Sea.

Reports suggest that China's neurostrike capabilities extend beyond traditional neuroweapons, encompassing the advanced use of human-machine interfaces to exert control over large populations and suppress dissent to preempt resistance. These reports indicate that neuroweapons are being integrated into China's standard arsenal, signalling ambitions to deploy these technologies in regular combat scenarios. This integration could enable precision strikes against adversaries during crises, reflecting a strategic focus on utilising neuroweapons for both domestic stability and international operations.[57] The development of these weapons and their associated operational concepts aligns with China's strategic anticipation of threats in key areas, including the First Island Chain, the South China Sea, and Xinjiang. These advancements highlight the dual-use potential of neuroweapons to address both internal and external security challenges, reinforcing China's broader geopolitical and military objectives.

Despite claims of China's development of New Concept Weapons (NCWs), assessing the veracity of neuroweapons use in crisis or conflict scenarios remains challenging. However, notable incidents in 2017 and 2018 in Guangzhou have drawn attention to the potential deployment of such technologies.

In late 2017, a U.S. Commerce Department employee reported waking to a distinct chirping sound emanating from a specific location, which triggered intense pressure in her head. Over the following months, she endured varying degrees of head sensations and was subsequently evacuated to the US in 2018. There, she

57 Ryan Clarke, Xiaoxu Sean Lin and Lj eads, *Enumerating, Targeting and Collapsing the Chinese Communist Party's NeuroStrike Program,* report (CCP Biothreat Initiative, 2020), https://www.ccpbiothreats.com/initiatives/project-one-ephnc-23hjt-xkgdj.

continued to experience lingering effects, including visual impairment, coordination issues, and memory loss. In the same year, similar symptoms prompted the evacuation of over a dozen US consulate members from China.[58]

During the 2020 standoff between China and India at the Line of Actual Control (LAC), Jin Canrong, Deputy Dean of the School of International Relations at Renmin University, Beijing, alleged that the Chinese PLA used non-lethal microwave weapons to disorient Indian troops and retake a strategic hilltop. Canrong claimed the weapon caused vomiting among Indian soldiers, forcing them to retreat.[59] India denied the claim, labeling it as fake news.[60] However, an annual review by India's Ministry of Defence mentioned the use of an 'unorthodox weapon' during the conflict, lending some plausibility to the allegation.[61]

---

58 Josh Lederman, "Evacuated after 'Health Attacks' in Cuba and China, Diplomats Face New Ordeals in U.S.," *NBC News,* October 29, 2018, https://www.nbcnews.com/news/investigations/evacuated-after-health-attacks-cuba-china-diplomats-face-new-ordeals-n920241.

59 Aakriti Sharma, "Has India Finally Acknowledged That Chinese PLA Used Microwave Weapons Against Indian Soldiers in Ladakh?," *Eurasian Times,* January 6, 2021, https://www.eurasiantimes.com/has-india-finally-acknowledged-that-chinese-pla-used-microwave-weapons-against-indian-soldiers-in-ladakh/.

60 David Hambling, "India Disputes Claim That China Routed Their Troops With Microwave Blaster," *Forbes,* July 19, 2021, https://www.forbes.com/sites/davidhambling/2020/11/20/disputed-claim-that-china-routed-indian-troops-with-microwave-blaster/.

61 Government of India, "Year End Review – 2020 Ministry of Defence," January 1, 2021, https://pib.gov.in/Pressreleaseshare.aspx?PRID=1685437.

Given the agreement between the two states to avoid firearms or explosives in disputed areas,[62] non-lethal weapons like microwave systems remain a plausible option. Such events, even if disputed, highlight concerns over the use of unconventional weapons in conflicts and their potential to serve as advanced psychological tools to disrupt and demoralise adversaries.

These instances demonstrate China's ability to deploy its NCWs with modern operational concepts making it an influential player in the emerging landscape of neurowarfare. Since the Gulf War, the Chinese PLA has been studying the US military's doctrinal evolution and way of war. The newly adopted 'intellegentised warfare' shows the PLA's anticipation of the advantages of neuroweapons, and development of new operational concepts to operationally deploy them to achieve cognitive overmatch over its regional and global adversaries.

Challenges of Integrating Neurotechnologies in Warfare

The growing adoption of neurotechnologies in future warfare presents considerable challenges, particularly in the legal, ethical, and moral domains. Some of these critical issues are outlined below:

Legal Challenges

The throttle of human-machine integration presents many challenges, particularly in keeping pace with existing legal frameworks. While international agreements such as the *Chemical Weapons Convention (CWC)* and the *Biological Weapons Convention (BWC)* prohibit the development of neurobiological weapons, modern neuroweapons—such as acoustic, microwave, and

62 United Nations, "Agreement between India and China on Confidence-Building Measures in the Military Field along the Line of Actual Control in the India-China Border Areas," November 29, 1996, https://peacemaker.un.org/en/node/9227.

electromagnetic systems—fall outside the scope of these definitions. This legal ambiguity creates a 'grey zone,' enabling such technologies to evade current regulatory frameworks. Moreover, the dual-use nature of neurotechnologies, where they serve both civilian and military purposes, heightens the risk of their weaponisation. This duality complicates efforts to regulate or explicitly ban malicious use of these technologies under the existing conventions, further challenging global disarmament and non-proliferation efforts.

The CWC also defines toxic chemicals as 'any chemical which, through its chemical action on life processes, can cause death, temporary incapacitation, or permanent harm to humans or animals.'[63] However, modern neuroweapons frequently employ unconventional agents that challenge traditional biolegal and arms control frameworks. For instance, some neuroweapons, such as microwave-based systems, can alter neural functions without causing direct physical damage to the brain. These technologies often utilise agents with low or negligible toxicity, operating in microdoses that fall outside conventional definitions of toxic chemicals as outlined by the CWC. This ambiguity enables such neuroweapons to bypass current regulatory frameworks, further complicating efforts to address their development and use within existing legal structures.

---

63 Organisation for the Prohibition of Chemical Weapons, "Article II, Definitions and Criteria, Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction," *Organisation for the Prohibition of Chemical Weapons*, June 7, 2020, https://www.opcw.org/chemical-weapons-convention/articles/article-ii-definitions-and-criteria#:~:text=%E2%80%9CToxic%20Chemical%E2%80%9D%20means%3A,harm%20to%20humans%20or%20animals.

Issue of Informed Consent

Apart from conventional medical experiments carried out on ill people, neuroweapons are tested in classified settings with the possibility of targetting healthy individuals resulting in partial or permanent brain damage. Furthermore, national security institutions often test the utility of these agents on individuals who may be unaware that they are being used as test subjects.[64] Such practices frequently bypass internal ethics reviews,[65] raising profound ethical and moral concerns. In these instances, individuals subjected to classified projects are typically unable to seek legal recourse against the government, as the state can invoke 'state secrets' privileges to shield its actions from judicial scrutiny.

Neurocrimes

Non-state actors, criminals, and hostile intelligence agencies might use neuroweapons for nefarious designs including torture, manipulation, and forced confessions from innocent individuals. Punitive torture is an illustration of this phenomenon where neurotransmitters are used to manipulate the time perceptions of a prisoner. It has been argued that this technique is a cost-effective method of caging a convict by giving him a drug and placing him in prison for a few days, which in turn would make him perceive incarceration for years.[66] Notwithstanding the rationale of such

---

64 Margaret Winter, "Don't Let the Military's Deadly "Pain Ray" Machine Invade the L.A. Jail," *ACLU,* August 26, 2010, https://www.aclu.org/news/national-security/dont-let-militarys-deadly-pain-ray-machine-invade-la-county-jail.

65 Central Intelligence Agency, "MK-Ultra/Mind Control Experiments," *Central Intelligence Agency*, December 23, 1984, https://www.cia.gov/readingroom/docs/CIA-RDP88-01070R000301530003-5.pdf.

66 Dylan Love, "Future Mind-Altering Drugs Could Make Prisoners Think They're in Jail for 1,000 Years," *Business Insider India,* August 19, 2014, https://www.businessinsider.in/future-mind-altering-drugs-

techniques, it can allow governments to conceal the torture due to the absence of physical evidence.

Overdose of Neuromedicines

Psychiatric drugs are considered mood stabilisers, anti-depressants, and antipsychotics to modulate brain functions. However, these agents are often overprescribed and misused for performance enhancement. These drugs can provide relief and enhance cognitive functions but with a burgeoning cost. In the future, military commanders may have the capability to modulate the neural activity of their troops, raising regulatory concerns over the potential misuse or overdose of neuromedicine.[67] This scenario underscores the need for robust oversight mechanisms to address the ethical, health, and operational risks associated with such practices.

Mind Hacking

As neurotechnologies modernise, mind hacking becomes a pertinent concern for strategic and military planners. The possible co-option of neural implants with external devices aggrandises the risk of information theft, hacking, and reprogramming of neutrally enhanced soldiers. Similarly, adversary forces can inflict brain damage on future 'super soldiers' by targetting them through mind-damaging weapons including lasers, microwaves, and DEWs.[68]

---

could-make-prisoners-think-theyre-in-jail-for-1000-years/articleshow/40425325.cms.

67 Heloise Goodley, "Pharmacological Performance Enhancement and the Military," (paper, Chatham House, 2020), https://www.chathamhouse.org/sites/default/files/2020-11/2020-11-11-pharma-enhancement-military-goodley_0.pdf.

68 Darlene Storm, "Hacking the Mind: 3 New Brain Hacks Expose New Realms of Security and Privacy Risks," *Computer World,* August 27, 2012, https://www.computerworld.com/article/1372372/hacking-the-mind-3-new-brain-hacks-expose-new-realm-of-security-privacy-risks.html.

Besides this, the emergence of DNA hacking could enable states and non-state actors to inject viruses into the human brain, opening a plethora of new problems.[69]

Neueroweapons and Future Warfare: What Comes Next?

Just as early warnings[70] about the potential dangers of cyberwarfare highlighted its transformative impact, this paper aims to draw attention to the emerging threat of neurowarfare, specifically its focus on mind control and direct manipulation. National security communities and military organisations must remain vigilant regarding advancements in neuroscience and their implications for defence. While significant progress is being made in developing performance-enhancement technologies, equal attention must be given to monitoring potential risks associated with performance degradation and implementing necessary countermeasures.

Advancements in neuroscience are expected to play a pivotal role in shaping great power rivalries, with the US and China actively pursuing neural and ocular enhancement technologies for their soldiers. These enhancements aim to improve alertness and enable stealthy communication through methods such as telepathy. Such capabilities are designed to empower troops to execute complex operations, including neutralising command-and-control systems, disabling radars, destroying fuel and ammunition depots, or rendering nuclear missiles, delivery vehicles, and launch systems inoperative.

---

69 "Crocus-Moscow Tells About Chips in Head of Terrorists," *RBC Ukraine*, April 1, 2024, https://newsukraine.rbc.ua/news/crocus-moscow-tells-about-chips-in-heads-1711935747.html.

70 John Arquilla and David Ronfeldt, "Cyberwar is Coming," *in In Athena's Camp: Preparing for Conflict in Information Age*, ed. John Arquilla and David Ronfeldt (Santa Monica: RAND Corporation, 1997), 23-61.

In addition, neuroweapons provide a unique toolkit that could inflict psychological and physical harm on the adversary's morale. Due to enhanced precision, these weapons could be employed to target key military planners, strategists, theatre commanders, and government officials, to inflict 'neural shock and awe.' Such actions will adversely impact interstate relations and aggravate mistrust and uncertainty.

Similarly, future conflicts are likely to see an increased reliance on Special Forces operating covertly behind enemy lines to carry out sabotage missions. In such scenarios, BCIs and other neural enhancement technologies could enable Special Forces personnel to endure extended operations, counteract sleep deprivation, and manage battlefield stress effectively. This potential is underscored by reports of cognitively enhanced fighters encountered by Western forces in Syria, who used amphetamines such as *Captagon* to remain awake for extended periods and engage in combat with reckless ferocity.[71] These examples highlight the operational advantages and ethical dilemmas associated with cognitive enhancement technologies in modern warfare.

Considering the lethality of these technologies in war, the international community must regulate them to prevent misuse. In this regard, existing legal frameworks and conventions should be revised, or new legal frameworks developed focused on regulating neurotechnologies in the military context. Instead of banning military-related research, CWC's definition of toxic chemicals should include the non-lethal chemical agents responsible for neural impairments and cognitive degradation. Likewise, states

71 U.S. Central Command, "$1.4 Million Terrorist Drug Cache Seized, Destroyed in Southern Syria," *U.S. Central Command*, June 18, 2018, https://www.centcom.mil/MEDIA/PRESS-RELEASES/Press-Release-View/Article/1553512/14m-terrorist-drug-cache-seized-destroyed-in-southern-syria/.

should raise task forces to monitor dual use of neurotechnologies, particularly in the private sector, academia, and research centres.

Currently, there are no specific guidelines addressing unauthorised access to human neural functions, which poses risks to brain health and cognitive integrity. To address this gap, governments must update and expand the *Universal Declaration on Bioethics and Human Rights*, placing particular emphasis on the normative challenges arising from advancements in neurotechnologies. Establishment of active regulatory bodies, comprising neuroscientists and legal experts, is also essential. These bodies should be tasked with conducting comprehensive in-house reviews, ensuring ethical and medical compliance, and providing consistent oversight regarding feasibility and implications of employing neuroscience in military contexts.

Conclusion

While neuroweapons possess transformative potential, their impact is more likely to enhance existing military capabilities than to redefine warfare entirely. By enabling commanders to exploit asymmetrical gaps, these technologies will supplement, rather than replace, traditional combat systems. The enduring dominance of conventional strategic paradigms—centred on legacy systems like tanks, submarines, strategic bombers, and guided missile frigates—illustrates this point. Sustained investments in adapting these systems to new threats reinforce the notion that conventional warfare will continue to dominate for the foreseeable future. Consequently, integration of neuroweapons into military frameworks is expected to be a gradual process, positioning them as supplementary tools rather than revolutionary game-changers

Neuroweapons also face other challenges. Lack of long-term research, ethical concerns around informed consent and autonomy, and complexity of their operational mechanisms also make their integration into existing battle systems difficult. Moving

forward, addressing these challenges will require a multidisciplinary effort involving scientific, ethical, and policy-driven approaches. Understanding the doctrinal implications, operational utility, and potential countermeasures of neuroweapons will be critical to shaping their role in future conflicts. As technology advances, these issues will require continuous examination to ensure their use aligns with international norms and strategic objectives.

Military use of neurotechnologies will also complicate the existing battlefield by raising questions about attribution and response. While efficacy of neuroweapons below the threshold of an armed conflict makes them an effective asymmetric tool to inflict sizeable damage to the adversary's leadership and population, secrecy surrounding development of neuroweapons heightens uncertainty and mistrust, potentially driving other states to pursue neurodegradation capabilities and fuelling a neuroweapons arms race. To mitigate this risk, it is crucial to establish regulatory frameworks that limit the development of neurotechnologies for nefarious purposes.

Shaheer Ahmad has worked at the Institute of Strategic Studies, Islamabad, and held roles at the Consortium of Indo-Pacific Researchers (New Jersey, USA) and Humanetek. A graduate of International Relations from National Defence University (NDU), Pakistan, his research focuses on international relations, geopolitics, military strategy, and emerging technologies, with a regional emphasis on the Indo-Pacific, Arctic, Eastern Europe, and South and Southeast Asia. He can be contacted at: ashaheer214@gmail.com.

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 35-67

Quantum Takeoff: Applications in the Aviation Sector

Shaza Arif

Abstract

At the intersection of advanced computer science and quantum physics, Quantum Computing has emerged as one of the most compelling technological frontiers of the 21st Century. Among the industries poised to benefit significantly, the aviation sector stands out as a key area where this transformative technology can drive substantial advancements. The findings of this research reveal several noteworthy applications of quantum computing in the aviation industry, including aircraft design, flight trajectory optimisation, navigation, schedule maintenance, and secure network management. Integrating this technology could bring numerous benefits to the aviation sector, enhancing operational efficiency, resource utilisation, and overall productivity. However, these advantages are contingent on overcoming existing challenges. As a developing country, Pakistan must also begin investing in efforts and resources to adopt quantum computing in its aviation sector, ensuring its readiness to leverage this transformative technology in the future.

Keywords: Emerging Technologies, Quantum computing, Qubits, Aviation Sector.

Introduction

Quantum computing has rapidly emerged as a transformative technology, earning its place among the most significant 'emerging' and 'disruptive technologies.'[1] In today's data-driven age, it enables unprecedented computational capabilities, solving complex problems at an accelerated pace and driving breakthroughs across various fields.[2] Its expanding applications have heightened expectations about its societal impact.[3] Among sectors such as finance, healthcare, and education, aviation is particularly poised to benefit from the profound potential of quantum computing.[4]

The aviation sector symbolises technological innovation, global connectivity, and the expansion of networks. It is currently undergoing significant transformations driven by factors such as increased connectivity, airline expansion, technological advancements, growing freight operations, emerging markets, and infrastructure development.[5] Quantum technology can further revolutionise this sector by enabling complex simulations and offering insights beyond traditional analytical methods. It has the

1 *Quantum Computing: A Sectoral Composition Approach,* report (Maryland: Center for International and Security Studies, 2020), 4, https://strategictraderesearch.org/wp-content/uploads/2020/10/Quantum.pdf.

2 Sarada Rajalaxmi and Suchita Reddy, "Quantum Computing: Applications and Future Importance," *International Research Journal on Advanced Science Hub* 3, no. 6 (2021): 157-160, https://rspsciencehub.com/article_12156_fdba83ed2793d8948d083f0238f60cf0.pdf.

3 Hiral Patel, Sejal Mishra, Rahul Jain and Nirali Kansara, "The Future of Quantum Computing and its Potential Applications," *Journal for Basic Sciences* 23, no.11 (2023): 513-518.

4 Rajalaxmi and Reddy, "Quantum Computing: Applications and Future Importance," 158.

5 Ibid.

potential to strengthen and expedite modernisation in aviation operations, making it crucial to analyse its impact on the industry.

This research paper explores the intersection of quantum computing and aviation, focusing on its applications within the sector. It begins with an overview of quantum computing, followed by an examination of its potential applications in aviation. The analysis culminates in actionable policy recommendations for leveraging this technology effectively. By highlighting the transformative role of quantum computing, this study aims to provide a foundation for understanding its implications and fostering future advancements in the aviation industry. It employs a qualitative approach, relying on secondary data sources such as books, book chapters, journal articles, reports, news articles, opinion pieces, and relevant websites. Thematic analysis is used to analyse the collected data. The research underscores the importance of quantum computing in the aviation sector and highlights its potential to transform the industry. It also opens new avenues for further in-depth exploration of quantum technology applications in various domains of aviation, paving the way for future research.

Quantum Computing

Before exploring the applications of quantum computing, it is important to understand the foundational concepts behind this technology. Quantum computing marks a major shift from traditional computing models, using principles of quantum mechanics to address complex problems with remarkable speed and efficiency. This emerging technology is often described as the 'next tech trend' due to its potential to transform computational methods.[6] The phenomena is considerably different from how

[6] Michael Chui, Mena Issler, Roger Roberts and Lareina Yee, *McKinsey Technology Trends Outlook 2023,* report (New York: McKinsey Digital, 2023), 8, https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-top-trends-in-tech#tech-trends-2023.

digital computers have been performing calculations and processing information for decades.[7] Unlike traditional digital computers, which rely on bits as the fundamental unit of information (representing either 0 or 1), quantum computing operates on quantum bits, or qubits.[8] Qubits are subatomic particles such as photons, neutrons, or electrons, which possess the unique ability to exist in multiple states simultaneously—a phenomenon known as superposition. This capability allows quantum computers to perform multiple calculations at once, dramatically enhancing their computational power.[9]

The operational principles of quantum computing are further distinguished by quantum gates, which manipulate the state of qubits. These gates serve as the fundamental building blocks of quantum circuits, enabling the execution of complex algorithms that go beyond the capabilities of classical computing.[10] In classical computing, bits operate independently without interacting with one another. In contrast, quantum computing enables qubits to share information once data is provided, facilitating multiple

---

7 Surya Teja Marella and Hemanth Sai Kumar Parisa, "Introduction to Quantum Computing" in *Quantum Computing and Communications* ed. Yongli Zhao (London: Intechopen, 2022), 2.

8 McKinsey and Company, "What is Quantum Computing?" April 5, 2024, https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-quantum-computing; K.S. Balamurugan, Sivakami A., Mathankumar Mounagurusamy, Yalla Jnan Devi Satya Prasad et al., "Quantum Computing Basics, Applications and Future Perspectives," *Journal of Molecular Structure* 1308, (2024): 137917, https://www.sciencedirect.com/science/article/abs/pii/S0022286024004 40X#:~:text=Unlike%20classical%20computers%2C%20the%20quantum,provided%20by%20the%20quantum%20computers.

9 Brett Landon Long, "Quantum Processing Speed: Unveiling the 'Why' Behind Quantum Computers' Lightning-Fast Calculations," *Medium*, July 19, 2023, https://medium.com/@brettlandonlong/title-quantum-processing-speed-unveiling-the-why-behind-quantum-computers-lightning-fast-7a11b2cbf1aa.

10 McKinsey and Company, "What is Quantum Computing?"

complex calculations simultaneously with greater speed and efficiency.[11]

Several phenomena associated with quantum computing contribute to its ability to perform faster calculations compared to classical computers. These include, but are not limited to, Superposition, Entanglement, and Quantum Interference. 'Superposition' enables qubits to exist in multiple states simultaneously, enhancing computational power. 'Entanglement', on the other hand, refers to the phenomenon where the quantum states of particles become interconnected, such that the state of one particle cannot be described independently of the other, regardless of the distance between them.[12] In 'Quantum Interference', particles exhibit wave-like behaviour. When two waves are in-phase, they interfere constructively, while out-of-phase waves interfere destructively. This principle is closely associated with Grover's Algorithm, which is designed to identify specific items that meet a given criterion. Grover's Algorithm consists of components such as state preparation, an oracle, measurement, and the diffusion operator, which plays a key role in quantum interference. By leveraging constructive interference to amplify correct solutions and destructive interference to suppress incorrect ones, the algorithm enhances efficiency and accuracy in solving search problems.[13]

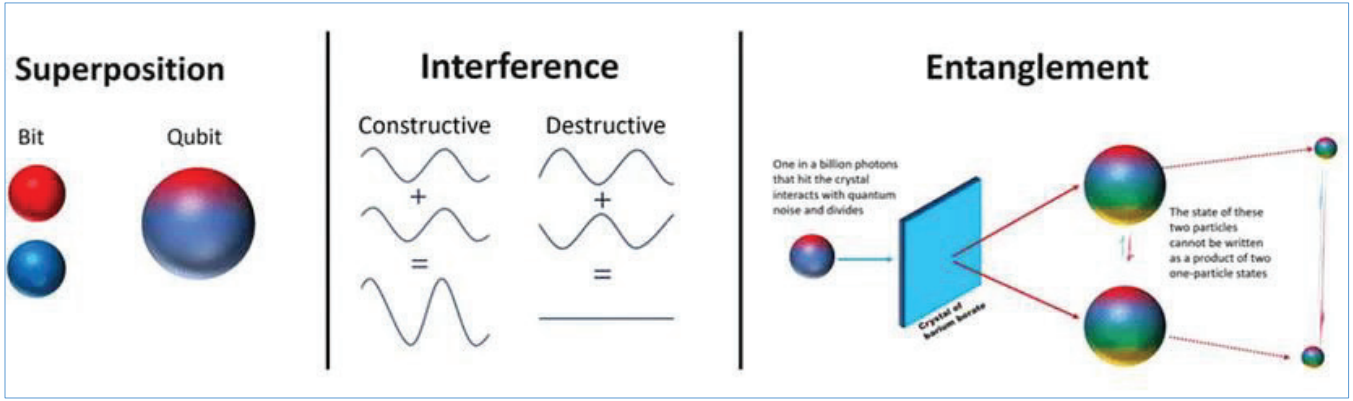
---

11 Ciaran Hughes, Joshua Isaacson, Anastasia Perry, Ranbel Sun and Jessica Turner, *Quantum Computing for the Quantum Curious* (Geneva: SpringerLink, 2021), 68.

12 Quantum Inspire, "Superposition and Entanglement," https://www.quantum-inspire.com/kbase/superposition-and-entanglement/ [Accessed September 12, 2024].

13 Classiq, "Interference in Quantum Computing," https://www.classiq.io/insights/interference-in- quantum-computing.

Figure I: Important Concepts of Quantum Computing



Source: Louis Chen, "A Brief History of Quantum Computing," *Medium*, April 2, 2023, https://quantumpedia.uk/a-brief-history-of-quantum-computing-e0bbd05893d0.

Another important characteristic of quantum computing is 'Quantum Annealing' which leverages quantum principles to identify low-energy states of a problem, providing the optimal or near-optimal combination of elements.[14] This approach is particularly effective in scenarios with numerous potential solutions, enabling faster and more efficient problem-solving.[15] On a case-to-case basis, each of these offer a substantial advantage in faster and more efficient calculations.

Ultimately, calculations using quantum computing can occur much more quickly and efficiently than classical computing. For instance, a 30-qubit quantum computer can surpass 10 trillion floating-point operations per second (TFLOPS).[16] In 2019, Google announced the development of a quantum machine capable of solving a problem in 200 seconds that would have taken a classical computer 10,000 years to complete.[17] More recently, in December 2024, Google unveiled a new quantum chip, Willow, which it claims can solve complex problems in just five minutes - problems that would

14 DWave, "What is Quantum Annealing?" https://docs.dwavesys.com/docs/latest/c_gs_2.html [Accessed September 12, 2024].

15 Cem Dilmegani, "Quantum Annealing in 2024: Practical Quantum Computing," *AI Multiple Research*, January 12, 2024, https://research.aimultiple.com/quantum-annealing/.

16 Filippo Di Giovanni, "Physical Principles Underpinning Quantum Computing," *Electronic Engineering Times,* January 5, 2024, https://www.eetimes.eu/physical-principles-underpinning-quantum-computing/.

17 Charles Riyle, "Google Claims its Quantum Computer Can Do the Impossible in 200 Seconds," *CNN*, October 23, 2019, https://edition.cnn.com/2019/10/23/tech/google-quantum-supremacy-scn/index.html.

otherwise take the world's fastest supercomputers ten septillion years.[18]

It is pertinent to mention that quantum computing is not a standalone replacement for digital computing, but a complementary technology designed to enhance computing power, precision, measurement capabilities, sensing, and the efficiency of existing and emerging computational methods. As a dual-use technology, it has applications in both civil and military domains. [19] While quantum computing has numerous civilian applications, it is also expected to influence warfare and battlefield outcomes.[20] However, this paper focuses exclusively on its commercial applications, specifically in the aviation sector.

Applications of Quantum Computing in the Aviation Sector

There is great optimism about the potential of quantum computing to deliver substantial benefits to the aviation industry. The sector has shown remarkable resilience, recovering rapidly from the losses incurred during the pandemic.[21]

---

18 Chris Vallance, "Google Unveils 'Mind-boggling' Quantum Computing Chip," *BBC*, December 9, 2024, https://www.bbc.com/news/articles/c791ng0zvl3o.

19 Michal Krelina, "Quantum Technology for Military Applications," *European Physical Journey Quantum Technology* 8, no.24, (2021): 1-53, https://link,".springer.com/content/pdf/10.1140/epjqt/s40507-021-00113-y.

20 Herald Andas, *Emerging Technology Trends for Defence and Security* (Kjeller: Norwegian Defence Research Establishment, 2020), 8.

21 Kaitano Dube, "Emerging from the COVID-19 Pandemic: Aviation Recovery, Challenges and Opportunities," *Aerospace* 10, no.1 (2023): 1-13.

In 2023, the global aviation market size reached approximately USD 841.5 billion, reflecting a 7% increase from 2022.[22] Similarly, passenger traffic has rebounded to 94.1% of pre-pandemic levels, highlighting the industry's steady recovery.[23] These developments indicate a positive trend for the aviation industry's recovery and growth. However, airlines continue to face intense competition in managing operational costs, particularly fuel and crew expenses,[24] along with challenges such as weather uncertainties and disruptions to flight operations.[25]

Meanwhile, the quantum computing market is projected to grow significantly, reaching an estimated USD 12,620 million by 2032.[26] This expansion presents considerable opportunities for the aviation sector. Exploring the intersection of these domains could unlock sizable benefits. The next section will examine potential applications of quantum technologies in the aviation industry.

---

22 "How Much Money Does the National and Global Airline Industry Make?" *Rosen Aviation,* February 21, 2024, https://www.rosenaviation.com/blog/how-much-money-does-the-national-and-global-airline-industry-make/#:~:text=In%202023%2C%20the%20national%20airline,revenue%20due%20to%20COVID%2D19.

23 Elias Al Helou, "Global Air Travel Reaches 94.1 Percent of Pre-Pandemic Levels: IATA," *Middle East Economy*, February 1, 2024, https://economymiddleeast.com/news/global-air-travel-iata/.

24 Brian Beers, "Which Major Expenses Affect Airline Companies?" *Investopedia,* July 20, 2023, https://www.investopedia.com/ask/answers/040715/what-are-major-expenses-affect-companies-airline-industry.asp.

25 Marika Svensson, "Quantum Computing for Airline Planning and Operations," (Licentiate diss., Chalmers University of Technology, Gothenburg, 2023).

26 Fortune Business Insights, "Quantum Computing Market Size," May 13, 2024, https://www.fortunebusinessinsights.com/quantum-computing-market-104855.

Aircraft Design

Quantum computing can have a profound impact on aircraft design in the future.[27] While the technology has not yet advanced to the point of designing complete aircraft components, initial efforts in this direction are already underway. Notably, private companies such as Boeing, in collaboration with IBM Computing, are making strides in leveraging quantum computing for aerospace engineering.[28] Boeing employs ply composite materials in its 787 Dreamliner, valued for their safety, lightweight properties, and strength, which enable reduced fuel consumption and extended flight distances.[29] However, designing aircraft with ply composites presents challenges due to the complexity of the required calculations, often involving up to 100,000 variables to determine the optimal placement and angles of ply strands. Classical computers struggle with such computational demands, leading engineers to simplify problems by dividing them into smaller units and later recombining them. While effective, this method is time-consuming and resource intensive.[30]

Quantum computing offers a transformative solution by expediting simulations and calculations, thereby reducing costs and resource

---

27 Nahla Davies, "Here's What Quantum Computing is—and How it's Going to Impact the Future of Work, According to a Software Engineer," *Fast Company*, July 19, 2024, https://www.fastcompany.com/91015535/housing-market-home-price-prediction-2024-zillow.

28 International Business Machines, "Boeing Seeks New Ways to Engineer Strong, Lightweight Materials," https://www.ibm.com/case-studies/boeing [Accessed April 20, 2024].

29 Rafi Letzter, "How Quantum Computers Could Help Design Airplanes," *International Business Machines*, June 27, 2023, https://www.ibm.com/quantum/blog/boeing-case-study.

30 International Business Machines, "Boeing Seeks New Ways to Engineer Strong, Lightweight Materials."

requirements.[31] This capability could accelerate adoption of innovative aircraft designs and enable the industry to explore novel approaches more efficiently. For instance, Boeing has collaborated with IBM to tackle binary optimisation problems.[32] Similarly, Airbus has partnered with various European agencies to explore the use of quantum computing to overcome computational fluid dynamics (CFD) bottlenecks in aircraft design.[33] Further efforts are being undertaken by companies such as Rolls Royce, NVIDIA, and Classiq, which are investing in quantum computing for jet engine design.[34] The King Abdullah University of Science and Technology (KAUST) is also working with the US-based Zapata Computing to apply quantum computing in CFD research, aiming to enhance aerodynamic design.[35] These advancements suggest that quantum computing will likely be adopted more widely by other companies seeking to optimise aircraft design processes.

---

31 Hunter Gaylor, "Quantum Computing in Aviation: Shaping the Future of Aerospace," *Quantum Minute*, August 31, 2023.

32 El Dawton, "How Quantum Computing Is Helping the Aviation Industry," *Medium*, July 12, 2023, https://medium.com/@eldawton/how-quantum-computing-is-helping-the-aviation-industry-cea8295e6db7.

33 Berenice Baker, "Airbus Looks to Quantum Computing for Decarbonization," *IoT World Today*, April 29, 2024, https://www.iotworldtoday.com/quantum/airbus-looks-to-quantum-computing-for-decarbonization.

34 Rivka Coleman, "Rolls-Royce, Nvidia and Classiq Apply Quantum to Jet Engines," *Our Crowd*, June 12, 2023, https://www.ourcrowd.com/startup-news/rolls-royce-nvidia-and-classiq-apply-quantum-to-jet-engines.

35 Matt Swayne, "KAUST and Zapata Explore How Quantum Computers Could Save Billions in Improved Aerodynamic Design of Airplanes and Cars," *Quantum Insider*, April 25, 2021, https://thequantuminsider.com/2021/04/25/kaust-and-zapata-explore-how-quantum-computers-could-save-billions-in-improved-aerodynamic-design-of-airplanes-and-cars/.

Flight Trajectory Optimisation

Flight trajectory optimisation is critically important for the aviation industry due to its potential to enhance aircraft efficiency while minimizing costs.[36] However, it remains a major challenge, as it involves navigating a complex interplay of factors such as fuel efficiency, collision avoidance, and environmental impact.[37] Furthermore, the dynamic environments in which flights operate, particularly during the climb phase, involve numerous changing variables, making speed and accuracy of calculations critical.[38] In this context, quantum computing, through the application of quantum algorithms, is anticipated to play a pivotal role in assisting the aviation industry with flight trajectory optimisation.[39] By employing quantum algorithms, real-time data comprising air traffic situation, weather patterns/condition, and other important factors can be analysed to reduce associated costs and time.[40] Moreover, quantum computing can address complex optimisation challenges arising from evolving circumstances. For instance, in scenarios requiring rerouting due to unforeseen events, quantum algorithms can simultaneously evaluate multiple variables to

---

36 Yibo Lia, Shuaitao Qin and Lei Jing, "Research on Flight Trajectory Optimization Based on Quantum Genetic Algorithm," *Journal of Physics* 1549 (2020): 1-7.

37 "The Role of Quantum Computing in Aviation: Advancements and Benefits," *Quantum AI*, December 9, 2023, https://quantumai.co/the-role-of-quantum-computing-in-aviation-advancements-and-benefits/.

38 Airbus, "Is Quantum Computing an Enabler for the Decarbonisation of Aviation?" April 25, 2024, https://www.airbus.com/en/newsroom/stories/2024-04-is-quantum-computing-an-enabler-for-the-decarbonisation-of-aviation.

39 Henry Makhanov, Kanav Setia, Junyu Liu and Vanesa Gomez-Gonzalez, "Quantum Computing Applications for Flight Trajectory Optimization," (paper, arXiv, 2023), https://arxiv.org/pdf/2304.14445.

40 Lia, Qin and Jing, "Research on Flight Trajectory Optimization Based on Quantum Genetic Algorithm," 1.

minimise disruption while ensuring operational efficiency.[41] In addition, advanced technologies such as quantum genetic algorithms have the potential to overcome technical issues and mitigate climb trajectory optimisation challenges for civil aircraft.[42] In this context, Airbus has collaborated with the BMW Group to launch the Quantum Mobility Quest, , an initiative aimed at addressing critical challenges faced by the aviation industry.

Quantum computing can also be utilised to optimise flight paths for Unmanned Aerial Vehicles (UAVs). In this regard, the Virginia Innovation Partnership Corporation has partnered with Quantum Computing Inc. to develop optimal flight trajectory solutions for UAVs. This initiative focuses on determining the most efficient speed, route, and timing for UAVs to reach their destinations. It also aims to address airspace challenges and minimise risks associated with weather conditions, obstacles, and interactions with other aircraft.[43] This optimisation is achieved through the use of entropy quantum computing systems, which enable efficient processing of complex variables to determine optimal flight paths and address associated challenges.[44] Airbus' Silicon Valley innovation centre, Acubed, is actively exploring quantum trajectory

41 "The Role of Quantum Computing in Aviation: Advancements and Benefits."

42 Lia, Qin and Jing, "Research on Flight Trajectory Optimization Based on Quantum Genetic Algorithm," 6.

43 "Quantum Computing Inc. Announces Full Year 2022 Financial Results," *PR Newswire,* March 29, 2023, https://www.prnewswire.com/news-releases/quantum-computing-inc-announces-full-year-2022-financial-results-301785169.html.

44 "VIPC Selects Quantum Computing Inc. as a Partner for Risk-Based Flight Trajectories, *Global News Wire*, October 5, 2022, ttps://www.globenewswire.com/en/news-release/2022/10/05/2529095/0/en/VIPC-Selects-Quantum-Computing-Inc-as-a-Partner-for-Risk-Based-Flight-Trajectories.html.

optimisation to enhance efficiency and innovation in flight operations.[45]

The aviation industry is a substantial contributor to greenhouse gas emissions, driving climate change. Quantum computing offers promising potential for reducing carbon emissions through optimal flight path optimisation. By identifying the most fuel-efficient routes between a source and destination, quantum computing could play a pivotal role in enhancing environmental sustainability within the aviation sector.[46]

Moreover, apart from minimizing greenhouse gases, optimal flight paths could help tackle the environmental aspect vis-à-vis increasing air traffic - something that is expected to rise in the coming decades. Similarly, improved flight optimisation can reduce contrail formation, another contributor to climate change.[47] In addition, quantum speedup across various operational areas could indirectly enhance revenue management for the aviation sector.[48]

Navigation

Quantum computing holds considerable potential for enhancing navigation, a critical aspect of aviation that ensures safe and efficient air travel. Quantum sensing can enable development of

---

45 Airbus, "Is Quantum Computing an Enabler for the Decarbonisation of Aviation?"

46 Makhanov, Setia, Liu and Gomez-Gonzalez, "Quantum Computing Applications for Flight Trajectory Optimization."

47 James Temple, "How Rerouting Planes to Produce Fewer Contrails Could Help Cool the Planet," *Technology Review,* March 12, 2024, https://www.technologyreview.com/2024/03/12/1089620/how-rerouting-planes-to-produce-fewer-contrails-could-help-cool-the-planet/.

48 Thomas Fiig, "Application of Quantum Computing in Airline Revenue Management," *Amadeus*, September 28, 2023, https://amadeus.com/en/blog/articles/application-quantum-computing-airline-revenue-management.

highly precise sensors capable of measuring physical quantities such as magnetic fields, acceleration, and rotation rates with unprecedented accuracy.[49] Consequently, navigation systems could greatly benefit from quantum sensors, improving positional accuracy and contributing to enhanced flight safety and more effective air traffic management.[50] Quantum technologies are anticipated to enhance positioning, navigation, and timing (PNT) systems, particularly in the context of inertial navigation. Emerging technologies and approaches are expected to lead to the development of highly sensitive precision instruments for PNT applications.[51] This is especially relevant in GPS-denied environments, operationally challenging terrains, or areas where GPS signals are degraded.[52] In such scenarios, quantum-enhanced PNT systems could offer reliable and effective navigation solutions. Airbus' Acubed, has already announced plans to leverage quantum sensing for navigation advancements.[53]

Boeing recently conducted a four-hour flight test to evaluate the quantum inertial measurement unit (IMU) for navigation in GPS-denied environments. Developed through a collaboration between Boeing and AOSense, the quantum IMU utilises interferometry, a technique that measures rotation and acceleration using atoms. This approach provides unparalleled precision and accuracy

---

49 AirBus, "Quantum Technologies: A Potential Game Changer in Aerospace," https://www.airbus.com/en/innovation/disruptive-concepts/quantum-technologies [Accessed March 20, 2024].

50 Gaylor, "Quantum Computing in Aviation: Shaping the Future of Aerospace."

51 Krelina, "Quantum Technology for Military Applications."

52 Jay Lowell, interview by Konstantinos Karagiannis, *Quantum Navigation and other Aviation Use Cases with Boeing*, March 8, 2023, https://www.youtube.com/watch?v=y_R-W_gWXm4.

53 Acubed, "Acubed Announces Exploration of Quantum Sensing as an Autonomy Enabler," December 5, 2025, https://acubed.airbus.com/blog/quantum/acubed-announces-exploration-of-quantum-sensing-as-an-autonomy-enabler/.

without relying on GPS.[54] The quantum inertial sensors within the IMU measure single-axis rotation and acceleration, enabling precise detection of an aircraft's position relative to its initial coordinates.[55] The development serves as a milestone in demonstrating reliability of quantum sensors for navigation, paving the way for advanced navigation systems in aviation.

Schedule Maintenance

Airlines continue to face numerous challenges related to scheduled maintenance and flight disruptions. These disruptions, which include factors such as adverse weather, airport closures, unexpected maintenance, and delays, often trigger a cascade of subsequent delays, [56] referred to as reactionary delays. The factors can lead to a chain reaction causing further delays, termed as Reactionary Delays. According to 2023 data, reactionary delays accounted for 43 percent of total delay minutes in Europe, highlighting the widespread impact of such challenges on airline operations.[57] The Aircraft Recovery Problem (ARP) encompasses the task of restoring disrupted flight schedules, recalculating departure times, revising routes, and addressing potential flight cancellations. A critical challenge within ARP is the need to generate efficient solutions under time constraints while simultaneously minimising operational costs associated with

54 Matt Swayne, "Boeing's Quantum-based Navigation System Takes Flight in Historic Test," *Quantum Insider,* August 9, 2024, https://thequantuminsider.com/2024/08/09/boeings-quantum-based-navigation-system-takes-flight-in-historic-test/.

55 Swayne, "Boeing's Quantum-based Navigation System."

56 Yi Su, Kexin Xie, Hongjian Wang, Zhe Liang and Wanpracha Art Chaovalitwongse, "Airline Disruption Management: A Review of Models and Solution Methods," *Engineering* 7, no.4, (2021): 435 - 447,https://www.sciencedirect.com/science/article/pii/S2095809921000175.

57 EuroControl, "All-Causes Delays to Air Transport in Europe," July 7, 2023, https://www.eurocontrol.int/publication/all-causes-delays-air-transport-europe-quarter-1-2023.

delays and disruptions. The complexity of ARP underscores its importance as a focus area for optimisation in aviation management.[58] Quantum computing has potential in addressing schedule maintenance challenges faced by airlines. An experiment conducted by TAP Air Portugal demonstrated valuable insights in this regard. In the study, the ARP was modelled using Quadratic Unconstrained Binary Optimisation (QUBO), a prominent framework for tackling optimisation challenges with quantum computing. The ARP model was solved using both classical and hybrid solvers to compare relative costs and flight schedules. The findings revealed that applying quantum computing to ARP facilitated faster, more cost-effective, and practical solutions for managing flight schedules and disruptions.[59] Similarly, a team at Q-CTRL investigated the potential of quantum computing to expedite redeployment of airline assets following disruptions, further illustrating its utility in optimising operational efficiency in the aviation sector.[60]

Secure Networks

Flight security carries immense significance for the aviation industry. One of the potential applications of quantum computing in the aviation sector comprises enhancing the digital security of

---

58 J. Vink, B.F. Santos, W.J.C. Verhagen, I. Medeiros, and R. Filho, "Dynamic Aircraft Recovery Problem - An Operational Decision Support Framework," *Computers & Operations Research* 117, (2020): 104892.

59 Andre Mamprin Mori, "Replanning Flight Schedules Using Quantum Computing," (M.Sc. diss., Faculdade De Engenharia Da Universidade Do Porto, Portugal, 2022).

60 Dan O'Shea, "Beyond Scheduling, Quantum Can Deliver in Other Ways for Airlines," *Inside Quantum Technology News*, January 2, 2023, https://www.insidequantumtechnology.com/news-archive/beyond-scheduling-quantum-can-deliver-in-other-ways-for-airlines/.

aviation networks.[61] Existing encryption methods used to secure data within aviation networks require sizable enhancements to address future threats. As advancements in technologies, particularly in cyber domains, continue to evolve, they are accompanied by increased vulnerabilities to sophisticated hacking techniques. In this context, the adoption of quantum computing offers a promising avenue to augment data security, providing robust solutions capable of mitigating emerging cyber threats in the aviation sector.[62] Quantum communication, which relies on quantum principles for secure data transfer, could improve encryption, making cyberattacks more difficult to execute. This technology can safeguard critical aviation systems, flight operations, confidential communications, and passenger data.[63] Acknowledging the strategic value of quantum technologies, the U.S. Air Force Research Laboratory has identified their potential to enhance C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) systems.[64] This recognition highlights the importance of integrating quantum advancements into defence and aviation networks to address the growing complexity of cybersecurity challenges and improve the resilience of critical systems.

Additional Applications

Quantum computing can also be employed for the smooth scheduling of cargo and passenger traffic vis-à-vis aircraft, gates, personnel, and managing the air traffic flow at

61 El Dawton, "How Quantum Computing Is Helping the Aviation Industry."
62 Gaylor, "Quantum Computing in Aviation: Shaping the Future of Aerospace."
63 "The Role of Quantum Computing in Aviation: Advancements and Benefits," *Quantum AI*.
64 El Dawton, "How Quantum Computing Is Helping the Aviation Industry."

arrivals/departures.[65] For instance, Cargo South has developed a software that is able to optimise cargo placement inside an aircraft using quantum algorithms.[66]

The complex dynamics of propulsion systems, aerodynamics, and structural integrity, etc. can be better explained by quantum simulations, paving the way for further improvements in the aviation sector.[67]

As previously discussed, quantum computing has the potential to deliver unparalleled accuracy in measurements. This heightened precision could enable detection of irregularities during flight operations, facilitating timely identification of potential risks, thereby enhancing overall flight safety.[68]

Early adopters of quantum computing in the aviation industry stand to gain a competitive edge through innovation and enhanced operational efficiency. Notably, several airlines have begun exploring quantum computing to optimise various aspects of their operations. Delta Airlines, for instance, became the first airline to enter into a comprehensive agreement with IBM to leverage quantum computing.[69] IBM-Q, a network comprising approximately

---

65 Hamed Mohammad Bagherpoor, Patrick Dreher, Mohannad Ibrahim, Young-Hyun Oh et al., "Exploring Airline Gate-Scheduling Optimization Using Quantum Computers," (paper, ArXiv, 2021), https://arxiv.org/pdf/2111.09472.

66 Jet Man Pay, "How Quantum Computing Software Enhances Air Cargo Industry," https://jetmanpay.com/how-quantum-computing-software-enhances-air-cargo-industry/ [Accessed September 19, 2024].

67 "The Role of Quantum Computing in Aviation: Advancements and Benefits," *Quantum AI*.

68 Ibid.

69 Chris Andrews, "Delta Airlines Taps IBM for Cloud Expertise and Red Hat Hybrid Cloud Platform," *International Business Machines Newsroom*, February 18, 2021, https://newsroom.ibm.com/2021-02-

500 organisations, including companies, research laboratories, academic institutions, and startups, focuses on practical applications of quantum computing across diverse sectors.[70] Through this partnership, Delta aims to enhance both customer and employee experiences by integrating quantum computing into its operations. The agreement grants Delta access to IBM-Q's advanced universal hardware quantum computers for research and commercial use, including the recently launched 53-qubit quantum computer.[71]

Discussion and Analysis

Existing literature indicates that, while still an emerging concept, quantum computing has the potential to profoundly influence various facets of the aviation sector. Its applications point to a future where operational efficiency is enhanced, costs are reduced, and environmentally sustainable practices are prioritised. Furthermore, the integration of quantum technologies could yield considerable economic benefits for airlines by optimising resource allocation and minimising operational disruptions.

Beyond operational improvements, quantum computing may elevate passenger experiences by enhancing service quality and reliability, thereby raising the overall standards of the aviation industry. These advancements also contribute to fortifying the

18-Delta-Air-Lines-Taps-IBM-for-Cloud-Expertise-and-Red-Hat-Hybrid-Cloud-Platform/.

70 Jan Lillelund, "50 Qs with IBM Q," *International Business Machines,* January 14, 2021, https://www.ibm.com/blogs/nordic-msp/50-qs-with-ibm-q/.

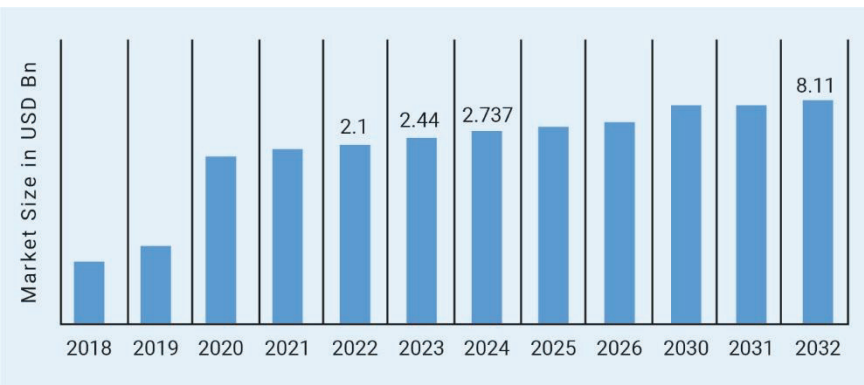
71 International Business Machines, "Delta Partners with IBM to Explore Quantum Computing - An Airline Industry First," January 8, 2020, https://newsroom.ibm.com/2020-01-08-Delta-Partners-with-IBM-to-Explore-Quantum-Computing-an-Airline-Industry-First.

sector's resilience by addressing critical logistical and operational challenges more effectively.

The exploratory applications of quantum computing are expected to drive further research and innovation, fostering advancements not only in aviation but across other industries. This ripple effect underscores the broader implications of quantum computing as a catalyst for breakthroughs and interdisciplinary solutions, reinforcing its importance as a foundational technology for the future.

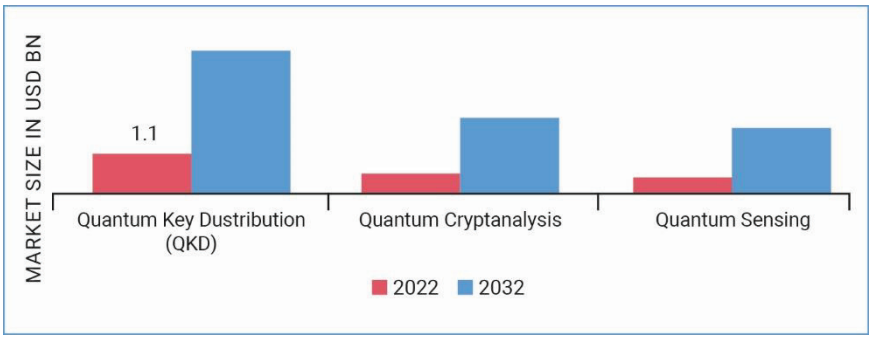
The quantum computing market within the aerospace and defence sectors is projected to grow, rising from USD 2.73 billion in 2024 to USD 8.11 billion by 2032, as shown in Figure II. This projection underscores the increasing adoption of quantum technologies across civil and military aviation domains:

Figure II : Quantum Computing in Aerospace & Defence Market



Source: Market Research Forecast, "Quantum Computing in Aerospace and Defence Market Overview," https://www.marketresearchfuture.com/reports/quantum-computing-aerospace-defense-market-7788 [Accessed September 20, 2024].

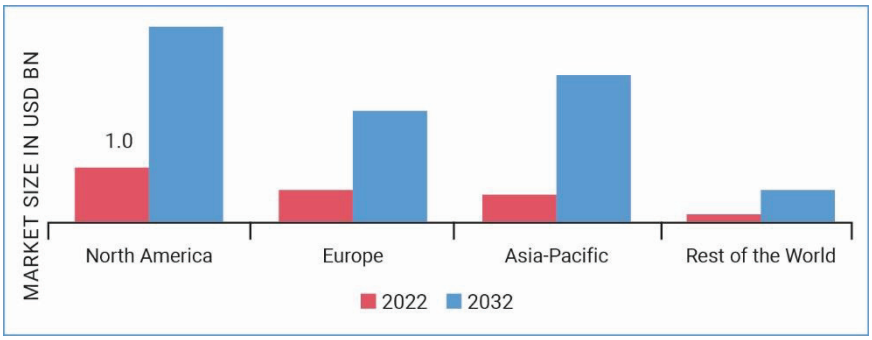
Figure III: Quantum Computing in Aerospace & Defence Market, by Application, 2022 & 2032 (USD Billion)



Source: Market Research Forecast, "Quantum Computing in Aerospace and Defence Market Overview," https://www.marketresearchfuture.com/reports/quantum-computing-aerospace-defense-market-7788 [Accessed September 20, 2024].

Figure III illustrates the expanding market size of quantum computing within the aerospace and defence sectors, highlighting its anticipated growth trajectory. These trends suggest that similar advancements are expected across related areas, including Quantum Key Distribution, Quantum Cryptanalysis, and Quantum Sensing, over the next decade. Such developments indicate a growing integration of quantum technologies in the aviation industry, as these advancements offer several advantages, including enhanced security, improved operational efficiency, and advanced sensing capabilities. The projected growth underscores the potential of quantum computing to address critical challenges and drive innovation within the sector.

Figure IV: Quantum Computing in Aerospace and Defence Market by Region



Source: Market Research Forecast, "Quantum Computing in Aerospace and Defence Market Overview," https://www.marketresearchfuture.com/reports/quantum-computing-aerospace-defense-market-7788 [Accessed September 20, 2024].

Figure IV highlights that North America, Asia-Pacific, and Europe are projected to experience the highest growth in quantum computing market size. These regions are expected to lead advancements in the aerospace and defence sectors through adoption of quantum technologies. The disparity in growth compared to other regions underscores the concentrated focus and investment in quantum computing within these leading markets, positioning them at the forefront of innovation and technological development.

The United States (US) is actively pursuing initiatives to maximise the potential of quantum computing, driving innovation across various sectors, including aerospace. Leading private companies such as Lockheed Martin, Google, IBM, Amazon, Intel, Honeywell, Microsoft, Northrop Grumman, D-Wave, and Rigetti Computing are at the forefront of advancements in quantum technology,

spearheading research and development efforts.[72] Furthermore, the US will be investing approximately USD 968 million for quantum research, doubling the figure of USD 449 as compared to 2019.[73]

China is also making substantial investments in quantum technology, accounting for nearly half of the global public funding in this domain, according to a report by the Centre for Strategic and International Studies (CSIS). Despite current legislative efforts to restrict China's access to quantum technology, the US risks falling behind Beijing in the development and implementation of quantum advancements. [74] China's advancements in quantum technology are evident through initiatives such as the partnership between the China Academy of Aerospace Aerodynamics and Origin Quantum Computing Technology Co. Ltd., aimed at enhancing aircraft design and manufacturing using quantum computing,[75] as well development of quantum radars for its aircraft.[76]

---

72 Dustin Carmack, *Beating China in the Race for Quantum Supremacy*, report (Washington, D.C.: Heritage Foundation, 2023), 6, https://www.heritage.org/sites/default/files/2023-04/SR268.pdf.

73 John Kelvey, "4 Reasons to Root for Quantum Computing," *Aerospace America*, August 2024, https://aerospaceamerica.aiaa.org/features/4-reasons-to-root-for-quantum-computing/.

74 William A Reinsch, *Optimizing Export Controls for Critical and Emerging Technologies*, report (Washington, D.C.: Centre for Strategic and International Studies), 3.

75 "Aerospace Sector Uses Quantum Technology to Beat Bottlenecks," *China Services Info*, October 9, 2023, https://govt.chinadaily.com.cn/s/202310/09/WS653390c9498ed2d7b7e9e1d2/aerospace-sector-uses-quantum-technology-to-beat-bottlenecks.html.

76 Brian Hart, Bonny Lin, Samantha Lu, Hannah Price et al., "Is China a Leader in Quantum Technologies," *China Power*, August 14, 2023, https://chinapower.csis.org/china-quantum-technology/.

Germany is also actively fostering industry-academia collaboration to leverage quantum computing for enhancing airport operations. A notable example is the partnership between the University of Hamburg and Lufthansa Industry Solutions, aimed at optimising various aspects of airport management.[77]

However, it is pertinent to mention that there are number of challenges associated with the integration of quantum computing in the aviation sector.

One of the key challenges in the adoption of quantum technologies is the volatile nature of qubits, which requires further exploration to achieve practical reliability. Additionally, quantum technologies are at varying Technology Readiness Levels (TRL), introducing further complexity in their development and deployment.[78] The differing time horizons and technological variations add to these challenges, complicating the realisation of their potential applications. For example, a quantum gravimeter for underground scanning may initially emerge as a static sensor mounted on a truck with limited resolution. Subsequent generations could feature improved sensitivity and resolution, enabling broader applications, such as deployment on aircraft or drones. However, there is also the possibility that despite advancements, the sensitivity and resolution may not reach the levels required for such use. Over time, technological limitations could hinder the integration of quantum systems into aviation platforms like aircraft and drones, delaying their widespread deployment.

Many potential applications of quantum computing remain theoretical and may not materialise as anticipated. The practical deployment of quantum technologies depends on several critical

---

77 "Quantum Computers to Optimize Airport Operations Worldwide," *Quantum Zeitgeis,* July 5, 2024, https://quantumzeitgeist.com/quantum-computers-to-optimize-airport-operations-worldwide/.

78 Krelina, "Quantum Technology for Military Applications," 22.

factors, including size, portability, speed, robustness, cost, and SWaP (Size, Weight, and Power) considerations. However, the current stage of quantum computing, known as the Noisy Intermediate Scale Quantum (NISQ) era, presents major challenges.[79] Susceptibility to errors and noise within quantum systems increases the risk of inaccuracies, complicating the transition of theoretical applications to practical use.

Expert opinions on the future of these challenges, often referred to as the 'Quantum Winter,' are divided.[80] While some argue that the engineering hurdles associated with quantum technologies could persist for several decades, others remain optimistic, anticipating that these issues may be resolved within a few years, paving the way for broader adoption and innovation. However, there is a consensus that the risk of error is a major challenge at the moment.

The integration of quantum technology with classical computing systems is also an issue. Compatibility issues may arise, potentially requiring the development of new infrastructure and frameworks to address these obstacles effectively.

Plus, the high cost associated with quantum technology further complicates its widespread adoption, underscoring the need for cost-effective solutions and innovations to enhance accessibility.[81] It is likely that numerous airlines might not be able to employ the technology due to economic constraints. The practicality and cost

---

79 James Dargan, "What Is NISQ Quantum Computing?" *Quantum Insider*, March 13, 2023, https://thequantuminsider.com/2023/03/13/what-is-nisq-quantum-computing/.

80 Ibid.

81 Beth Stackpole, "Quantum Computing: What Leaders Need to Know Now," MIT Management Sloan School, January 11, 2024.

of the technology, will influence its employment across different sectors.[82]

The aviation industry is among the most heavily regulated sectors, and the introduction of new technologies, such as quantum computing, is likely to necessitate development of new regulatory frameworks. Establishing these frameworks will be a complex undertaking, requiring collaboration among industry stakeholders, regulatory bodies, and policymakers to ensure compliance, safety, and standardisation while fostering innovation.

Chris Coleman, a condensed matter physicist, describes the current Noisy Intermediate Scale Quantum (NISQ) era as akin to the early stages of Artificial Intelligence. He notes, 'Although still needing to overcome limitations, in many instances we're seeing the foundation being laid for bigger things to come, and there is no doubt that the field is making steady progress. This can be seen across the ecosystem.'[83] Realising the potential benefits of quantum computing will require considerable time, investment in research and development, infrastructure expansion, and financial resources.

Recommendations

Given the potential role of quantum computing in the aviation sector, it is imperative to draft certain recommendations in general and relevant / specific to Pakistan.

Pakistan's aviation industry is yet to take off, compounded by the country's limited advancements in quantum computing compared to other nations. This disparity can be attributed to resource constraints and the absence of a directed focus on developing

82 Krelina, "Quantum Technology for Military Applications," 22.
83 Dargan, "What Is NISQ Quantum Computing?"

quantum technologies.[84] The following section outlines policy recommendations aimed at addressing these challenges and fostering the integration of quantum computing in Pakistan's aviation sector for future advancements.

Quantum Ecosystem

Developing a robust national quantum ecosystem that integrates government, industry, academia, and the private sector is essential for strategically determining the scope, timing, and scale of investments in quantum computing. While the immediate applications of quantum computing may not be directly applicable to Pakistan's aviation sector, its broader adoption across other industries could create pathways for subsequent integration into aviation.

Establishing dedicated quantum research facilities focused exclusively on aviation would be a critical step in this direction. Furthermore, the creation of innovation hubs centred on quantum computing, bringing together startups, private sector stakeholders, and the research community, could foster collaboration and drive the development of tailored solutions for challenges in the aviation industry. Such initiatives would position Pakistan to gradually bridge the gap in quantum advancements while aligning with global trends.

Research & Development

There is a critical need to promote sector-specific research and development in quantum computing, particularly in areas relevant to the aviation sector such as aircraft design, traffic management, flight route optimisation, navigation, and secure networks. In

---

84 Abdul Hannan, "The Future of Quantum Computing in Pakistan," *Medium,* December 28, 2021, https://kelpersoft.medium.com/the-future-of-quantum-computing-in-pakistan-4e8c39ff4fed.

Pakistan's context, universities must be incentivised to undertake projects and research focused on quantum computing. Establishing collaborations with international universities leading in this technology could serve as a strategic step, fostering knowledge transfer and capacity building through joint research initiatives and student exchange programmes on quantum computing platforms.

To facilitate the practical application of quantum technology in the aviation sector, consistent and extensive collaboration between the aviation industry and academic, governmental, and private sectors is imperative. Pilot testing of quantum solutions should also be prioritised to assess their feasibility and scalability within relevant institutions. Quantum research institutes should focus on creating frameworks for the commercialisation of quantum technologies, aligning them with the specific demands of the aviation sector.

Government Support

Given the expansive scope of the aviation sector, it is essential for the government to actively support the adoption of quantum computing through funding, incentives, and the establishment of regulatory frameworks. In Pakistan, targetted grants and funding should be allocated to projects and initiatives that advance the integration of quantum computing in the aviation industry. This could include providing tax breaks or other incentives to airlines that adopt the technology, encouraging its widespread use.

Equally important is the development of regulatory frameworks that establish clear standards for the application of quantum computing in aviation, ensuring safety, compliance, and operational efficiency. These efforts should also prioritise improving the performance of Pakistan International Airlines (PIA), the state-owned carrier, by leveraging quantum computing to enhance flight operations, reduce inefficiencies, and position it competitively within the global aviation landscape.

Collaborative Model

Expensive technologies in their nascent stages often require collaborative models to drive advancements. One viable approach involves establishing one or two major facilities where multiple entities pool resources and capital to procure the technology and share its benefits.

In the context of Pakistan, a similar model could be adopted, with key stakeholders such as the flag carrier PIA, relevant universities, and private sector entities collaborating to develop a national quantum computing facility. This facility, potentially managed by the government, could operate on a time-sharing basis, ensuring equitable access for all stakeholders.

Initial Employment

In the initial employment, the aviation industry should prioritise certain areas that could benefit from quantum computing in Pakistan. These may include using quantum computing for accurate weather forecasting which is likely to mitigate issues associated with turbulence. Likewise, traffic management in aerodrome control comprises an important aspect, which is also prone to human error. Hence, a centralised system using quantum computing could be used for aerodrome control. The operating airlines could also use predictive maintenance for efficient operations.

Increased Automation

While employing quantum computing offers numerous advantages across different areas in the aviation sector, prior actions could enhance the effectiveness and integration of technology. With respect to Pakistan, there is a need to have directed focus on automation. Enhanced automation can enable better integration of quantum technology. This could provide added benefits as well. For instance, combination of enhanced automation, facial recognition

and controlled access to national databases can improve airport security.

Engaging Overseas Quantum Experts

Quantum computing is a highly intricate and specialised field that requires subject-matter experts for its effective implementation. In the context of Pakistan, engaging with the expatriate community settled abroad presents a valuable opportunity to access technical expertise in this domain. Offering targetted incentives and opportunities to attract these experts could increase the country's capacity to advance quantum technologies. Leveraging the diaspora for such initiatives offers a distinct advantage, as these individuals bring with them a wealth of knowledge and expertise acquired from leading global institutions and industries. This approach could accelerate timelines for various projects and initiatives, bridging the expertise gap and fostering rapid progress in quantum computing applications across key sectors, including aviation.

Improving Human Capital

Adoption of quantum computing in the aviation sector necessitates development of a skilled workforce equipped with technical expertise in this advanced technology. Simultaneously, it is crucial to familiarise the existing workforce in the aviation industry with the fundamentals and applications of quantum computing to facilitate seamless integration. In the context of Pakistan, targetted training programmes must be designed to bridge the knowledge gap. These programmes should focus on equipping engineers and technical professionals in the aviation industry with the requisite knowledge and skills to effectively utilise quantum computing. Such initiatives would play a pivotal role in ensuring the successful adoption of the technology and fostering its long-term integration within the sector.

Curriculum Development

While cross-cutting technologies are evolving with every passing day, there is a need to update and revamp curriculum in higher educational institutes accordingly. With respect to Pakistan, there is a need to chalk out new courses for universities whose students would later be joining relevant organisations. Subjects related to aviation and quantum computing need to be part of the curriculum. These may include Quantum Computing in Aviation, Quantum Algorithms, Classical and Hybrid Systems, and Quantum Optimisation etc.

Developing Quantum-Safe Infrastructure

With the anticipated growth of quantum computing across various sectors, it is imperative to develop comprehensive countermeasures to address emerging security challenges. Specifically, encryption methods must be advanced to safeguard aviation data against quantum-enabled threats, which could compromise critical systems and operations. In this regard, a lot of investment is required in complementary technologies such as cybersecurity and AI. Cybersecurity innovations will be essential to mitigate vulnerabilities introduced by quantum computing, while AI can enhance threat detection and response mechanisms, creating a multi-layered defense system. Proactively addressing these challenges will be key to ensuring the resilience and integrity of aviation systems in a quantum-enabled future.

Conclusion

The findings of this paper indicate that quantum computing has the potential to usher in a new era of innovation within the aviation industry. Its unparalleled capabilities in handling complexity, speed, and multiplicity are poised to transform global aviation, driving advancements across various operational and strategic dimensions. Although the technology is still in nascent stages, multiple applications of the technology are already on the horizon.

These include but are not limited to Aircraft Design, Flight Trajectory Optimisation, Navigation, Schedule Maintenance and Secure Networks.

While quantum computing holds immense promise for the aviation sector, its adoption is not without challenges. The technology's nascent and uncertain nature poses barriers that may delay the realisation of its full potential. Time and continued advancements will play a crucial role in determining its practical applications within the aviation industry. For Pakistan, it is imperative to take proactive measures to harness the potential of this technology and align with global advancements. This includes establishing a robust quantum ecosystem, fostering R&D, enhancing government support, and engaging Pakistani experts from the diaspora. Furthermore, investing in workforce development, updating educational curricula to include quantum computing, and building quantum-safe infrastructure are essential steps toward maximising the benefits of quantum technology in the aviation industry.

Shaza Arif has studied Defence and Diplomatic Studies from the Fatima Jinnah Women University, Pakistan. Her areas of interest are Space, Artificial Intelligence, Military Modernisation and Strategy. She has been extensively published in international and national newspapers on issues related to politics and modern warfare. She can be contacted at: shazaarif14@gmail.com

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 68-96

Technological Sovereignty of Great Powers: A Case Study of China

Shah Muhammad

Abstract

The traditional focus on geopolitics is shifting toward a geoeconomic paradigm, where emerging technologies are increasingly viewed as central to the dynamics of great power politics. States are pursuing technological sovereignty as a policy choice to achieve self-reliance and sovereign control over critical technologies, aiming to maximise their autonomy and influence in a competitive international landscape. This paper examines China's approach to technological sovereignty by analysing key government initiatives, like 'Science & Technology in China: A Roadmap to 2050', 'Digital Silk Road', and 'Made in China 2025' and the role of Chinese big tech corporations. Due consideration has also been accorded to the multifaceted impacts of China's technological sovereignty on global power politics, with special focus on the intensifying Sino-US tech war. Lastly, it evaluates the rapid transitions that may unfold on a global scale as a result of these developments.

Keywords: Technological Sovereignty, Fourth Industrial Revolution, Great Power Politics, Sino-US Tech War, Global Politics.

Introduction

The global power struggle is increasingly characterised by a shift away from the traditional pre-eminence of geopolitical and military modes of influence, moving toward economic and technological domains. Core technologies have emerged as a pivotal source of power, prompting states to compete for self-sufficiency and dominance in these areas. This pursuit of technological sovereignty entails achieving self-reliance within the technological sphere, enabling states to assert autonomy and reduce dependencies on other nations. Such dependencies can erode state sovereignty, motivating countries to develop and follow an indigenously crafted roadmap to shape their economic and technological futures. Advent of the Fourth Industrial Revolution (4IR) has amplified the critical intersection of power and technology. Emerging technologies such as Artificial Intelligence (AI), cloud computing, the Internet of Things (IoT), and robotics have become central to this landscape, further reflecting the strategic importance of technological innovation and independence. This dynamic underscores the evolving nature of global influence in an era increasingly driven by technological advancement, as well as reinforces the enduring notion that the quest for power remains constant, while the modes of acquiring and wielding it continue to adapt and transform.

In the contemporary era, global power dynamics are increasingly shaped by the Sino-US rivalry, which has become the defining feature of international relations. Given the critical and strategic significance of technology in this landscape, this competition is aptly termed the Sino-US tech war. At its core, this struggle is about dominance in cutting-edge technological domains, including AI, quantum computing, semiconductor development, and telecommunications, which are expected to define the global

balance of power in the coming decades.[1] The US has resorted to a multipronged approach to thwart China's adoption and commercialisation of emerging technologies while the latter is undertaking initiatives like 'Science and Technology Roadmap 2050', 'Made in China 2025' and 'Digital Silk Road' to make greater leaps in the race for technological supremacy. Against this backdrop, China is materialising the notion of technological sovereignty to maximise its autonomy and influence at a global scale.

This evolving trend toward technological sovereignty is analysed in this paper through the theoretical framework of geoeconomics. This paradigm suggests that the traditional focus on military and geopolitical strategies is increasingly being supplanted by non-military and economic modes of power among states. In this era of geoeconomics, competition and conflict are often waged through non-military instruments, with technology emerging as the most potent tool in this arsenal.[2] The Sino-US rivalry exemplifies this shift, where technology has become the dominant non-military means in the broader struggle for global influence. From AI and semiconductor supremacy to control over data and digital infrastructure, technology is central to the strategies employed by both states in their pursuit of power. In this context, geoeconomic statecraft offers novel perspectives for understanding international relations and security dynamics, challenging the dominance of traditional theoretical frameworks such as realism and liberalism.

By looking at the economic and technological dimensions of power, geoeconomics provides a more nuanced lens through which to analyse the interplay of states in an increasingly interconnected

---

1 Anu Bradford, "The Battle for Technological Supremacy: The US–China Tech War," in *Digital Empires: The Global Battle to Regulate Technology*, ed. Anu Bradford (London: Oxford University Press, 2023).

2 Robert D. Blackwill and Jennifer M. Harris, *War by Other Means: Geoeconomics and Statecraft* (Harvard University Press, 2017).

and technology-driven world. This approach highlights how economic interdependence and technological innovation are reshaping the global order, necessitating a rethinking of conventional strategies and theories in the fields of international relations and security studies.

This paper begins with the elucidation of technological sovereignty and geoeconomics theory and goes on to briefly evaluate the role of technology in great power politics across all epochs of industrial revolutions. After discussing China's ascension as a great power, the paper casts a comprehensive analytical glance on Chinese technological sovereignty with a special focus 'Science & Technology in China: A Roadmap to 2050', 'Digital Silk Road', and 'Made in China 2025', alongwith Chinese tech corporations. Subsequently, the paper covers the impacts of China's technological sovereignty on great power politics with a special focus on the contours of Sino-US technological rivalry. The last section anticipates the future scenario of China's technological sovereignty and ensuing global power dynamics.

Technological Sovereignty Defined

The Westphalian system marks a pivotal epoch in the conceptual evolution of sovereignty. Traditionally, this term has been associated with the state, highlighting its autonomy in international engagements and advocating for non-intervention by other states. However, technological advancements have introduced the need to integrate technology into the broader framework of sovereignty. 'Technological sovereignty' can be defined as a state's capacity to exercise autonomy in developing and providing critical technologies while minimising structural dependencies on other nations. It reflects a growing recognition of technology's strategic role in shaping the independence and resilience of states in the

modern era,[3] enabling them to shape and influence their economic and political standing on an international scale.[4] Viewed through a dual lens, it serves both as a geoeconomic approach and a deliberate policy choice adopted by states to maximise their autonomy and extend their influence.

Theory of Geoeconomics

The economic dimensions of statecraft are increasingly gaining prominence in both the study and practice of international relations. Edward Luttwak, in his seminal article 'From Geopolitics to Geoeconomics', laid the foundation for the theory of geoeconomics.[5] This theory posits that economic tools and strategies are being employed in ways traditionally associated with military and geopolitical instruments, signaling a shift in how states exert influence and pursue their national interests.

Geoeconomics also highlights the use of economic statecraft, such as trade policies, investment flows, and technological dominance, as a means of achieving strategic objectives. By framing economic interactions as arenas of competition rather than purely cooperative engagements, Luttwak's work provides a framework to

---

3 Tiana Ramahandry et al., *Key Enabling Technologies for Europe's Technological Sovereignty* (Brussels: European Parliamentary Research Service, December 2021), 1, https://www.europarl.europa.eu/RegData/etudes/STUD/2021/697184/EPRS_STU(2021)697184_EN.pdf; Jakob Edler et al., *Technology Sovereignty: From Demand to Concept* (Karlsruhe: Fraunhofer Institute for Systems and Innovation Research, July 2020), 2, https://www.econstor.eu/bitstream/10419/233462/1/policy-brief-02-2020.pdf.

4 Francesco Crespi et al., "European Technological Sovereignty: An Emerging Framework for Policy Strategy," *Intereconomics* 56, no. 6 (2021): 6, https://doi.org/10.1007/s10272-021-1013-6.

5 Edward N. Luttwak, "From Geopolitics to Geo-Economics: Logic of Conflict, Grammar of Commerce," *National Interest*, no. 20 (1990).

understand how economic power can be wielded in the service of political and strategic goals. This approach has become particularly relevant in the context of global power rivalries, where economic competition increasingly supplants traditional military confrontations.[6] Besides the attainment of security interests through economic means, states strive for an economic edge over adversaries in the quest for dominance of international markets.[7]

Innovative technologies play a central role in geoeconomics as they underpin strategic industries, creating asymmetrical dependencies among states.[8] Hence, the choice of this theoretical framework stems from its interdisciplinary nature, offering a holistic perspective on technological sovereignty by integrating elements of economic statecraft, geopolitics, and global power dynamics. Unlike the mono-causal approaches of dominant theories such as realism, liberalism, and Marxism, geoeconomics provides a more nuanced and comprehensive lens.[9] Therefore, analysing evolution of great power politics through this framework presents a distinctive approach.

Great Power Politics and Industrial Revolutions

The technological advancements and economic means across historical epochs have noticeably influenced and substantially shaped the geopolitical tussles and territorial outreach of great powers. Centred in Britain in the mid-18th Century, the First Industrial Revolution mechanised production through steam-power technology and heralded the industrial economy. Britain resorted to

6 Glenn Diesen, *Great Power Politics in the Fourth Industrial Revolution: The Geoeconomics of Technological Sovereignty* (London: Bloomsbury Publishing, 2022), 44-45.
7 Luttwak, "From Geopolitics to Geo-Economics," 21.
8 Diesen, *Great Power Politics in the Fourth Industrial Revolution*, 8.
9 Gyula Csurgai, "The Increasing Importance of Geoeconomics in Power Rivalries in the Twenty-First Century," *Geopolitics* 23, no. 1 (2018): 2, https://doi.org/10.1080/14650045.2017.1359547.

state intervention and employed protectionist policies to protect its nascent industrial base in those times.[10] Britain's dominance in international markets was driven more by its productive manufacturing base than by the strength of the Royal Navy, enabling it to outcompete colonial powers such as France and Spain. At the heart of this manufacturing base was steam power technology, which played a crucial role in Britain's rise to global leadership.[11] Contrary to the liberal view of free trade as a mechanism for mutual benefit, it often serves as a geoeconomic strategy employed by dominant powers to maintain their comparative advantage within the international political economy. This perspective highlights the strategic, rather than purely cooperative, nature of free trade in global power dynamics.

The Second Industrial Revolution, helmed primarily by the United States (US) and Germany in the mid-19th Century, was symbolised by groundbreaking inventions such as electricity, telegraph and combustion engine. The telegraph, a pivotal telecommunications technology, was effectively used by France and Britain as a geopolitical tool to expand colonial influence[12] and maintain the Mediterranean balance of power. It also played a strategic role in World War I, where both Allied and Central powers used it for wartime communication. In 1914, Britain severed Germany's global cable network by cutting its five Atlantic telegraph cables, prompting Germany to retaliate through U-boat raids targetting Allied cables.[13] Observing these developments, the US recognised

10 William J. Ashworth, *The Industrial Revolution: The State, Knowledge and Global Trade* (London: Bloomsbury Publishing, 2017).

11 John R. Ward, "The Industrial Revolution and British Imperialism, 1750-1850," in *The Rise and Fall of Modern Empires, Volume III,* ed. Sarah Stockwell (Routledge, 2017), 60.

12 Daniel R. Headrick, *The Invisible Weapon: Telecommunications and International Politics, 1851-1945* (Oxford: Oxford University Press, 1991), 15.

13 Jonathan Reed Winkler, "Information Warfare in World War I," *The Journal of Military History* 73, no. 3 (2009): 849.

its vulnerability to similar attacks and began constructing its own cable network, a move that contributed to its emergence as a global power.[14] World War II, in many ways, represented a continuation of World War I, but with more advanced technologies.[15]

The Third Industrial Revolution, also known as the Digital Revolution, transformed industries with innovations like microprocessors, semiconductors, and the Internet. During this period, the US provided government support to its multinational corporations to boost innovation and sustain global market dominance. This approach contradicted the *laissez-faire*, market-oriented principles of the Washington Consensus that the US promoted internationally.[16]

As Cold War-era geopolitics receded, geoeconomics gained prominence, with the US adopting an antagonistic economic stance even toward traditional allies. A notable example occurred in 1987 when Japan's semiconductor market share surged to 75%, while the US share dropped to 20%. Accusing Japan of unfair trade practices, the US responded by imposing 100% tariffs on Japanese imports.[17] The increasing penetration of Japanese and American firms in European markets was viewed as 'technological colonization' as they only produced merely low-skilled jobs and diminished Europe's capability to develop spin-offs.[18] Further

14 Jonathan R. Winkler, *Nexus: Strategic Communications and American Security in World War I* (Cambridge: Harvard University Press, 2008), 12.

15 Headrick, *The Invisible Weapon*.

16 Fred Block, "Swimming against the Current: The Rise of a Hidden Developmental State in the United States," *Politics & Society* 36, no. 2 (2008): 181–182.

17 Douglas A. Irwin, "The US-Japan Semiconductor Trade Conflict," in *The Political Economy of Trade Protection*, ed. Anne O. Krueger (Chicago: University of Chicago Press, 1996), 5–14.

18 Dietmar Keller, "Should Europe Provide Selective Assistance for Key Industries?" *Intereconomics* 27, no. 3 (1992): 112.

advancements in the Third Industrial Revolution paved way for the next epoch in the industrial evolution of the world.

Great Power Politics and Fourth Industrial Revolution

The term Fourth Industrial Revolution (4IR), coined by Klaus Schwab, represents a distinct evolution from the Third Industrial Revolution in terms of its velocity, scope, and systemic impact.[19] It is increasingly defined by emerging technologies such as AI, IoT, nanotechnology, robotics, 3D printing, biotechnology, and blockchain. This era has intensified the geoeconomic strategies of great powers, as they compete for technological leadership to reduce dependencies, dominate markets, and ultimately secure global influence.[20] UNCTAD's 'Technology and Innovation Report 2023' estimates that the market size of Industry 4.0 technologies will reach USD 9.5 trillion by 2030, including AI (USD 1582 billion), IoT (USD 4422 billion), nanotechnology (USD 34 billion), robotics (USD 150 billion), 3-D printing (USD 51 billion), biotechnology (USD 36 billion) and blockchain (USD 88 billion).[21]

The transformative impact of 4IR has not only reshaped industries but also heightened concerns about digital security and sovereignty. A decade after the Snowden Revelations, these disclosures continue to underscore the importance of protecting

19 Klaus Schwab, "The Fourth Industrial Revolution: What It Means and How to Respond," *World Economic Forum*, January 14, 2016, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

20 Rush Doshi, "The United States, China, and the Contest for the Fourth Industrial Revolution," *Brookings*, July 31, 2020, https://www.brookings.edu/articles/the-united-states-china-and-the-contest-for-the-fourth-industrial-revolution/.

21 UNCTAD, *Technology and Innovation Report 2023*, report (New York: UN Conference on Trade and Development, 2023), https://unctad.org/system/files/official-document/tir2023_en.pdf.

states from digital espionage and securing domestic control over critical infrastructure and digital ecosystem.

This growing awareness has extended beyond academic discourse into policy-making circles, reinforcing the connection between technological sovereignty, economic independence, and strategic autonomy. In 2019, Ursula von der Leyen, President of the European Commission, stated, 'We must have mastery and ownership of key technologies in Europe.'[22] Similarly, Thierry Breton, the EU's Internal Market Commissioner, has stressed that Europe's digital and green transitions are contingent upon achieving technological sovereignty, urging action to close digital gaps.'[23]

Emerging technologies have thus become a critical dimension of geopolitics, with immense potential to reinforce states' economic and strategic influence. Russian President Vladimir Putin highlighted the geopolitical stakes of technology by declaring that leadership in AI could determine global dominance.[24] He advocated for Russia's technological sovereignty, calling it essential for the country's security, defence, and socioeconomic stability. In line with this vision, Russia has implemented its 'sovereign internet', granting it greater control over its digital space. Against this backdrop, the rise of China demands close examination. Its technological advancements and strategic ambitions are central to understanding the shifting dynamics of global power in the 21st Century.

China's Rise to Global Power Status

China's historical trajectory demonstrates the interplay between economic strength and global influence, a core tenet of the

22 Crespi et al., "European Technological Sovereignty," 6.
23 Ibid., 6.
24 President of Russia, "Meeting on the Development of Artificial Intelligence Technologies," May 30, 2019, http://en.kremlin.ru/events/president/news/60630.

geoeconomic framework. Once a leading civilisation, China's progress peaked during the Qing Dynasty but declined sharply during the 'Century of Humiliation' (1840–1949), initiated by the Opium Wars and European colonial interventions.

In the 1970s, Deng Xiaoping's market-oriented reforms shifted China away from socialist central planning, integrating the nation into global value chains and attracting international investments and technology. These structural changes propelled China's economy to grow at an average rate of over 9%, as per the World Bank, lifting approximately 800 million people out of poverty[25] - a transformation that has drawn global attention to the 'Chinese model' as an alternative to the Washington Consensus.

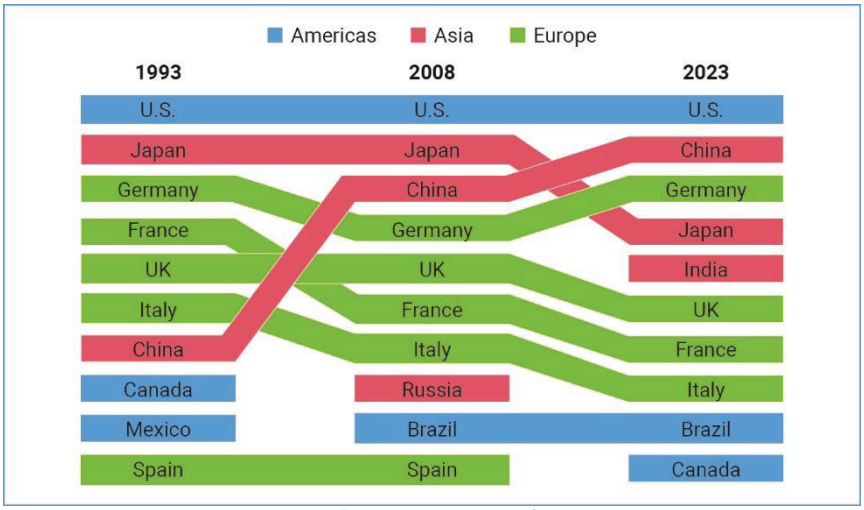
With a GDP of USD 18.53 trillion, China is the world's second-largest economy, following the US. Sustained economic growth has strengthened China's financial and technological capabilities, enabling military modernisation, making it the third-largest military power after the US and Russia.[26] As illustrated in Figure 1, China's exponential economic growth from 1993 to 2023 underscores the geoeconomic principle that enduring economic strength forms the foundation of military modernisation and global power. This analytical perspective frames China's rise as a quintessential example of economic leverage shaping international power dynamics.

---

25 World Bank, "The World Bank in China," April 2024, https://www.worldbank.org/en/country/china/overview.

26 Global Firepower, "2024 Military Strength Ranking," May 11, 2024, https://www.globalfirepower.com/countries-listing.php.

Figure 1: Biggest Economies Over Time (1993-2023)

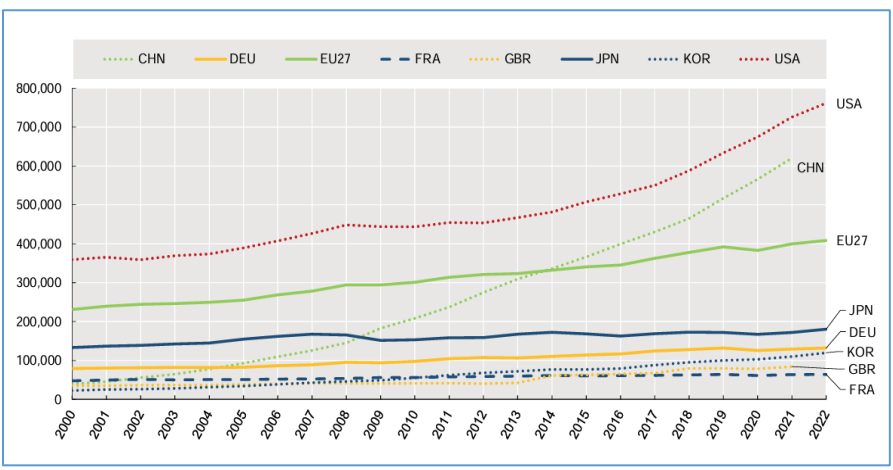


Source: Katharina Buchholz, "Continental Shift: The Biggest Economies Over Time," Statista, February 21, 2024, https://www.statista.com/chart/31788/the-biggest-economies-over-time-nominal.

Technological adoption has been a cornerstone of China's rise and its sustained ascent to global power status. Following a period of economic stagnation and limited technological progress in the decades after independence, China leveraged Deng Xiaoping's reforms to integrate with the global economy and implement strategic initiatives aimed at advancing its technological capabilities. Key measures included joint Research and Development (R&D) programmes with foreign countries, sending students abroad to acquire cutting-edge knowledge, and mobilising diaspora networks in the 1980s. These efforts were further supported by the creation of Overseas Chinese Scholar (OCS) programmes in the 1990s and the establishment of National Technology Transfer Centres in the early 2000s. These well-directed steps laid the foundation for China's technological transformation, which has become a critical driver of its economic

and geopolitical ascent.[27] In addition, the Chinese innovation and start-up ecosystem was steered through state-funded and state-supported initiatives. China has surpassed Japan and European countries in R&D expenditure, now ranking second globally, behind only the United States. Figure 2 illustrates the GDP expenditure on R&D by selected economies from 2000 to 2022, with values displayed in USD million, adjusted for inflation. Unlike many Western countries, China focuses heavily on directed R&D, aligning innovation efforts closely with the commercial needs of its industries. This approach enhances the productivity of R&D investments, driving both innovation and wealth generation.[28]

Figure 2: GDP Expenditure on R&D (2000-22)



Source: OECD, *OECD Main Science and Technology Indicators*, report (Organisation for Economic Co-operation and Development, March 2024), https://www.oecd.org/sti/msti2024march.pdf.

27 William C. Hannas and Didi K. Tatlow, *China's Quest for Foreign Technology: Beyond Espionage* (Routledge, 2020), 5.

28 Jospeh P. Lane, *The ABC'S of Science, Technology & Innovation (STI) Policy: Spelling Out Problems, Consequences and Viable Solutions* (Springer, 2023), 191.

Impetus behind China's Technological Sovereignty

In the strategically important context of 4IR, great power politics is being increasingly shaped by the contest for technological supremacy. The US wary of China's growing technological capabilities, has implemented a series of punitive measures reminiscent of its earlier actions against Japan. This technological contest gained momentum with Donald Trump's trade war in 2018 and escalated with measures such as the crackdown on Huawei in 2019, the continuation of trade restrictions under Joe Biden in 2021, US restrictions on China's chip industry in 2022, expansion of the Entity List in 2023, and the threats to ban TikTok in 2024.[29] Against this backdrop of a competitive and uncertain international landscape, China's leadership has increasingly recognised that technological sovereignty is crucial for securing its economic growth and maintaining its strategic autonomy.

Hence, technological sovereignty underscores China's pursuit of indigenous high-tech capabilities and global leadership in advanced manufacturing. President Xi Jinping has long championed this agenda, advocating for cyber sovereignty and warning against cyber hegemony as early as 2015.[30] In 2018, he highlighted the transformative potential of emerging technologies for global development, urging China to seize opportunities for leapfrog progress.[31] By 2023, Xi reinforced the need for self-reliance and strength in science and technology to augment China's competitiveness in military and economic domains against the

29 "US-China Relations in the Biden-Era: A Timeline," *China Briefing*, May 14, 2024, https://www.china-briefing.com/news/us-china-relations-in-the-biden-era-a-timeline/.

30 "China Internet: Xi Jinping Calls for 'Cyber Sovereignty,'" *BBC News*, December 16, 2015, https://www.bbc.com/news/world-asia-china-35109453.

31 Xi Jinping, "Xi Jinping: Follow the Trend of the Times and Achieve Common Development," *Communist Party of China*, July 25, 2018, http://cpc.people.com.cn/n1/2018/0726/c64094-30170246.html.

West.[32] Thus, the Chinese leadership has openly stated its goals for technological sovereignty because the means of pursuing a zero-sum game amongst great powers are increasingly being defined by technologies.

The next section evaluates the initiatives China has undertaken to advance its technological sovereignty such as 'Science & Technology in China: A Roadmap to 2050', the 'Digital Silk Road', and 'Made in China 2025', alongside the role of leading Chinese big tech firms, including Baidu, Alibaba, Tencent, and Huawei. These companies are at the forefront of major global technological breakthroughs, acting as pivotal agents in driving innovation and solidifying China's position in the competitive landscape of 4IR.

Science & Technology in China: A Roadmap to 2050

China's push toward high-tech indigenisation has been guided by a strategic vision outlined in the 'Science & Technology in China: A Roadmap to 2050',[33] a comprehensive report developed by the Chinese Academy of Sciences, a state-backed science and technology think tank. The report marked a paradigm shift by underscoring directed R&D to align scientific innovation with industry commercialisation goals. It acknowledged the transformative role of technology in past industrial revolutions and underscored the urgency for China to move away from traditional growth models toward innovative and sustainable production methods.[34] Anticipating 4IR, the report declared that 'the world is at

---

32 Meaghan Tobin, Christian Shepherd, and Lily Kuo, "China's Xi Promises to Build 'Great Wall of Steel' in Rivalry with West," *Washington Post*, March 13, 2023, https://www.washingtonpost.com/world/2023/03/13/xi-jinping-china-tech-self-reliance/.

33 *Science & Technology in China: A Roadmap to 2050*, report (Chinese Academy of Sciences, 2010), https://bdp.cas.cn/zlqbygg/202307/t20230705_4924999.html.

34 Ibid., 7.

the eve of a new S&T Revolution,' urging the government to prioritise 'transition from imitation to innovation.'[35] The report is reflective of China's official embrace of the innovation-driven economy which lies at the core of technological sovereignty.

The 2050 Roadmap calls for building eight basic and strategic systems for socioeconomic development including a green system of advanced materials and intelligent manufacturing as well as a system of ubiquitous information networking.[36] Under the ambit of these systems, the Roadmap lays out 22 S&T initiatives that it deems of strategic importance to China's modernisation. These are characterised by initiatives pertaining to international competitiveness, national security, sustainability and cutting-edge research.[37] The 2050 Roadmap envisions these modernisations tailored with Chinese characteristics, aligning with the nation's political structure and cultural values.

Digital Silk Road

Announced in 2015, China's 'Digital Silk Road' (DSR) is an integral part of its overall Belt and Road Initiative (BRI). Through DSR, China aims to enhance its digital infrastructure, build partnerships and offer assistance to countries in the areas of telecommunication networks, cloud computing, AI, surveillance technology, e-commerce and smart cities.[38] In contemporary times, power dynamics and geopolitical tug of war have extended to the digital domain where telecommunication networks and the Internet have become vulnerable to security risks. DSR should, hence, be viewed within the broader context of its pursuit of technological sovereignty and greater autonomy over its digital ecosystem. It represents a strategic initiative aimed at strengthening China's

35 Ibid., 116.
36 Ibid., 42.
37 Ibid., 92.
38 Council on Foreign Relations, "Assessing China's Digital Silk Road Initiative," https://www.cfr.org/china-digital-silk-road.

technological independence and enhancing its global influence specifically through digital infrastructure development.[39] Agreements have been signed with approximately 40 countries – (USD 79 billion[40]) – which are one-fourth of the total BRI signatories.[41] Thus, China is in a position to push alternative technology standards and digital practices to recipient countries that could enhance Chinese influence over global economic and technological policy. Additionally, Chinese companies have completed over a dozen undersea fibre cable projects in Southeast Asia while 20 more are currently in operation.[42] These fibre networks are critical for global data transmission and internet connectivity. Through these initiatives, China is not only expanding its digital infrastructure footprint but also promoting its internet governance model, training recipient countries to implement regulatory frameworks aligned with its vision of state-controlled internet management.[43]

One of the most ambitious projects under the DSR is 'Pakistan & East Africa Connecting Europe' (PEACE). It aims to establish Chinese dominance in fibre optic cables connecting the Middle East, Africa and Europe.[44] Huawei Marine is at the forefront of

---

39 Anirudh Suri, *The Great Tech Game: Shaping Geopolitics and the Destiny of Nations* (Harper Collins, 2022), 216.

40 Sanoop S. Koshy, *Rise of China in the New World Order: An Analysis on Digital Silk Road* (Surabaya: Airlangga University Press, 2023), 332.

41 Sameer Patil and Gupta Prithvi, "The Digital Silk Road in the Indo-Pacific: Mapping China's Vision for Global Tech Expansion," *Observer Research Foundation*, January 2024, https://www.orfonline.org/public/uploads/posts/pdf/20240103105252.pdf.

42 Ibid., 333.

43 Council on Foreign Relations, "Assessing China's Digital Silk Road Initiative."

44 Thomas Blaubach, "Connecting Beijing's Global Infrastructure: The PEACE Cable in the Middle East and North Africa," *Middle East Institute*, March 7, 2022,

Chinese headways in this regard. The PEACE project may enable China to dominate the future digital economy by offering greater connectivity. There is a persisting global digital divide considering that only 35% of people in developing countries are connected to the internet, in contrast to over 80% of people online in developed countries.[45] Due to this, DSR is likely to appeal to developing countries by enhancing internet penetration and contributing to bridging the global digital divide. The geoeconomic influence gained through the DSR has the potential to translate into geopolitical advantages for China, particularly in regions like Africa and the Middle East, where digital infrastructure gaps remain pronounced.

Made in China 2025

China has devised a multi-pronged policy to secure technological sovereignty with the goal of attaining technological self-sufficiency culminating in global technological leadership. Announced in 2015, 'Made in China 2025' aims to catapult the country to a 'manufacturing superpower' through indigenous innovation and self-sufficiency in industry 4.0 technologies.[46] The plan could be viewed as a comprehensive roadmap to shore up its financial, technical and human resources to climb up the global value chains and reduce dependencies on other countries. In essence, its

https://www.mei.edu/publications/connecting-beijings-global-infrastructure-peace-cable-middle-east-and-north-africa.

45 Douglas Broom, "These are the Places in the World Where Internet Access is still an Issue – and Why," *World Economic Forum*, September 5, 2023, https://www.weforum.org/agenda/2023/09/broadband-no-luxury-basic-necessity/.

46 Jost Wübbeke et al., *Made in China 2025*, report (Mercator Institute for China Studies, December 2016), https://kritisches-netzwerk.de/sites/default/files/merics_-_made_in_china_2025_-_the_making_of_a_high-tech_superpower_and_consequences_for_industrial_countries_-_76_seiten_1.pdf.

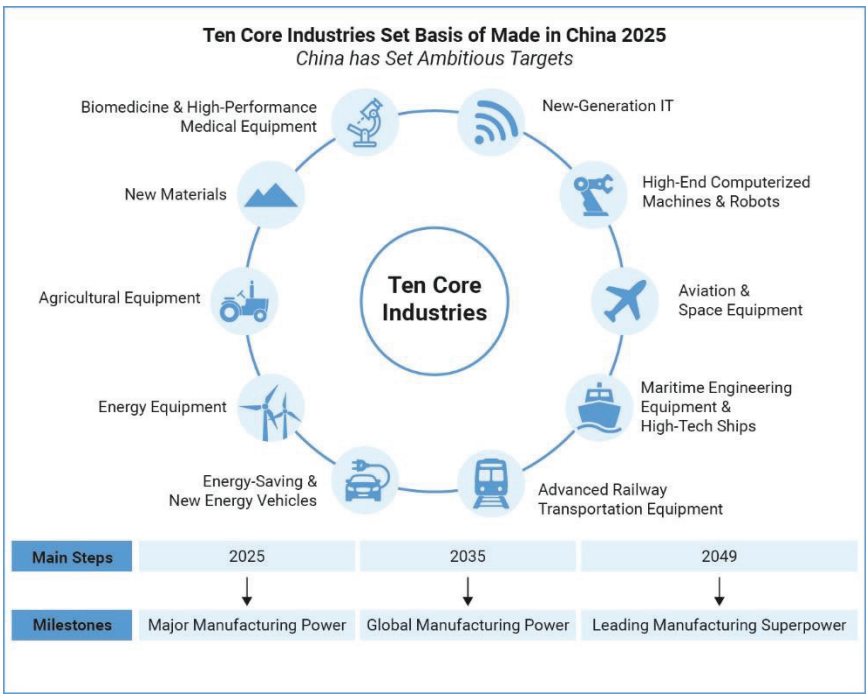
ambitious goals are planned to be achieved in three phases. The first phase (till 2025) envisages indigenisation and upgradation of key industries with a focus on smart manufacturing technologies. The second phase (till 2035) focuses on innovative breakthroughs at the global level and the uptake in the ownership of intellectual property. In the last phase (till 2049), China hopes to achieve leadership in global high-tech manufacturing in ten core industries (Figure 3). Thus, the government has been subsidising these tech industries under this vision.[47]

The geoeconomic strategy underpinning 'Made in China 2025' should be analysed within the context of an increasingly competitive international environment, where states are deploying similar policies to secure an edge in the technological race of 4IR. For instance, the US has introduced the National Strategic Plan for Advanced Manufacturing, Germany has adopted its Industry 4.0 policy, and Japan has implemented the New Robot Policy.[48]

47 Kenji Kawase, "Made in China 2025 Plan Thrives with Subsidies for Tech and EV Makers," *Financial Times*, August 1, 2022, https://www.ft.com/content/f7df0f64-25b5-4526-82fa-ca1b554b541b.

48 Ma Huimin et al., "Strategic Plan of 'Made in China 2025' and Its Implementation," in *Analyzing the Impacts of Industry 4.0 in Modern Business Environments*, ed. Richard Brunet-Thornton and Felipe Martinez (IGI Global, 2018), 1–23.

Figure 3: Made in China 2025



Source: Max J. Zenglein and Anna Holzmann, *Evolving Made in China 2025*, report (Mercator Institute for China Studies, July 2019), https://www.merics.org/sites/default/files/2020-04/MPOC%20Made%20%20in%20China%202025.pdf.

China's success in achieving technological sovereignty and global leadership will depend on the effective implementation of the strategies and plans discussed earlier and its ability to overcome challenges posed by foreign powers seeking to counter its rise. This highlights the intricate relationship between geoeconomics, technological innovation, and global power dynamics in shaping the future of international competition.

Big Tech Firms

The big tech firms are a geoeconomic instrument for states to maintain their technological sovereignty and magnify their international prestige and power. Chinese big tech firms are at the forefront of major technological breakthroughs on a global scale. Some of the leading Chinese tech giants are Baidu, Alibaba, Tencent and Huawei which rivalled by their American counterparts i.e. Google, Amazon, Facebook and Apple, respectively. The dominance of domestic tech companies over the local market resonates with the notion of technological sovereignty, given that foreign corporations are left with lesser ground to extract resources and influence the market.

Baidu is a search engine which is dominating with a 55% share in the Chinese market, having reduced Google's share drastically to a mere 1.5%.[49] Alibaba leads the e-commerce market in the country with a 58% share, while Amazon is trailing behind with 0.7%.[50] These tech giants have started making inroads into foreign markets which showcase their burgeoning influence. Out of the five most downloaded apps in the US, four trace their origin to Chinese companies. Moreover, a 35% share of Alibaba's revenue in 2023 came from international operations,[51] whereas Tencent recorded a 14% surge in its revenue from the international gaming sector.[52] Additionally, Huawei is collaborating with governments and

---

49 Lai L. Thomala, "Market Share of Leading Search Engines in China from May 2019 to May 2024," *Statista*, May 10, 2024, https://www.statista.com/statistics/253340/market-share-of-search-engines-in-china-pageviews/.

50 Jeff Beckman, "Insightful Alibaba Statistics: Impact, Revenue, and Trends for 2023," *Tech Report*, January 28, 2024, https://techreport.com/statistics/alibaba-statistics/.

51 Ibid.

52 "Tencent Announces 2023 Third Quarter Results," *Yahoo Finance*, November 15, 2023, https://finance.yahoo.com/news/tencent-announces-2023-third-quarter-100500759.html.

corporations globally to extend operations in the areas of 5G, AI and mobile operating systems.

Chinese big tech companies – mainly Huawei, ZTE and Alibaba – are the prominent beneficiaries of 'Digital Silk Road' projects in Southeast Asia, and these firms also receive policy support from Beijing to expand their businesses.[53] Moreover, under the ambit of 'Made in China 2025', the Chinese government is augmenting the innovation capability of tech firms through generous subsidies and tax cuts.[54] At the centre of the Sino-US tech war, Huawei received 7.3 billion yuan in government subsidies in 2023, exemplifying state support for big tech firms in the global struggle for technological dominance.[55] While these policy initiatives and corporate efforts align with China's overarching goal of achieving technological sovereignty, they also carry multifaceted economic, geopolitical, implications for global power dynamics.

Impact on Great Power Politics

Emerging technologies have become one of the dominant sources of power in the era of Industry 4.0, with the potential to influence the nature as well as trajectory of great power politics. China is advancing rapidly through its policies and corporate initiatives to

---

53 Wang Zheng, "China's Digital Silk Road (DSR) in Southeast Asia: Progress and Challenges," (ISEAS – Yusof Ishak Institute, January 5, 2024), https://www.iseas.edu.sg/articles-commentaries/iseas-perspective/2024-1-chinas-digital-silk-road-dsr-in-southeast-asia-progress-and-challenges-by-wang-zheng/.

54 Farrukh Nawaz, Khalil Abu Saleem and Umar Kayani, "The Made in China 2025 Strategy: Perceptions and Reservations of China's State Capitalist Economic Model," *Corporate & Business Strategy Review* 5, no. 1 (2024), https://doi.org/10.22495/cbsrv5i1siart16.

55 Che Pan, "China Pumps up State Subsidies as Chip War with US Intensifies," *South China Morning Post*, August 16, 2024, https://www.scmp.com/tech/tech-war/article/3274599/tech-war-china-pumps-state-subsidies-chip-industry-counter-us-sanctions.

secure technological sovereignty and achieve supremacy in the high-tech industry. Being a preponderant power in the post-WWII period, the US has started regarding China's meteoric rise as a threat to its hegemony. This is primarily the reason why contemporary US-China relations have morphed into what is being termed as the 'tech war.'[56] In his first address as President, Joe Biden referred to China as the 'most serious competitor,'[57] reflecting escalating tensions. Approximately 42% of the American population now perceives China as an 'enemy', underscoring the growing antagonism in public and political discourse.[58]

Citing national security concerns, the US is hampering many Chinese tech sectors through restrictions, export controls and sanctions. For instance, China's technological sovereignty through 'Made in China 2025' extends to indigenisation of semiconductors which are essential for innovative developments and global leadership in AI, automation, and electric vehicles. In response, the US is sanctioning China to thwart its endeavours for self-reliance in the semiconductor industry and has, in turn, earmarked approximately USD 52.7 billion to revitalise its R&D and indigenous manufacturing in semiconductors.[59] Thus, tech war is an emerging dimension of great power politics which has traditionally been

---

56 Bradford, "The Battle for Technological Supremacy."

57 Owen Churchill, "Biden Calls China 'Most Serious Competitor' to the US, in First Foreign Policy Speech," *South China Morning Post*, February 5, 2021, https://www.scmp.com/news/china/diplomacy/article/3120618/first-foreign-policy-address-president-biden-calls-china-most.

58 "More Americans Consider China an Enemy, Pew Research Says," *Bloomberg*, May 1, 2024, https://www.bloomberg.com/news/articles/2024-05-01/more-americans-consider-china-an-enemy-pew-research-says.

59 Citi Group, "The U.S.-China Chip War: Who Dares to Win?," January 2, 2024, https://www.citigroup.com/global/insights/the-u-s-china-chip-war-who-dares-to-win.

dominated by geopolitical tussles, military confrontations, and proxy wars.

Nationalism and alliance politics were defining features of the years leading up to the world wars. The advent of the digital era initially fostered optimism that the openness and connectivity of digital platforms might mitigate great powers' inclination toward zero-sum competition. However, the push for technological sovereignty and the emergence of the US-China tech war have instead given rise to a new form of nationalism: techno-nationalism.[60]

States like China and Russia are increasingly turning inward to consolidate control over core technologies, digital ecosystems, and data flows. China's 'Great Firewall' exemplifies a techno-nationalist strategy, enabling regulatory control and censorship that limits the presence of American social media firms within its borders. This approach not only enhances state control but also provides a competitive advantage to indigenous platforms, strengthening their global positioning. This strategy is part of a broader tech war that now extends to big tech firms. In 2023, the Chinese government demonstrated its commitment to this effort by granting 7.3 billion yuan in subsidies to Huawei, underscoring state-backed support for domestic technology companies in their competition with Western tech platforms.[61]

The normalisation and subsequent escalation of techno-nationalism could partially undermine the post-WWII global governance system, particularly in addressing technological issues. To remain effective, the traditional governance framework must evolve by incorporating technological considerations into

60 Bradford, "The Battle for Technological Supremacy."

61 Che Pan, "China Pumps up State Subsidies as Chip War with US Intensifies," *South China Morning Post*, August 16, 2024, https://www.scmp.com/tech/tech-war/article/3274599/tech-war-china-pumps-state-subsidies-chip-industry-counter-us-sanctions.

international law, ensuring it is equipped to manage the complexities of a rapidly advancing digital and technological landscape.

Traditionally, alliances have been formed based on geopolitical and military considerations, but in the current era, technology has emerged as a critical determinant of alliance formation. For instance, China and Russia have initiated discussions on cooperation between Huawei's HarmonyOS and Russia's AuraOS, signaling the potential for a techno-alliance aimed at reducing reliance on the US.[62] China's DSR further underscores its strategy to deepen technological influence, particularly in Africa and Southeast Asia, raising the likelihood of these regions becoming strategically dependent on Beijing and DSR evolving into a geopolitical and techno-alliance framework. Countries like Cambodia, Malaysia, Thailand, and Nepal are increasingly adopting regulatory and censorship frameworks that align more closely with Beijing's approach.[63] Through the DSR, China could further expand its techno-alliances, potentially reshaping the balance of power in the Asia-Pacific region.

Simultaneously, the Biden administration has proposed an alliance of techno-democracies, termed T-12, to counter China's technological ascendancy.[64] Similarly, the Quad security bloc is

62 "China-Russia Joint Communique Urges Cooperation on Huawei's Harmony OS for First Time," *Global Times*, December 1, 2021, https://www.globaltimes.cn/page/202112/1240360.shtml.

63 Lin Yang, "China's Digital Silk Road Exports Internet Technology, Controls," *Voice of America*, May 28, 2024, https://www.voanews.com/a/china-s-digital-silk-road-exports-internet-technology-controls/7626266.html.

64 David Ignatius, "Biden's Ambitious Plan to Push Back against Techno-Autocracies," *Washington Post*, February 11, 2021, https://www.washingtonpost.com/opinions/bidens-ambitious-plan-to-push-back-against-techno-autocracies/2021/02/11/2f2a358e-6cb6-11eb-9ead-673168d5b874_story.html.

incorporating technological objectives, such as isolating China from critical supply chains for microchips and semiconductors, thereby blending traditional security strategies with technology-driven goals.[65]

Future Scenario

An analytical assessment of the future trajectory of China's technological sovereignty and its impact on great power politics is essential.

While a comprehensive evaluation of 'Made in China 2025' will only begin post-2025, current indicators suggest that China still faces challenges. For instance, a 2023 study reveals that the US dominates the AI sector, hosting 60% of top AI companies and employing 57% of the world's leading AI talent, compared to China's 12% share of AI talent.[66] However, China is making notable strides - its contribution to the production of top AI researchers increased from 29% in 2019 to 47% in 2022, signaling rapid progress.

Despite this, the US continues to attract a larger share of AI venture capital, and its restrictions on China have dampened investment flows into the Chinese AI sector. Another challenge for China is the trend of supply chain reshoring and repatriation by Western companies. Technological advancements have made local manufacturing increasingly cost-effective, reducing the incentive to offshore production. Moreover, geopolitical considerations, particularly efforts by Western nations to decouple from China, have further fueled this shift. These developments pose hurdles for China's technological sovereignty and could impede its progress in the coming years.

---

65 Suri, *The Great Tech Game*, 285.

66 Macro Polo, "The Global AI Talent Tracker 2.0," https://macropolo.org/digital-projects/the-global-ai-talent-tracker/.

The US-China tech war is expected to persist, but a complete decoupling of technologies remains unlikely, as the full 'balkanization' of the digital economy would not serve the interests of either nation. The deeply interconnected nature of emerging technologies and the global digital economy may also act as a deterrent against escalating the rivalry into a full-blown conflict. While the US is actively pursuing techno-alliances to counter China, such as the proposed T-12, China could respond by leveraging its influence within Chinese-led blocs like BRICS and the Shanghai Cooperation Organization (SCO). These platforms provide China with opportunities to deepen technological cooperation with member states, further advancing its technological sovereignty and broadening its sphere of influence in the global digital economy.

The US may also struggle to form a rigid Cold War-style coalition against China, largely because European Union (EU) countries have generally maintained cooperative and cordial relations with Beijing. Xi Jinping's recent visit to France exemplifies this growing mutual trust and commitment to collaboration. French President Emmanuel Macron has put emphasis on the importance of the EU avoiding entanglement in the US-China rivalry, advocating for an independent stance that prioritises Europe's strategic interests.[67]

While a US-China rapprochement remains unlikely given the zero-sum and conflict-driven tendencies inherent in the current international system, reducing the intensity of the rivalry may be achievable. Identifying areas of mutual interest, such as climate change, global health, or sustainable development, could provide a pathway for cooperation, offering an opportunity to contribute to global peace and stability.

---

67 Tara Varma, "Xi's Visit Exposes Fault Lines in European Unity," *Brookings*, Accessed May 13, 2024, https://www.brookings.edu/articles/xis-visit-exposes-fault-lines-in-european-unity/.

Conclusion

China's remarkable rise has positioned it in an era where innovative technologies hold political, economic, and strategic significance. The leadership has proactively embraced Industry 4.0, pursuing technological self-reliance and challenging Western dominance in the technological domain. Through initiatives like 'Roadmap 2050', 'Made in China 2025', and the 'Digital Silk Road', alongside the global reach of its big tech firms, China is steadily advancing toward technological sovereignty. 'Made in China 2025' outlines a path from developing innovative competencies to achieving technological leadership by 2049, while the 'Digital Silk Road' expands China's influence globally by fostering partnerships in the digital economy and telecommunications. Together, these efforts aim to secure China's position as a leader in 4IR.

Having been a preponderant global power in the post-WWII period, the US deems China's rise as a threat to its entrenched power across different sectors. However, it is the technological growth of China that the US is more apprehensive of, considering that innovative technologies have become instrumental sources of power. The ensuing Sino-US tech war has solidified as a defining feature of international relations, with the geoeconomic modality of a zero-sum game taking precedence over the military bloc politics of the Cold War era. This shift has fueled a global trend toward techno-nationalism, where states increasingly assert control over their technological landscapes and innovation capabilities. The ongoing reshoring and repatriation of global supply chains further reflect this paradigm, as nations prioritise technological sovereignty and strategic autonomy.

While US-China competition for technological supremacy is likely to persist and even intensify, complete decoupling is improbable, as it would disrupt both nations and destabilise global supply chains. China is expected to continue advancing and employing political, socioeconomic, and diplomatic strategies to achieve its ultimate

goal of global technological leadership. If technologies remain competitive and strategically deployed in inter-state relations, the concept of technological sovereignty could solidify as a global policy norm. In coming years, the complexities of geoeconomic competition and technological orientation of global power dynamics will become increasingly apparent.

Shah Muhammad's research interests include emerging technologies, national security, defence modernisation and global governance. He has undertaken a research fellowship with the Hanns Seidel Foundation (HSF) and is also member of 'Future Leaders Connect' (FLC) – a global policy network jointly hosted by the British Council and Cambridge University. He can be contacted at: shanistaan@gmail.com

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 97-121

5G Geopolitics: Securitisation, Sino-US Contention and Technological Dependence for Developing States

Mustafa Bilal

Abstract

This paper provides a nuanced perspective on the interplay between security, geopolitics, and economic pragmatism in the global 5G domain. It examines the origins and dynamics of the diplomatic pressure campaign led by the United States against Chinese telecommunications companies since 2018. Using a qualitative methodology and Securitisation Theory, the study analyses how US policymakers and academics have framed Chinese telcos as national security threats. The study also explores the broader implications of Sino-US tensions over 5G. The findings reveal that securitising Chinese telcos, notably Huawei, has been a strategic move to curtail their expanding global influence. However, state responses to this campaign have been shaped by differing geopolitical and economic considerations. While most US allies have distanced themselves from Chinese telcos, many developing states, such as those in Africa and South Asia, have continued to embrace them due to their strong economic, political, and technological ties with China.

Keywords: 5G, China, US, Geopolitics, Chinese Telcos, Huawei, Securitisation, Developing States.

Introduction

5G is crucial for the digital transformation of societies as it holds the key to unlocking the potential of future industries via its speed, latency, and bandwidth.[1] This paper examines how 5G has become a priority area in international relations, underscored by GSMA's estimation that 5G will make up 15% of global mobile networks by 2025.[2] There are estimated to be 1 billion 5G connections in China alone.[3] However, think tanks in the United States (US) have expressed concern that the country is likely to face vulnerabilities as China's lead in 5G development could impact both economic prosperity and national security.[4] This concern was also underscored by the admission by former US Secretary of Commerce Gina Raimondo that the 5G race had begun and the US

1 Börje Ekholm, "How 5G's Innovation Potential Will Lift Digitalization to the Next Level," *World Economic Forum,* January 12, 2024, https://www.weforum.org/agenda/2024/01/5g-innovation-digitalization/.

2 GSMA, "New GSMA Study: 5G to Account for 15% of Global Mobile Industry by 2025 as 5G Network Launches Accelerate," press release, February 25, 2019, https://www.gsma.com/newsroom/press-release/new-gsma-study-5g-to-account-for-15-of-global-mobile-industry-by-2025/.

3 GSMA, "China's 5G Market Is Set to Add Almost $260 Billion to the Chinese Economy in 2030 with Connections Set to Top 1 Billion This Year, " press release, December 13, 2024, https://www.gsma.com/newsroom/press-release/chinas-5g-market-is-set-to-add-almost-260-billion-to-the-chinese-economy-in-2030-with-connections-set-to-top-1-billion-this-year/.

4 Ngor Luong, *Forging the 5G Future: Strategic Imperatives for the US and Its Allies*, report (Washington, D.C.: Atlantic Council, September 4, 2024), https://www.atlanticcouncil.org/in-depth-research-reports/report/forging-the-5g-future-strategic-imperatives-for-the-us-and-its-allies/.

would strive to win.[5] From the US perspective, compelling allies and friendly states to ban Chinese telecommunications companies (referred to as 'telcos') was key to winning this race.

Against this backdrop, the paper explores how development and deployment of 5G infrastructure has become marred by contentious geopolitics. It examines how the US has adopted a strategy centred on restricting market access to Chinese telcos and pressuring their allies to follow their lead. Central to this examination is emphasising this strategy's core foundation: *securitisation of Chinese telcos*.

The paper will seek to address the following research questions: Why has 5G become a focal point of Sino-US tensions? How did the US diplomatically pressure allies to ban Chinese telcos? How have Western academic publications further propagated this securitisation discourse? And how have developing states like Pakistan and India navigated the Sino-US geopolitical tensions over 5G?

Theoretical Framework

Scholars have asserted that there are three clusters of research on the politics of cybersecurity. The third cluster focuses on securitisation, in which the thematic points are the actors and their practices and policies that construct specific issues as security threats.[6] Securitisation theory holds the most explanatory power

---

5 Timothy M. Bonds et al., *America's 5G Era: Gaining Competitive Advantages While Securing the Country and Its People,* report (Santa Monica: RAND Corporation, 2021), https://www.rand.org/pubs/perspectives/PEA435-1.html.

6 Myriam Dunn Cavelty and Andreas Wenger, *Cyber Security Politics: Socio-Technological Transformations and Political Fragmentation,* First Edition (London: Routledge, 2022).

considering the topic of this research.[7] Therefore, it will be helpful to analyse the securitisation discourse regarding Chinese telcos propagated by the US through the lens of securitisation theory. In this regard, the paper draws on work of the Copenhagen School, which has influenced academic understanding of securitisation and adapts it to the cybersecurity of telecommunication infrastructure.

The book *Security: A New Framework for Analysis* is widely regarded as a foundational text on the concept of securitisation.[8] It argues that securitising moves are essentially speech acts through which specific issues are framed as existential threats. For instance, in the case of US policymakers, framing of Chinese telecommunications companies as existential threats exemplifies such a securitising move. The process of securitisation is completed when the targetted audience - such as US allies - accepts this framing, legitimising extraordinary measures to address the perceived threat. Notably, Donald Trump vehemently criticised Chinese telcos and even boasted about convincing 'many' countries to abandon them because they posed a significant security threat.[9] The British government even admitted that geopolitical pressure from the US partly contributed to its decision to ban Chinese telcos.[10] The book also underscores how an

7 Clara Eroukhmanoff, "Securitisation Theory: An Introduction," *E-International Relations,* January 14, 2018, https://www.e-ir.info/2018/01/14/securitisation-theory-an-introduction/.

8 Barry Buzan, Ole Wæver and Jaap de Wilde, *Security: A New Framework for Analysis* (Boulder: Lynne Rienner Publishers, 1998).

9 Pia Victoria Freiin von Blomberg, "Cybersecurity in the European Union: The Securitization of Chinese 5G Providers," (Bachelor Thesis, Ludwig-Maximilians-Universität München, 2023), https://epub.ub.uni-muenchen.de/105955/.

10 Toby Helm, "Pressure from Trump Led to 5G Ban, Britain Tells Huawei," *Observer*, July 18, 2020, sec. Technology, https://www.theguardian.com/technology/2020/jul/18/pressure-from-trump-led-to-5g-ban-britain-tells-huawei.

external power (the US) leveraged references to threats to national security and intelligence sharing as a means to influence and align the decision-making of its allies with its own strategic priorities. This point was exemplified by former Secretary of Defense Mark Esper, who cautioned that any state adopting Chinese telecommunications companies risked jeopardising its relationship with the US.[11] Similarly, former Secretary of State Mike Pompeo issued veiled warnings, suggesting that states embracing Chinese telcos would do so at the expense of their diplomatic and military ties with the US.[12]

Methodology

A comprehensive literature search was conducted across multiple academic databases, including JSTOR, SpringerLink, and Taylor & Francis, using a combination of keywords and Boolean operators to refine the search. Keywords included 'Chinese telcos,' 'securitisation,' '5G development,' 'Western perspectives,' and 'Developing States.' Google Scholar was also used to identify relevant publications from 2019 to 2024. The rationale for focusing on this time frame stems from the Trump administration's initiation of the securitisation of Chinese telcos, highlighted by Trump's declaration of a national IT emergency in May 2019.

All identified publications were imported into Zotero, a reference management software, to facilitate organisation, track keyword

---

11 Claude Barfield, "The Munich Security Conference: Good News and Bad on US-China, Huawei, and 5G," *American Enterprise Institute,* February 20, 2020, https://www.aei.org/technology-and-innovation/the-munich-security-conference-good-news-and-bad-on-us-china-huawei-and-5g/.

12 Øystein Soknes Christie, Jo Jakobsen and Tor Georg Jakobsen, "The US Way or Huawei? An Analysis of the Positioning of Secondary States in the US-China Rivalry," *Journal of Chinese Political Science* 29, no. 1 (2024): 77-108, https://link.springer.com/article/10.1007/s11366-023-09858-y.

connections, and streamline citations. Titles and abstracts were screened against predefined inclusion criteria to ensure relevance to the research objectives, particularly with regard to Chinese telcos and securitisation. The primary sources included peer-reviewed journal articles, books, think tank reports, and dissertations. To include diverse perspectives, the review included publications from the European Union, Pakistan, and India. Full-text assessments ensured that each publication explicitly addressed one or more research questions. Key themes, such as securitisation narratives and geopolitical framing, were systematically extracted from the texts. The extracted data were analysed qualitatively to identify patterns, themes, and insights aligned with the research questions, providing a comprehensive understanding of the securitisation of Chinese telcos within varying geopolitical contexts.

National Security and 5G

According to Barry Buzan, there are five sectors of security, including the military and economy.[13] In the case of 5G, economic and military imperatives are driving its development, as 5G has the potential to revolutionise commercial industries and military-industrial complexes by leveraging its defining technical features: highest speed and bandwidth, lowest latency, and ultra-reliability.

Moreover, the military's demand for data is expected to grow with the integration of emerging technologies such as Artificial Intelligence (AI). 5G can not only meet this increasing demand but also enable critical advancements, including improved connectivity between sensors and shooters, powering algorithms to enhance battlefield transparency in complex information environments, improving intelligence, surveillance, and reconnaissance (ISR)

13 Marianne Stone, "Security According to Buzan-A Comprehensive Security Analysis?," (paper, Security Discussion Papers Series 1, Sciences Po, Paris, 2009), https://docs.neu.edu.tr/staff/nur.koprulu/Security_for_Buzan.mp3_10.pdf.

capabilities, streamlining logistics, and supporting the development of more autonomous weapon systems.[14] Therefore, a state that achieves a first-mover advantage in 5G technology will strengthen not only its economic power but also its military power, amplifying its strategic position globally.

Cybersecurity and Technical Vulnerabilities of 5G

Beyond the military, 5G carries serious implications for national security, as critical sectors will increasingly depend on its networks. These sectors include the automated industries of the future, networks managing thousands of driverless cars, and hospitals where remote surgeries will rely on 5G's ultra-low latency.[15] Even a minor disruption in such systems could endanger countless lives. Given the transformative societal and industrial applications of 5G, the risks of sabotage are likely to increase exponentially. Achieving the lowest latency and fastest speeds necessitate placing software and servers at the network's edge, which creates additional vulnerabilities. These edge systems, while crucial for efficiency and performance, could become prime targets for malicious actors, amplifying the stakes for national and global security.[16] The former US Federal Communications Commission (FCC) Chairman Tom Wheeler highlighted these vulnerabilities by noting that 5G might be the last physical network overhaul in generations as only software updates would be needed afterwards. This would require the vendor

---

14 Kelley M. Sayler, *National Security Implications of Fifth Generation (5G) Mobile Technologies*, report (Washington, D.C.: Congressional Research Service, March 14, 2023), https://sgp.fas.org/crs/natsec/IF11251.pdf.

15 D. Loghin et al., "The Disruptions of 5G on Data-Driven Technologies and Applications," in *IEEE Transactions on Knowledge and Data Engineering* 32, no. 6 (2020): 1179-1198, https://ieeexplore.ieee.org/document/8961984.

16 Tom Wheeler, "5G in Five (Not so) Easy Pieces," *Brookings*, July 9, 2019, https://www.brookings.edu/articles/5g-in-five-not-so-easy-pieces/.

to have persistent access to the network, which could compromise its security if the vendor was unreliable.[17] Moreover, professionals at the FCC have observed that 5G networks will pave the way for the widespread adoption of the Internet of Things (IoT). The anticipated complexity of IoT networks, coupled with the sheer number of interconnected devices, significantly heightens concerns about cyber insecurity. These vulnerabilities could be exploited to disrupt critical systems, compromise sensitive data, and undermine trust in the digital infrastructure that underpins modern society.[18] Thus, the complexity of 5G technology and its network infrastructure has been used to justify the political securitisation of Chinese telecommunications companies. This securitisation hinges on fears of potential cyber espionage or large-scale network disruptions, which could exploit the vulnerabilities inherent in such a complex and critical system.[19]

Case Study: Salt Typhoon Cyberattack and Chinese Telcos

The securitisation of Chinese telcos gained traction in October 2024 following a high-profile cyberattack widely reported across the US.[20] Media outlets revealed that a group of Chinese hackers, later identified as 'Salt Typhoon,' had infiltrated a substantial

---

17 Iryna Bogdanova, "Politicisation of the 5G Rollout: Litigation Way for Huawei?" (paper, Social Science Research Network, February 2023), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4345025.

18 Shane Fonyi, "Overview of 5G Security and Vulnerabilities," *The Cyber Defense Review*, Spring (2020): 117-132, https://cyberdefensereview.army.mil/Portals/6/CDR%20V5N1%20-%2008_%20Fonyi_WEB.pdf.

19 Karsten Friis and Olav Lysne, "Huawei, 5G and Security: Technological Limitations and Political Responses," *Development and Change* 52, no. 5 (2021): 1045-1273, https://onlinelibrary.wiley.com/doi/10.1111/dech.12680.

20 Chris Jaikaran, *Salt Typhoon Hacks of Telecommunications Companies and Federal Response Implications,* report (Washington, D.C.: Congressional Research Service, November 15, 2024), https://crsreports.congress.gov/product/details?prodcode=IF1279.

portion of the US telecommunications network. The severity of the breach prompted Senator Mark Warner, Chair of the Senate Intelligence Committee, to describe it as the most significant telecom hack in US history, stating that it dwarfed previous cyberattacks against the country.[21] Subsequent confirmations by the Cybersecurity and Infrastructure Security Agency (CISA) and the Federal Bureau of Investigation (FBI) validated these reports, detailing how Salt Typhoon exploited vulnerabilities in telecom infrastructure, particularly through compromised switches and routers. Brandon Wales, former Executive Director of CISA, indicated out that major US telecom providers, including AT&T, Verizon, and Lumen, were affected, with vulnerable edge devices - specifically Cisco routers - identified as the primary intrusion vector.[22]

The incident underscored the risks associated with critical network infrastructure, intensifying calls for action against reliance on Chinese-manufactured telecommunications equipment. In response, the U.S. House of Representatives proposed legislation allocating over USD 3 billion to support telecom companies 'to rip and replace' Chinese-made equipment,[23] reflecting a policy shift driven by concerns over national security and cyber resilience.

China strongly refuted allegations linking the Salt Typhoon cyberattack accusing US officials of using cybersecurity as a

---

21 Ellen Nakashima, "Top Senator Calls Salt Typhoon 'Worst Telecom Hack in Our Nation's History,'" *Washington Post*, November, 21 2024, https://www.washingtonpost.com/national-security/2024/11/21/salt-typhoon-china-hack-telecom/.

22 Brandon Wales, Interview by Steven Rosenbush, *WSJ CIO Network,* October 7, 2024, https://cionetwork.wsj.com/video/cio-network-summit-7/8/.

23 David Shepardson, "US House to Vote to Provide $3 Billion to Remove Chinese Telecoms Equipment," *Reuters*, December 8, 2024, https://www.reuters.com/world/us/us-house-vote-provide-3-billion-remove-chinese-telecoms-equipment-2024-12-08/.

pretext to smear Beijing for geopolitical gain.[24] Chinese analysts argue that the forced removal of Chinese telecom equipment would significantly raise costs for US operators and degrade user experience. Zhang Xiaorong, Director of the Beijing-based Cutting-Edge Technology Research Institute, asserted that such isolationist actions by the US would also harm the global telecom industry.[25] Nevertheless, the scale and scope of the Salt Typhoon hack are likely to prompt policymakers to accelerate efforts to eliminate Chinese telecom presence entirely, both domestically and among allies. With the incident occurring just weeks before the inauguration of Trump's second presidency, the incoming administration is expected to aggressively relaunch its international securitisation campaign against Chinese telcos.

Contentious Geopolitics of 5G and Sino-US Tensions

Numerous studies have analysed the interlinkage between emerging technologies and geopolitical risk. This linkage underscores why contentious geopolitics have impeded global 5G deployment.[26] The impediment is partly explained by Deloitte's assessment, highlighting that the state leading in 5G development

24 Lewis Wiseman "Terrifying Chinese Hacking Campaign Sees Large Numbers of Americans' Data Stolen, US Officials Say," *ABC News*, December 5, 2024, https://www.abc.net.au/news/2024-12-05/united-states-allege-china-behind-salt-typhoon-telecoms-hack/104687712.

25 "US' Forcible Removal of Chinese Telecom Equipment Only Increases Cost, Harms User Experience: Analyst," *Global Times*, December 8, 2024, https://www.globaltimes.cn/page/202412/1324601.shtml.

26 Khalid Khan et al., "Geopolitics of Technology: A New Battleground?", *Technological and Economic Development of Economy* 28, no. 2 (2022): 442-62, https://journals.vilniustech.lt/index.php/TEDE/article/view/16028.

could attain a competitive advantage for many years.[27] Such assessments underline why the debate over 5G is frequently viewed through the lens of zero-sum geopolitical competition between the US and China. Notably, according to Nigel Inkster, the domination of 5G has become a key battleground in the broader geopolitical Sino-US contestation. Moreover, he has posited that China's lead in the global 5G market represents another 'Sputnik moment' - challenging long-held presumptions of US supremacy in telecommunications.[28]

Successive US administrations have thus initiated a domestic crackdown on Chinese telcos by enacting laws to prevent the transfer and sales of telecom equipment to Chinese telcos.[29]

On the international front, the US capitalised on concerns that resonated with Western audiences, particularly those related to data privacy, to garner opposition to Chinese telcos. Senior US officials have been warning and applying diplomatic pressure on other states to restrict market access for Chinese telcos. In fact, countering the latter's global digital expansion became one of the rare issues that has had bipartisan consensus in the US. To operationalise this strategy, the U.S. State Department launched the 'Clean Network' initiative in August 2020, aimed at addressing 'long-term threats to data security from malign authoritarian actors.' [30] It focused on forging joint declarations on 5G security with countries

---

27 Dan Littmann et al., *The Imperative for US Leadership on the 5G Deployment*, report (New York: Deloitte, 2018), https://www2.deloitte.com/us/en/pages/consulting/articles/5G-deployment-for-us.html.

28 Nigel Inkster, *The Great Decoupling China, America and the Struggle for Technological Supremacy* (London: Hurst Publishers, 2020), 156.

29 Qingxiu Bu, "Behind the Huawei Sanction: National Security, Ideological Prejudices or Something Else?" *International Cybersecurity Law Review* 5 (2024): 263-300, https://link.springer.com/article/10.1365/s43439-024-00112-6.

30 Christie et al., "The US Way or Huawei?," 80.

across Central and Eastern Europe. Subsequently, in May 2021, Congress proposed the Transatlantic Telecommunications Act (TTA) to fund development and protection of 5G infrastructure in Eastern Europe.[31]

The TTA was similar to the agreements China had signed with Belt and Road Initiative (BRI) states, which guaranteed market access for Chinese telcos. However, explicit binaries in the language of such agreements (democratic vs. authoritarian) contributed to a gradual securitisation of 5G across Europe as European security and technical experts started echoing US concerns regarding the risks posed by Chinese telcos. For instance, this led to the European Parliament referencing the Prague Proposals (2019), a report that assessed the cybersecurity risks associated with 5G deployment. The proposals outlined principles for states to follow, including implicit recommendations to limit cooperation with China on 5G infrastructure.[32]

China's Pursuit of Leading the 5G Race

Even before US attempts at choking technology access to Chinese telcos and urging allies to ban them, China had long been cognizant of the geopolitical imperative of leading the 5G race. Since 2016, Chinese officials have argued that innovation in emerging and established industries will be spurred by 5G.[33] Chinese development strategies also highlight progress in 5G and associated sectors to promote long-term growth, further

31 Bogdanova, "Politicisation of the 5G Rollout."
32 Friis and Lysne, "Huawei, 5G and Security," 1186.
33 Elisa G. Prestes, "The Digital Geopolitics of 5G: Elements to Understand the Chinese Technological Development of the Fifth Generation of Mobile Telephony," *Geousp* 26, no. 2 (2022), e-194823, https://www.scielo.br/j/geo/a/dRW7hLXpQzRKS3WfZYTgLrq/.

underscoring its significance.[34] For instance, China considers 5G crucial for achieving the goals envisioned in its 'Made in China 2025' plan. Moreover, China's 5G market is expected to contribute nearly USD 260 billion to the Chinese economy in the coming years.[35]

On the international front, China first officially unveiled the 'Digital Silk Road' (DSR) in 2015 in a government white paper. 5G was stated to be the foundation of the DSR for emerging technologies such as AI and IoT.[36] China's then-Foreign Minister, Wang Yi, outlined that the DSR would be a key priority for advancing 5G cooperation under the BRI. As part of this strategy, China views establishing itself as a standards-setter in 5G as a core foreign policy objective of the DSR.[37] To this end, Beijing has leveraged its leadership in 5G development to shape international technical standards. By 2019, China had signed over 85 cooperation agreements on technical standardisation, involving nearly 50 BRI-participating countries.[38] These agreements are expected to advance China's aspiration to become the world leader in setting

---

34 Hannah Reilly, "Connection and Competition: Navigating the U.S.-China Race to 5G," (CMC Senior Theses, Claremont Graduate University, 2021), https://scholarship.claremont.edu/cmc_theses/2910/.

35 "China's 5G Market Is Set to Add Almost $260 Billion."

36 John Hemmings, "Reconstructing Order: The Geopolitical Risks in China's Digital Silk Road," *Asia Policy* 15, no. 1 (2020): 5-22, https://www.jstor.org/stable/26891385.

37 He Yujia, "Chinese Digital Platform Companies' Expansion in the Belt and Road Countries," *The Information Society* 40, no. 2 (2024): 96-119, https://www.tandfonline.com/doi/abs/10.1080/01972243.2024.2317058.

38 Erik Baark, "China's Digital Silk Road: Innovation in a New Geopolitical Environment," *East Asian Policy* 16, no. 01 (2024).

international standards for next-generation telecom technologies as part of its 'Standards 2035' strategy.[39]

China has also accelerated efforts to develop and promote an alternative internet architecture. In 2019, Huawei introduced a New Internet Protocol (IP), which Western academics interpreted as a manifestation of China's geopolitical ambitions. This initiative is seen as part of a broader strategy to internationally advance an 'internet with Chinese characteristics,' focused on state-centric control and governance over digital infrastructure.[40]

Western Securitisation of Chinese Telcos

As discussed in the preceding section, China has established robust technological partnerships with states worldwide, primarily through the DSR. However, an analysis of the discourse surrounding China's digital cooperation reveals that dominant narratives often originate from Western think tanks. These perspectives, closely align with those of US policymakers, frequently portray China's digital initiatives as having ulterior motives, such as undermining democratic institutions, exporting digital authoritarianism, and engaging in data theft.[41] The most

---

39 Fakhar Hussain et al., "Infrastructure Development for the Digital Silk Road (DSR) and its Implications for China Under the Belt and Road Initiative," *Asia-Pacific Social Science Review* 23, no. 4 (2023), https://animorepository.dlsu.edu.ph/apssr/vol23/iss4/7/. The 'China Standards 2035' strategy builds upon the earlier 'Made in China 2025' plan, to establish China as a global standard-setter in emerging technologies, including 5G, by promoting technical standardisation and enhancing compatibility across industries.

40 Inkster, *The Great Decoupling*, 147.

41 Richard Heeks et al., "China's Digital Expansion in the Global South: Systematic Literature Review and Future Research Agenda," *The Information Society* 40, no. 2 (2024): 69-95, https://www.tandfonline.com/doi/full/10.1080/01972243.2024.2315875.

commonly referenced example in Western literature is the Chinese construction of smart cities with the latest surveillance technologies, like AI-enabled facial recognition. Leading Chinese firms such as Huawei and ZTE have been involved in more than 350 smart city projects globally. However, Western academics have deemed these projects the most extensive intelligence collection network ever built.[42]

Western publications also assert that increasing overseas expansion of Chinese telcos accompanies significant geopolitical implications as they continue to construct the backbone of ICT infrastructure in both developing and developed states. In this context, Western scholars have posited that China's objective of expanding digital cooperation with other states should be a major concern for the US and its Western allies since key players in China's telecom sector are state-backed telcos. They substantiate their argument by highlighting that China's state-backed banks, such as the Export-Import Bank of China (EXIM) and the China Development Bank (CDB), have provided tens of billions in financing China's overseas ICT projects.[43]

Furthermore, Western literature frequently frames China's digital cooperation as a form of 'data colonialism,' wherein China is perceived as exerting control over digital infrastructure, IT systems, and data flows in partner states.[44] Given the intrinsic link between data and states' economic and political power, the increasing digitisation of the global economy has emerged as a critical arena for geopolitical competition. In this context, much of the reviewed Western literature on the security of 5G networks references China's 2017 National Intelligence Law. This law is widely

42 Hemmings, "Reconstructing Order," 14.

43 Ibid., 7.

44 Lizhi Liu, "The Rise of Data Politics: Digital China and the World," *Studies in Comparative International Development* 56, no.1 (2021): 45-67, https://link.springer.com/article/10.1007/s12116-021-09319-8.

speculated to impose a legal obligation on Chinese companies, including telecom firms, to 'participate in assisting intelligence work,' regardless of their global operations.[45] This interpretation amplifies concerns about the security implications of Chinese digital infrastructure in a highly interconnected world.

Huawei: Focal Point of Sino-US 5G Tensions

While US policymakers view all Chinese telecommunications companies with suspicion, Huawei has been the primary focus, viewed through the lens of an increasingly fraught US-China relationship. A pivotal moment came with President Trump's Executive Order declaring a 'national IT emergency' targetting Huawei, which marked the beginning of the US securitisation of Chinese telcos. This executive order politicised telecom technology, transforming what was once a technical issue into a critical national security concern. By 2022, Huawei's founder openly acknowledged the challenging geopolitical environment and its profound implications for the company's international operations.[46] He conceded that Huawei would need to forgo business opportunities in countries with deep security alliances with the US, reflecting the geopolitical constraints imposed by the securitisation narrative.

Consequently, while Huawei was in a prime position to acquire contracts for deploying 5G in European states as it had been a key player in their 4G deployment, it encountered vociferous opposition from the US. For example, the UK was initially open to allowing Huawei equipment in the non-core components of its 5G networks. However, in July 2020, it banned Huawei over its inability to procure

45 Bu, "Behind the Huawei Sanction," 286.

46 Rohit Dube, "Huawei's Trajectory in India - Crippled by the Chinese Military," (paper, Research Gate, 2023), 1-7, https://www.researchgate.net/publication/368652430_Huawei"s_trajectory_in_India_-_crippled_by_the_Chinese_military.

secure components following US sanctions.[47] Huawei officials tried to alleviate Western states' concerns by opening information security labs to invite investigations of its 5G equipment and review source codes. However, such transparency initiatives were not enough to counteract the securitisation discourse propagated by the US.[48]

Geopolitics and Huawei's Diverging Trajectories in Pakistan and India

Studies have highlighted an overlap between the commercial interests of Chinese telcos and the digital development agendas set by host states.[49] For example, developing states like Pakistan have set ambitious digital aspirations, and Chinese telcos are invited to compensate for their technological, financial, and infrastructural shortcomings.[50] This is evident in how China established all-weather optical fibre and satellite communication channels in Pakistan. In the digital age, these communication channels have become what China calls the 'information highway' and form the basis for enhancing cooperation between Chinese telcos and Pakistan.[51] Huawei played an integral role in constructing and operating this information highway. Notably, it has invested USD 100 million to establish a regional headquarters in Islamabad. Moreover, it has built Pakistan's first Cloud Data

47 Jonathan Pelson, *Wireless Wars, China's Dangerous Domination of 5G and How We're Fighting Back* (London: Penguin Random House, 2021), 212.

48 Friis and Lysne, "Huawei, 5G and Security," 1182.

49 Yujia, "Chinese Digital Platform Companies' Expansion," 5.

50 Alivia A. Johnson, "Navigating Incentives of States' Engagement in Huawei Amidst Western Pressures," (Senior Thesis, California State University Maritime Academy, 2023), https://scholarworks.calstate.edu/downloads/6969z805j.

51 Xin Yue Shen, "Chinese ICT on the Digital Silk Road: A Case Study of Infrastructure Building in Pakistan," (Masters Thesis, Simon Fraser University, Burnaby, 2020), https://summit.sfu.ca/item/20723.

Centre and Safe City surveillance system.[52] Studies have also highlighted how Huawei Pakistan's cloud solutions have revamped the country's banking industry. The State Bank of Pakistan has even praised the Chinese telco for assisting banks in navigating the opportunities and challenges posed by the digital age.[53]

Meanwhile, across the border, Huawei incrementally expanded its presence in India over the past two decades. At one point, Huawei had the largest external Research and Development (R&D) presence in India. Moreover, similar to Europe, in 2018, Huawei was positioned to win 5G contracts in India as it was a leading equipment provider to major telecom operators.[54]

Until 2019, Huawei's trajectory in India mirrored its growing presence in Pakistan, reflecting China's broader regional ambitions. However, this trajectory sharply diverged in subsequent years due to shifting geopolitical dynamics. India became a key target audience for the US campaign to securitise Chinese telcos. Unlike other states, the US required little effort to convince India, as the deadly clashes between Chinese and Indian soldiers in the Galwan Valley in June 2020 significantly altered India's approach to Chinese tech firms.[55] In the aftermath of the incident, the Indian government implemented stringent measures against Chinese companies, including Huawei, as part of a broader clampdown on Chinese tech operations. This shift was not merely a reaction to the

---

52 Johnson, "Navigating Incentives of States' Engagement in Huawei," 23.

53 Hassan Nawaz et al., "Huawei Pakistan Providing Cloud Solutions for Banking Industry: A Data Driven Study," *The Asian Bulletin of Big Data Management* 4 (2024): 89-107, https://abbdm.com/index.php/Journal/article/view/122.

54 Manoj Kewalramani and Anirudh Kanisetti, "5G, Huawei & Geopolitics: An Indian Roadmap," (paper, Social Science Research Network, 2019), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3414860.

55 Dube, "Huawei's Trajectory in India," 5.

Galwan Valley clashes but also a reflection of India's recalibrated strategic alignment, influenced by growing tensions with China and closer ties with the US. Consequently, Huawei found itself ensnared in a complex geopolitical struggle, with its operations in India severely impacted by both domestic and international pressures.

Thus, Pakistan and India's engagements with Huawei are emblematic of the broader geopolitical tensions between China and the US over Chinese telcos in general and Huawei in particular. While Huawei's expanding presence in Pakistan reflects Islamabad's increasing technological alignment towards China, the company's shrinking footprint in India underscores the deepening Indo-US strategic partnership in which technological cooperation is a key pillar.[56]

Challenges of Banning Chinese Telcos for Developing States

The Atlantic Council has observed that while the US has effectively curtailed the expansion of Chinese telecom companies among its allies, its efforts have been less successful in other regions.[57] Geopolitical and alliance dynamics partly explain why US securitisation initiatives have been less impactful in many developing states. However, additional factors may account for why these states have resisted US pressures and chosen to contract Chinese telcos for the development of their telecom network.

One contributing factor is the disparity in US engagement. While the US has relied on long-standing strategic and intelligence partnerships to influence its Western allies, its interactions with

---

56 Mustafa Bilal, "Indo-US Strategic Tech Alliance: AI's Prospects and Perils," *Stratheia*, January 17, 2024, https://stratheia.com/indo-us-strategic-tech-alliance-ais-prospects-and-perils/.

57 Reilly, "Connection and Competition," 43.

developing countries have been relatively limited, reducing its capacity to shape their decisions.

Beyond strategic considerations, structural issues in the telecom sector also played a role. In 2021, Jeremy Fleming, then head of Britain's Government Communications Headquarters (GCHQ), acknowledged that Western nations had effectively 'lost the conversation' on 5G infrastructure a decade earlier. He attributed this to the withdrawal of Western telecom companies from investing in foundational infrastructure, which was often dismissed as unprofitable 'white elephant' projects. Fleming conceded that this neglect left Western states with limited alternatives, thereby enabling Chinese telcos to dominate the market in developing regions.[58]

Meanwhile, Chinese telcos capitalised on the vacuum and cultivated strong technological partnerships with developing states, as evidenced by the fact that Huawei has developed 70% of Africa's 4G networks.[59] Hence, according to the Institute for National Security Studies, the US cannot secure leadership in the global 5G race solely by curbing China's technological advancements.[60] A major challenge lies in the absence of a domestic competitor to Chinese telecommunications firms. In response, the US has focused on actively supporting European 5G companies to fill this gap. Toomas Hendrik Ilves, the former President of Estonia, underscored this issue during a 2021 NATO

58 Jonathan E. Hillman, *The Digital Silk Road, China's Quest to Wire the World and Win the Future* (New York: Harper Collins, 2021), 58.

59 Johnson, "Navigating Incentives of States' Engagement in Huawei," 11.

60 Łukasz Gołota, "The Role of 5G Technology in Superpower Rivalry between the United States and China: An Offensive Realist Approach," *Polish Political Science Yearbook* 52, no. 4 (2023): 173-190, https://czasopisma.marszalek.com.pl/images/pliki/ppsy/52/ppsy202396.pdf.

meeting, questioning the efficacy of the US strategy. He pointedly remarked that while the US has been vocal about the risks posed by Chinese telcos, it has yet to provide a viable alternative for states to adopt.[61]

To date, no viable alternative to Chinese telecom companies has emerged, particularly in the context of developing states. Conversely, the Chinese narrative of mutual benefit through South-South cooperation, underscoring co-development with local stakeholders, has resonated strongly with these nations. Developing states view China as a global leader in ICT technology capable of addressing their digital divide with the developed world. In this context, Chung has highlighted the pivotal role of China's engagement in the Global South in implementing national ICT strategies across various socioeconomic sectors. By providing high-quality, competitive services at costs approximately 30% lower than those of Western competitors,[62] China has greatly facilitated digital transformation of many developing nations, reinforcing its appeal as a partner in their technological advancement.

Thus, Hillman has argued that for most developing states, the financial advantages of opting for Chinese telecom companies outweigh concerns about information security, which are often considered secondary. These states prioritise importing digital technologies and technical expertise from China to develop their telecommunications networks in a more cost-effective manner, addressing critical digital infrastructure needs without significant capital outlays.[63] For example, despite Western states' outcry over allegations that Huawei had been transferring data from the African

61 Hillman, *The Digital Silk Road*, 85.
62 Chien-peng Chung, "China's Digital Silk Road," *East Asian Policy* 15, no. 2 (2023): 123-137.
63 Hillman, *The Digital Silk Road*, 85.

Union's headquarters to China for years, the African Union and Huawei subsequently expanded their digital partnership.[64]

Jonathan Pelson has similarly assessed the importance of Chinese Telcos for developing states, noting that the cost of refusing them is substantial. Replacing existing Chinese telecom equipment, he argues, would require billions of dollars, with additional costs incurred from the price premiums charged by Western 5G providers like Nokia and Ericsson compared to their Chinese counterparts.[65]

Banning market access to Chinese telcos poses challenges for developing states, particularly those like Pakistan. For such states, removing Chinese equipment, as the US and its allies have done, would be both financially prohibitive and logistically impractical.[66] Germany, for example, initially resisted an outright ban on Chinese telcos, arguing that it would hinder 5G deployment given the dominance of Chinese companies in 5G patents.[67] However, this year, Germany was compelled to take the economically costly step of phasing out Chinese telecom equipment.[68] Similarly, British

64 Salem Solomon, "After Allegations of Spying, African Union Renews Huawei Alliance," *Voice of America*, June 6, 2019, https://www.voanews.com/a/after-allegations-of-spying-african-union-renews-huawei-alliance/4947968.html.

65 Pelson, *Wireless Wars*, 214.

66 Stacie Hoffmann, Samantha Bradshaw and Emily Taylor, "Networks and Geopolitics: How Great Power Rivalries Infected 5G," *Oxford Information Labs*, August 5, 2022, https://oxil.uk/blog/geopolitics-of-5g/index.html.

67 Corina Lozovan, "The 5G Conundrum amid Geopolitics and Security in Europe," (paper, Research Centre of the Institute for Political Studies (CIEP) Institute for Political Studies, Lisbon, 2021), https://ciencia.ucp.pt/en/publications/the-5g-conundrum-amid-geopolitics-and-security-in-europe.

68 Christopher F. Schuetze, "Germany to Strip Huawei from Its 5G Networks," *New York Times*, July 11, 2024, https://www.nytimes.com/2024/07/11/business/huawei-germany-ban.html.

Telecom highlighted that replacing Chinese equipment would cost billions of pounds, yet the UK government pressed ahead with the decision, as noted earlier.[69] These cases underscore the tension between economic pragmatism and geopolitical imperatives, illustrating the difficult trade-offs states face when addressing security concerns in their digital infrastructure.

Way Forward

For the US and its like-minded allies in Europe, geopolitical and economic decisions are intertwined with national security. However, US allies face pressing concerns stemming from diplomatic pressure from the US. Relatedly, in response to the intensifying securitisation of 5G, the EU envisioned a technological sovereignty policy, and EU member states tried to navigate the Sino-US confrontation over 5G diplomatically. Still, most states could not stay neutral and eventually either banned or restricted market access to Chinese telcos. For example, as discussed earlier, European states like France and Germany, who once championed technological sovereignty, could not hold out against pressure from the US to ban Chinese telcos.

Therefore, the contentious geopolitics of 5G has created the challenge of balancing autonomy ambitions with global technological interdependencies. Analysts suggest that developing states like Pakistan are likely to continue relying on Chinese telecom companies to build 5G infrastructure.[70] However, digital infrastructure can be categorised into military, government, and private sector domains, each requiring varying levels of access for

69 Pelson, *Wireless Wars*, 210.

70 CASS, "Air and Space Technologies: Harnessing the Innovation Economy", seminar organised by Centre for Aerospace & Security Studies, Islamabad, September 24, 2024, https://casstt.com/air-and-space-technologies-harnessing-the-innovation-economy/.

foreign firms.[71] This approach could help mitigate security risks while leveraging external expertise.

Building 5G infrastructure, however, presents several challenges. Using multiple vendors may lead to interoperability issues, while environmental factors can further complicate deployment. Technologies like Network Function Virtualisation (NFV), which allows network operators to virtualise various functions, could expand the threat surface, particularly when integrated with open radio access networks (Open RAN). Reliance on foreign cloud vendors also raises concerns about sensitive communications and data security. To address these challenges, Pakistan should evaluate vendor proposals with a security-first perspective, ensuring that long-term national interests are prioritised.[72] Ultimately, developing indigenous capacity for critical digital infrastructure should remain a strategic objective to reduce dependence on foreign technologies and enhance security.[73]

Conclusion

A state's leadership in 5G development is pivotal, as it not only drives economic growth but also enhances national security by enabling dominance in emerging civil and military industries. The

71 Fahad Nabeel (Research Lead, Geopolitical Insights), in discussion with the author, December 9, 2024.

72 Ibid.

73 CASS, "Air and Space Technologies: Harnessing the Innovation Economy", seminar organised by Centre for Aerospace & Security Studies, Islamabad, September 24, 2024, https://casstt.com/air-and-space-technologies-harnessing-the-innovation-economy/; CASS, "Cyberspace as a Global Common: Formulation and Applicability of International Law", roundtable organised by Centre for Aerospace & Security Studies, Islamabad, July 8, 2024, https://casstt.com/cyberspace-as-a-global-common-formulation-and-applicability-of-international-law/.

strategic importance of 5G lies in its transformative economic and military implications, coupled with its potential to introduce unforeseen risks to national security. As such, the controversy surrounding 5G deployment is best understood through a geopolitical lens, where power dynamics significantly shape and are shaped by the evolution of this critical technology.

The development of 5G equipment, standards, and software has become a focal point in the broader geopolitical rivalry, particularly between China and the US. This struggle represents the opening phase of a protracted competition over emerging technologies that will be built on the backbone of 5G infrastructure. For states seeking to preserve strategic autonomy, this rivalry presents a diplomatic challenge, forcing them to navigate a delicate balance between aligning with Chinese or Western telecommunications providers. As Sino-US tensions over 5G escalate, the decisions states make regarding their 5G partnerships will have far-reaching implications, potentially reshaping their broader geopolitical alignments and future relations with both powers. This underscores the centrality of 5G not just as a technological race but as a key determinant of global power structures in the years to come.

Mustafa Bilal has done his BS in International Relations from the National Defence University (NDU), Pakistan. His research interests include technopolitics, astropolitics, military aviation and warfare. He can be contacted at: mustafabilal27924@gmail.com

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 122-148

Distributed Solar Energy Generation in Pakistan: Potential, Barriers and Policy Recommendations

Zahra Niazi

Abstract

Pakistan's energy generation mix remains heavily reliant on imported fossil fuels, contributing to current account deficit and fiscal pressures, high circular debt in the energy sector, and inflationary pressures for the population. Pakistan is endowed with tremendous solar energy potential that can be proactively capitalised to reduce reliance on foreign energy supply to meet domestic energy needs. Distributed solar energy generation is a promising means of exploiting this tremendous potential. However, its growth pace in Pakistan, notwithstanding the increase over recent years, is still considered unsatisfactory compared to the country's solar power generation potential. Given this, the present research sought to identify the strengths, weaknesses, opportunities, and threats for the adoption and diffusion of distributed solar energy generation in Pakistan. The viability of developing a thriving distributed solar energy generation market will be contingent on addressing the weaknesses while proactively seizing opportunities and mitigating threats.

Keywords: Solar Power, Distributed Energy Generation, Renewables, Net metering.

Introduction

The world is currently undergoing a process of energy transition that rests on a shift away from fossil fuels as the major energy source towards renewable sources of power. This transition is the product of a global push to reduce the impact of energy production and consumption on the environment. Distributed Solar Energy Generation (DSEG), sometimes referred to as on-site solar energy generation, distributed solar or decentralised generation, now plays a vital role in this transition towards a clean energy future, and according to the International Energy Agency (IEA), it can potentially become the principal contributor to the global transition to renewable energy.[1]

Distributed solar involves production of solar electricity closer to the point of use, such as on individual buildings, at industrial sites, or within communities.[2] On-grid and off-grid systems are the two major categories of DSE systems. Whereas an off-grid system functions independently of the power grid, an on-grid system is connected to the utility grid. The market size of DSEG was valued at USD 130.31 billion in 2022.[3] It is estimated to rise at a Compound Annual Growth Rate (CAGR) of 6.96%, reaching USD 195.12 billion by 2029, driven by factors such as declining costs of solar photovoltaic (PV) panels or escalating global temperatures,

1 Redex, "The Growth of Distributed Solar Power," Accessed 26 April, 2024, https://redex.eco/the-growth-of-distributed-solar-power/.

2 L. Mehigan, J. P. Deane, BP. Ó Gallachóir, and V. Bertsch, "A Review of the Role of Distributed Generation (DG) in Future Electricity Systems," *Energy* 163 (2018): 822-836, https://doi.org/10.1016/j.energy.2018.08.022.

3 GII Global Information, "Distributed Solar Power Generation Market – Global Size, Share, Trend Analysis, Opportunity, and Forecast Report – 2019-2029, Segmented by Solar Module; By Type; By End Use; By Region," December 26, 2023, https://www.giiresearch.com/report/blw1401181-distributed-solar-power-generation-market-global.html.

stimulating a greater push to reduce global carbon dioxide (CO_2) emissions.[4]

Developing countries, in general, have the highest solar potential,[5] and decentralised generation is an effective way for these nations to exploit their rich solar resources. Pakistan, a developing country in South Asia, has considerable potential for solar power generation, and it can fulfil its present electricity demand 'if just 0.071% of its area is exploited for solar energy generation.'[6] Moreover, 1,015 potential (large size and high density) mini-grid sites with an average PV capacity of 158 *kilowatt peak* (kWp) can cover the energy needs of Pakistan's 1.8 million rural population.[7]

DSEG has been increasing in popularity within the country, particularly within the residential sector.[8] The use of solar PV in the agricultural sector has also amplified. Residential, industrial, agricultural, and commercial sectors are the major consumers of

4 GII Global Information, "Distributed Solar Power Generation Market."

5 Nick Ferris, "How Countries with Potential can Reap Big Benefits from the Solar Boom," *Energy Monitor*, November 5, 2021, https://www.energymonitor.ai/renewables/the-world-is-primed-for-a-solar-boom-will-countries-with-the-most-potential-reap-the-benefits/.

6 The World Bank, "Expanding Renewable Energy in Pakistan's Electricity Mix," November 10, 2020, https://www.worldbank.org/en/news/feature/2020/11/09/a-renewable-energy-future-for-pakistans-power-system.

7 The World Bank, Pakistan Least-Cost Electrification Study, report (Washington, D.C: The World Bank, 2024), https://documents1.worldbank.org/curated/en/099071824081524723/pdf/.

8 Naila Saleh and Sara, "Distributed Generation Landscape in Pakistan: An Overview," (paper, Institute of Policy Studies, 2020), https://www.ips.org.pk/wp-content/uploads/2020/08/DISTRIBUTED-GENERATION-LANDSCAPE-IN-PAKISTAN-final.pdf.

electricity, and the transition to solar PV in these sectors has important implications for Pakistan's energy landscape.

Specifically, with the introduction of the National Electric Power Regulatory Authority's (NEPRA) net metering regulations in 2015, deployment of distributed solar PV systems grew.[9] Net metering regulations allow consumers from all categories—including residential, agricultural, commercial, and industrial—with three-phase connections to be compensated at the off-peak retail tariff for contributing excess electricity to the grid after availing this facility.[10] The total number of net metering consumers increased from 108 in June 2017 to 157,844 by the end of June 2024, with 1,181 MW of total capacity added from net metering during FY 2023-24 compared to 583 MW during FY 2022-23.[11] The uptake of grid-independent solar installations, such as residential standalone systems, solar water pumps, and solar street lighting, has also increased. PV technologies have definite prospects for these off-grid applications. For instance, street lighting and irrigation account for over 350 megawatts (MW) and 1000 MW of electricity consumption, respectively and can be easily shifted to solar power.[12]

---

9 Naila Saleh and Paul Upham, "Socio-technical Inertia: Understanding the Barriers to Distributed Generation in Pakistan," *Economics of Energy and Environmental Policy* 11, no. 1 (2022): 79-100, https://doi.org/10.5547/2160-5890.11.1.NSAL.

10 Saleh and Upham, "Socio-technical Inertia."

11 National Electric Power Regulatory Authority, *State of Industry Report 2017*, report (Islamabad: National Electric Power Regulatory Authority, 2018), https://nepra.org.pk/publications/State%20of%20Industry%20Reports.php; –– *State of Industry Report 2024,* report (Islamabad: National Electric Power Regulatory Authority, 2025), https://nepra.org.pk/publications/State%20of%20Industry%20Reports.ph.

12 Private Power and Infrastructure Board, "Solar Energy Applications Viable in Pakistan," Accessed August 8, 2024,

However, the growth pace of distributed solar, notwithstanding the increase over recent years, is still considered unsatisfactory compared to the country's solar power generation potential.[13] This is reflected in the meagre contribution of solar energy to Pakistan's total energy mix. In the first half of fiscal year 2024 (FY24), Pakistan produced 0.6% of its electricity through solar, as against 14% by coal, 14.2% by Re-Gasified Liquefied Natural Gas (RLNG), and 11.3% by gas.[14]

Pakistan's energy sector depends heavily on imported petroleum group commodities,[15] accounting for around 30% of the country's import bill.[16] This is a major impediment to Pakistan's economic growth and development. Expanding solar energy generation, including DSEG is, therefore, imperative to reduce excessive dependence on imported commodities and diversify the country's energy mix. A thriving DSEG sector can play an instrumental role in achieving the Government of Pakistan's aim to increase the contribution of renewables in the country's energy mix. The Indicative Generation Capacity Expansion Plan (IGCEP) 2024-34

---

https://ppib.gov.pk/wp-content/uploads/2023/07/SOLAR-ENERGY-APPLICATIONS-VIABLE-IN-PAKISTAN.pdf.

13 Saleh and Upham, "Socio-technical Inertia."

14 Arif Habib Limited, "Pakistan Power Sector: Actual Generation in 2QFY24 fell by 15.2% Compared to the Reference," January 18, 2024, https://arifhabibltd.com/api/research/open?path=178/65a8cd1a15fdcdc42f1634fa.pdf.

15 Lubna Riaz, "Navigating Pakistan's Power Sector Challenges: Tackling High Electricity Cost," (paper, Institute of Policy Studies, 2023), https://www.ips.org.pk/navigating-pakistans-power-sector-challenges-tackling-high-electricity-cost/.

16 State Bank of Pakistan, "Import Payments by Commodities and Groups," Accessed April 26, 2024, https://www.sbp.org.pk/ecodata/Import_Payments_by_Commodities_and_Groups.pdf.

envisages an increase in the share of electricity generated by solar sources from 1% in 2024 to 7% by 2029 and 10% by 2034.[17]

In view of this, the study aimed to identify the potential and barriers to DSEG in Pakistan through a SWOT (Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T)) analysis technique. More specifically, it identified the 'strengths' that provide Pakistan with an advantage in solar power generation and the 'opportunities' to promote uptake of distributed solar energy systems. In addition, it explored 'weaknesses' restricting greater adoption and diffusion of DSEG in Pakistan and the 'threats' that could hinder its prospects. Numerous studies have been undertaken on the potential and barriers to solar energy generation in Pakistan. However, given that solar PV is a fast-evolving domain characterised by rapidly emerging challenges and opportunities, the subject necessitates constant research and updates. Given this, the present study was undertaken to identify both the past and new developments.

The paper has been structured into five sections. Following the introduction, the next section presents an overview of the theoretical framework. Section three outlines the study's methodology, and section four presents the results. Section five presents a discussion of the findings. Section six concludes the study and offers recommendations.

Theoretical Framework: Diffusion of Innovation Theory

The present study applies the Diffusion of Innovation (DOI) theory to provide a roadmap for discussion. Everett Rogers, a sociologist

---

17 National Transmission and Dispatch Company, *Indicative Generation Capacity Expansion Plan*, report (Islamabad: National Transmission and Dispatch Company, 2024), https://nepra.org.pk/Admission%20Notices/2024/05%20May/IGCEP%202024-34%20Report.pdf.

and a communication scholar, developed this theory in 1962.[18] The theory describes how innovation develops and spreads in a specific social system over time. Rogers outlined the innovation-decision process to explain how decision-making units reject or adopt innovations. He divided the process into five distinct steps or phases: knowledge, persuasion, decision, implementation, and confirmation. These five steps have been detailed in Table I. In the knowledge phase, the decision-making unit learns about the existence of innovation and seeks information about it, while the persuasion stage involves shaping one's attitude (positive or negative) towards the innovation after learning about it. In the decision phase, the decision-making unit chooses to accept or reject an innovation, followed by the implementation phase, which involves implementing the innovation. In the confirmation stage, the decision-making unit evaluates whether or not the innovation achieves the expected value.

[18] Fredrik Lind and Beatrice Åman, "Diffusion and Adoption of Renewable Energy Products for Enhanced Societal Wellbeing," (Bachelor Thesis., Karlstad University, Karlstad, 2022).

Table I: Five Phases of the Innovation-Decision Process

Phase	Description
Knowledge	The moment the individual becomes aware that the innovation exists and gains knowledge of how it works
Persuasion	When the individual forms a negative or positive attitude towards the innovation
Decision	The individual engages in activities that will lead to a decision whether to adopt the innovation or not
Implementation	The individual implements the innovation and continues learning about it
Confirmation	The individual evaluates during the use of the innovation whether it achieves the expected value or not. If the expected value is achieved, the individual continues to use the innovation, otherwise, may discard it.

Source: Lind and Åman, "Diffusion and Adoption of Renewable Energy Products."

Materials and Methods

The study employed the SWOT analysis technique, identifying the strengths (S), opportunities (O), weaknesses (W), and threats (T) for the adoption and diffusion of DSEG in Pakistan through a comprehensive review of the literature. Secondary data sources were utilised, including articles from reputable national and international journals, books, reports from NEPRA, National Transmission and Dispatch Company (NTDC), International Institute for Sustainable Development (IISD), the World Bank, and newspaper articles. Majority of the utilised sources were published between 2019 and 2024.

SWOT analysis is one of the most prevalent and results-oriented methods used for strategic planning.[19] It offers the advantage of analysing multiple domains quickly and seamlessly through multidimensional modelling.[20] This tool has been extensively applied, and in recent years, it has also been employed in studies related to energy, including wind and solar power generation,[21] evidencing its appropriateness for the present study.

Results and Findings of the SWOT Analysis

The following section details the findings of the SWOT analysis. It amalgamates all findings, including those relevant to residential, agricultural, and industrial sectors and those applicable to specific sectors.

Strengths

Strong solar irradiation: The amount of irradiance falling over a surface horizontal to the ground, i.e., the global horizontal irradiance (GHI), is an important determinant of the electricity generated by solar power systems. The GHI depends on factors such as geographic latitude, atmospheric transparency, sunshine time, altitude, or air quality. Pakistan's annual mean daily GHI is noticeably high compared to the global average—5.30 kilowatt

19 Marilyn M. Helms and Judy Nixon, "Exploring SWOT Analysis – Where Are We Now?" *Journal of Strategy and Management* 3, no. 3 (2010): 215-251, DOI 10.1108/17554251011064837.

20 Christine Namugenyi, Shastri L Nimmagadda and Torsten Reiners, "Design of a SWOT Analysis Model and its Evaluation in Diverse Digital Business Ecosystems Context," *Procedia Computer Science* 159 (2019): 1145-1154, 10.1016/j.procs.2019.09.283.

21 Hengtian Wang, Xiaolong Yang, Qihe Lou and Xinxin Xu, "Achieving a Sustainable Development Process by Deployment of Solar Power in ASEAN: A SWOT Analysis," *Processes* 9, (2021): 630, https://doi.org/10.3390/pr9040630.

hours per square metre (kWh/m2),[22] while in the southwestern parts of the country, irradiance levels go as high as 6.5 to 7 kWh/m2.[23] In comparison, the global mean yearly daily GHI is 3.61 kWh/m2.[24]

Enough sunshine hours: Pakistan is situated at a favourable location as far as the duration of sunlight availability is concerned. Solar panels, on average, require 1000 watts of sunlight per square metre (W/m2) daily in order to run optimally, for which roughly four to five hours of peak solar hours are sufficient.[25] According to most estimates, the average sunshine duration in the majority of Pakistan is between eight and ten hours per day,[26] while peak solar hours range from four to six hours a day.[27]

---

22 Z. R. Tahir and Muhammad Asim, "Surface Measured Solar Radiation Data and Solar Energy Resource Assessment of Pakistan: A Review," *Renewable and Sustainable Energy Reviews* 81, (2018): 2839-2861, http://dx.doi.org/10.1016/j.rser.2017.06.090.

23 Haleema Qamar, Hafsa Qamar and Muhammad Umair Khan, "Solar Irradiance and On Grid Solar Power Systems with Net Metering in Pakistan," *Advances in Science, Technology and Engineering Systems* 1, no. 2 (2016): 1-5, https://www.astesj.com/publications/ASTESJ_010201.pdf.

24 Tahir and Asim, "Surface Measured Solar Radiation Data," 4.

25 JFK Electrical Solar and Air, "How Much Direct Sunlight Do Solar Panels Need," June 21, 2022, https://jfkelectrical.com.au/does-solar-panel-need-direct-sunlight/.

26 FengCheng Chien, Hafiz Waqas Kamran, Gadah Albashar and Wasim Iqbal, "Dynamic Planning, Conversion, and Management Strategy of Different Renewable Energy Sources: A Sustainable Solution for Severe Energy Crises in Emerging Economies," *International Journal of Hydrogen Energy* 46, (2021): 7745-7758, https://doi.org/10.1016/j.ijhydene.2020.12.004.

27 Ecospark Solar, "Peak Sun Hours in Pakistan (Islamabad, Punjab, KPK, Baluchistan, and Sindh," Accessed April 21, 2024, https://ecosparksolar.com/peak-sun-hours-in-pakistan/.

Fairly consistent availability of sunshine throughout the year: The reasonably consistent availability of sunshine throughout the year establishes solar as a reliable energy source in Pakistan. The seasonal variability in the sunshine hours is low, with annual mean daily sunlight period ranging from seven to eight hours during winter and nine to ten hours during summers across most of the country, except the Northern Areas.[28] Additionally, on average, most of the country receives more than 300 sunshine days a year.[29]

Weaknesses

High initial costs of solar energy systems, specifically for low and middle-income earners*:* The cost of hardware for solar energy systems, such as solar PV panels or solar batteries, has decreased over time.[30] While this has increased the affordability of solar energy use for a relatively larger segment of society, for many low and middle-income earners and households, the initial cost of a solar energy system continues to be high.

Concerns about the quality of solar system equipment in the market: The quality control and supervision of solar system equipment in Pakistan is not up to par, which lowers customers'

---

28 Sara Batool Naqvi, "Solar Energy in South Punjab/Pakistan: Domestic Users' Perceptions," *American Scientific Research Journal for Engineering, Technology, and Sciences* 67, no. 1 (2020): 171-182, https://asrjetsjournal.org/index.php/American_Scientific_Journal/article/view/5889.

29 Z. R. Tahir and Muhammad Asim, "The Evaluation of Reanalysis and Analysis Products of Solar Radiation in Sindh Province, Pakistan," *Renewable Energy* 145, (2020): 347-362, https://doi.org/10.1016/j.renene.2019.04.107.

30 Mehreen Gul, Yash Kotak and Tariq Muneer, "Review on Recent Trend of Solar Photovoltaic Technology," *Energy Exploration and Exploitation* 34, no. 4 (2020): 486-526, DOI: 10.1177/0144598716650552.

trust in solar technology.[31] Poor quality solar system equipment, including solar PV panels, can pose many challenges, resulting in cost overruns or solar energy systems running down earlier than expected. For instance, microcracks due to the usage of low quality silicon cells in PV panels, among other factors, are a significant cause of solar panel malfunctions, or low quality plastics in solar panels can result in delamination, involving separation of the plastic backing of a solar panel from the glass.[32]

Inadequate dissemination of technical information: Insufficient knowledge about the long-term operation and maintenance of solar energy systems increases the actual or perceived complexity of solar energy use. Although campaigns to promote investment in solar energy usage are rising, there is still inadequate dissemination of practical information among consumers regarding the usage of a solar energy system, such as information about routine maintenance of the system, system performance monitoring, backup power options, or net metering system, among others, to alleviate the complexity of transitioning to solar energy use.[33]

Challenges of solar net metering uptake*:* Net metering is the billing mechanism that credits owners of solar energy systems for adding excess electricity to the grid and offers a strong incentive for uptake or expansion of solar energy usage. Pakistan has been among early

31 Muhammad Irfan, Zhen-Yu Zhao, Munir Ahmad and Marie Clarie Mukeshimana, "Solar Energy Development in Pakistan: Barriers and Policy Recommendations," *Sustainability* 11, no. 4 (2019): 1206, https://doi.org/10.3390/su11041206.

32 Durbek Fattakhov, "Problems Which You May Face Using Low-Quality PV Modules," *LinkedIn*, December 28, 2017, https://www.linkedin.com/pulse/problems-which-you-may-face-using-low-quality-pv-durbek-fattakhov/.

33 Irfan et al., "Solar Energy Development in Pakistan," 16.

movers in the net metering space.[34] However, multiple obstacles have continued to affect consumers' ease of net metering installation. Among them are the high upfront cost of net metering, inadequate tailored lending mechanisms to facilitate its uptake, cumbersome procedures for obtaining net metering licences, or non-cooperation of concerned authorities.[35] Additionally, the current net metering market is limited to three-phase users. It excludes single phase customers, while research has shown that 7.54 Terawatt hour (TWh) can be renewably added to the grid by just allowing 5% single phase net energy metering.[36]

Challenges in accessing finance for solar products: Solar financing is vital to encouraging greater uptake of solar energy systems by facilitating initial capital investment and increasing return on it. Solar financing facilities in Pakistan exist; however, certain factors impede the ease with which potential adopters of solar energy systems can access finance. The State Bank of Pakistan (SBP) introduced a 'concessionary financial scheme' requiring commercial banks to extend loans to applicants at easy terms and subsidised interest rates. However, according to a follow-up evaluation, not all commercial banks have embraced this scheme.[37]

---

34 Hina Aslam, Ahad Nazir and Ubaid ur Rehman Zia, *Annual State of the Renewable Energy Report Pakistan 2021-2022*, report (Islamabad: Sustainable Development Policy Institute, 2022), https://sdpi.org/assets/lib/uploads/SDPI-RENEWABLE%20ENERGY%20REPORT-2022.pdf.

35 Aslam et al., *Annual State of the Renewable Energy Report*, 67; Naila Saleh and Paul Upham, "Sociotechnical Misalignments and Micro-Renewables Adoption: The Case of Distributed Solar PV in Pakistan," *Renewable and Sustainable Energy Transition* 4, (2023): 100071, https://doi.org/10.1016/j.rset.2023.100071.

36 Muhammad Usman Tahir, Kiran Siraj, Syed Faizan Ali Shah and Naveed Arshad, "Evaluation of Single-Phase Net-Metering to Meet Renewable Energy Targets: A Case Study from Pakistan," *Energy policy* 172, no. 7 (2023): 113311, DOI:10.1016/j.enpol.2022.113311.

37 Saleh and Upham, "Sociotechnical Misalignments," 6.

The strict eligibility criteria set by many banks to acquire finance under the scheme further limit potential adopters' accessibility to solar financing.[38] Additionally, interest rates have increased significantly since 2023,[39] which has posed challenges to acquire financing facilities from banking institutions.

Reliance on the single buyer electric power market model: The current structure of Pakistan's electricity market is based on the single buyer model, where the Central Power Purchasing Agency (CPPA-G) purchases electricity on behalf of distribution companies (DISCOs). In 2020, NEPRA approved a Competitive Trading Bilateral Contract Market (CTBCM) model, providing a roadmap for opening the wholesale electricity market in Pakistan. A CTBCM model allows bulk power consumers to purchase electricity from a competitive supplier or DISCOs.[40] Such an arrangement means better pricing for the solar adopters for the sale of excess electricity, thus making adoption of solar energy systems more economically attractive.However, although several announcements have been made since its approval, the materialisation of the CTBCM model appears unlikely in the near future.[41]

Opportunities

Declining solar PV panel costs: Solar PV panels constitute the largest portion of the solar energy system cost. Their prices have been steadily declining over an extended period. Domestically, in 2022, the Government of Pakistan (GoP) announced removal of the 17% General Sales Tax (GST) on imported solar panels, significantly

38 Saleh and Upham, "Sociotechnical Misalignments," 6.
39 Trading Economics, "Pakistan Interest Rate," Accessed August 3, 2024, https://tradingeconomics.com/pakistan/interest-rate.
40 National Electric Power Regulatory Authority, "Competitive Trading Bilateral Contracts Market," Accessed August 3, 2024, https://www.nepra.org.pk/ctbcm.php.
41 Afia Malik, "IPPs and Capacity Payments," *Dawn*, July 29, 2024, https://www.dawn.com/news/1848654.

alleviating price pressures and facilitating the adoption of solar PV systems.[42] Globally, technological advancements have increased the light-to-electricity conversion efficiency of solar panels, thus lowering their cost per watt.[43] Additionally, with the proportion of solar panel production in China having risen, the cost of producing solar panels has reduced due to lower production costs of firms from China compared to firms from other parts of the world. Moreover, manufacturing capacity of firms producing solar technology and equipment is growing worldwide while capital equipment prices have decreased.[44] As a result, global solar PV panel prices have been declining. The trend has picked up momentum, and in just 2023, the spot prices of solar PV modules decreased by almost 50% year-on-year (YoY).[45] In Pakistan, the price of solar panels also decreased from PKR 80 per watt in 2022 to PKR 37 per watt in 2024, representing more than 50% decrease.[46] This trajectory is likely to be maintained in the ensuing period. The global solar manufacturing capacity will remain at more than double annual installation in the upcoming years, which will continue to put downward pressure on global solar panel prices.[47]

---

42 Imran Ayub, "PM Removes 17pc GST on Solar Panels," *Business Recorder*, May 21, 2022, https://www.dawn.com/news/1690683.

43 Unni Pillai, "Drivers of Cost Reduction in Solar Photovoltaics," *Energy Economics* 50, (2015): 286-293, http://dx.doi.org/10.1016/j.eneco.2015.05.015.

44 Pillai, "Drivers of Cost Reduction in Solar Photovoltaics," 288.

45 International Energy Agency, "Renewables 2023," Accessed April 22, 2024, https://www.iea.org/reports/renewables-2023/executive-summary.

46 "Solar Panel Prices Drop Further in Pakistan," *News International*, 11 May, 2024, https://www.thenews.com.pk/print/1187754-solar-panel-prices-drop-further-in-pakistan.

47 Alex Blackburne, "World Stuck in Major Solar Panel 'Supply Glut'; Module Prices Plummet: IEA," *S&P Global*, January 12, 2024, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/011224-world-stuck-in-major-solar-panel-supply-glut-module-prices-plummet-iea.

Improvements in efficiency of solar PV panels: The overall conversion efficiency of solar panels has been on the rise, resulting from improvements in solar cell technology and manufacturing processes. One notable advancement, for instance, has been development of passivation techniques to minimise energy losses at the solar cell's surface.[48] As a result of these advancements, the average panel conversion efficiency, over recent years, has risen to over 23% from 15%, increasing the power rating of a standard size panel from 250W to more than 440W.[49] A higher light-to-electricity conversion efficiency of solar panels increases the amount of electricity produced for a similar area,[50] thus shortening the solar payback period or the time the investment takes to break even its cost.

Advances in battery technologies for solar applications: Advancements in solar storage battery technologies are key to increasing solar energy systems' efficiency, scalability, and reliability. Innovations in manufacturing and battery chemistries have reduced the costs of lithium-ion batteries and improved their performance.[51] Sodium-based batteries are also emerging as a promising alternative to traditional lithium-ion batteries as they utilise a less expensive and more abundant resource for energy

48 M. M. Hasan, Shakhawat Hossain, M. Mofijur, Zobaidul Kabir, Irfan Anjum Badruddin et al., "Harnessing Solar Power: A Review of Photovoltaic Innovations, Solar Thermal Systems, and the Dawn of the Energy Storage Solutions," *Energies* 16, no. 8 (2023): 6456, https://doi.org/10.3390/en16186456.

49 Jason Svarc, "Most Efficient Solar Panels 2024," *Clean Energy Reviews*, February 23, 2024, https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels.

50 Pillai, "Drivers of Cost Reduction in Solar Photovoltaics," 287.

51 "A Global Review of Battery Storage: The Fastest Growing Clean Energy Technology Today," *Energy Post*, May 27, 2024, https://energypost.eu/a-global-review-of-battery-storage-the-fastest-growing-clean-energy-technology-today/.

storage, i.e., sodium ions. Moreover, emerging storage technologies, such as flow batteries and hydrogen storage systems, show promising results in enabling large-scale and long-duration solar energy storage.[52] Flow batteries and hydrogen storage systems have longer lifetimes and can store relatively larger amounts of energy than lithium-ion batteries.[53]

Growing possibilities of solar technology utilisation: The evolution of solar technologies is not just improving efficiency of solar energy systems but also expanding the possibilities of solar technology utilisation, particularly at space-constrained sites. For instance, building-integrated photovoltaics (BIPV) is one major solar solution involving PV materials that replace conventional building materials, such as on rooftops, facades, or skylights.[54] Likewise, solar carports are another popular alternative involving ground-mounted solar panels that can be installed in vehicle parking lots, allowing for better land utilisation.[55] Similarly, in the agricultural sector, agrivoltaic systems have emerged as a promising solution. These include PV panels positioned at a height, allowing for regular farming practices to be carried out below. These growing

52 Hasan et al., "Harnessing Solar Power," 15-16.

53 Hasan et al., "Harnessing Solar Power."; Aditi Ambadkar, "What is a Flow Battery: A Comprehensive Guide to Understanding and Implementing Flow Batteries," *Wevolver*, June 23, 2023, https://www.wevolver.com/article/what-is-a-flow-battery-a-comprehensive-guide-to-understanding-and-implementing-flow-batteries.

54 Zuher R. Khalifa Abojela, Mohd Khairunaz Mat Desa and Ahmad H. Sabry, "Current Prospects of Building-Integrated Solar PV Systems and the Application of Bifacial PVS," *Frontiers in Energy Research* 11, (2023), DOI:10.3389/fenrg.2023.1164494.

55 Salman Habib, Muhammad Tamoor, Muhammad Ans Zaka and Youwei Jia, "Assessment and Optimisation of Carport Structures for Photovoltaic Systems: A Path to Sustainable Energy Development," *Energy Conversion and Management* 195, (2023): 117617, https://doi.org/10.1016/j.enconman.2023.117617.

possibilities of solar technology utilisation can enhance the prospects of solar PV uptake.

Reducing subsidies on commercial fuel: The GoP has been phasing out subsidies for commercial fuel in recent years to address the country's mounting fiscal pressure.[56] This inevitably increases the monetary incentive for solar PV adoption, as any decision to consider between renewables and conventional energy sources is influenced by the cost of the latter. Research has repeatedly shown that commercial fuel subsidies slow down uptake of renewable energy by improving the relative cost of traditional energy sources.[57]

Solar support schemes: The federal and provincial governments have announced solar support schemes, specifically for farmers and financially constrained households. Notable among them is the 'CM Punjab Solar Panel' scheme under the *'Roshan Gharana'* programme announced in April 2024, which aimed to provide 50,000 solar panels to users of up to 100 units of power per month.[58] Similarly, the federal and Balochistan governments signed an agreement worth PKR 55 billion in July 2024 to solarise

---

56 Rubina Ilyas, Khadim Hussain, Mehreen Zaid Ullah and Jianhong Xue, "Distributional Impact of Phasing Out Residential Electricity Subsidies on Household Welfare," *Energy Policy* 163, (2022): 112825, https://doi.org/10.1016/j.enpol.2022.112825.

57 Richard Bridle and Lucky Kitson, *The Impact of Fossil Fuel Subsidies on Renewable Electricity Generation*, report (Geneva: International Institute for Sustainable Development, 2014), https://www.iisd.org/system/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf.

58 Directorate General Public Relations, "CM Punjab Solar Panel Scheme: A Step Towards Sustainable Energy," June 13, 2024, https://dgpr.punjab.gov.pk/index.php/node/33574.

agricultural tube-wells.[59] Similar schemes have also either been announced or are in the implementation stage.

Prioritisation of sustainability in the global markets: A significant transformation is forthcoming in global trade as countries consider trade instruments to apply a carbon price on imported goods. In this regard, the European Union (EU) has led the way by introducing the first Carbon Border Adjustment Mechanism (CBAM). CBAM is set to be fully integrated with the EU's Emissions Trading System (ETS) by 2026, placing an import tariff on carbon-intensive products from non-EU countries.[60] This implies that exporters from non-EU countries may face increased costs if they do not enhance their carbon efficiency, which will inevitably reduce their competitiveness and profit margins.[61] The mechanism presents an opportunity for the growth of DSEG at the industrial level in non-EU countries, including Pakistan, by providing industries with an impetus to invest in sustainable and cleaner production practices.

Growing stakeholder pressure for Environmental, Social, and Governance (ESG) reporting: Stakeholder pressure on companies to report on Environmental, Social, and Governance (ESG) practices has been growing worldwide, including Pakistan.[62] Commitment to sustainable practices is vital for companies to ensure investor confidence, maintain a strong reputation, and build a positive brand

---

59 Zulqernain Tahir, "Accord Signed to 'Solarise' Tube Wells in Balochistan," *Dawn*, July 9, 2024, https://www.dawn.com/news/1844774.

60 Rahat Sabyrbekov and Indra Overland, "Small and Large Friends of the EU's Carbon Border Adjustment Mechanism: Which non-EU Countries are Likely to Support It," *Energy Strategy Reviews* 51, (2024): 101303, https://doi.org/10.1016/j.esr.2024.101303.

61 Sabyrbekov and Overland, "Small and Large Friends of the EU's Carbon Border Adjustment Mechanism."

62 Pakistan Stock Exchange Limited, "Environmental Social Governance," Accessed July 31, 2024, https://www.psx.com.pk/psx/environmental-social-governance.

image. This provides a strong imperative for industries to transition to renewable energy as part of their Corporate Social Responsibility (CSR) strategies.

Pakistan's approval for Renewable Energy Certificate (REC) issuance: The Renewable Energy Certificate (REC) is among the major policy instruments that countries have widely adopted to provide market demand for renewable electricity and accelerate the uptake of renewables.[63] In 2022, Pakistan and eight other markets received approval for International-REC (I-REC) issuance.[64] A REC is a 'tradable, non-tangible energy commodity representing proof that 1 MW-hour (MWh) of electricity was generated from renewable sources.'[65] It can be sold through bilateral trades or exchanges and can be a source of additional revenue generation.

Threats

Unstable/uncertain government policies: Previous research has suggested that countries that have experienced rapid growth in solar PV have maintained relatively stable policies.[66] Although Pakistan has implemented incentive policies to promote solar PV uptake, such as removal of GST on imported solar equipment,[67] it needs a better track record of policy consistency and certainty. As a case in point, in 2022, the GoP announced removing 17% GST on imported solar panels, contributing to a reduction in the prices of

63 Qingyuan Zhu, Xifan Chen, Malin Song, Xingchen Li and Zhiyang Shen, "Impact of Renewable Electricity Standard and Renewable Energy Certificates on Renewable Energy Investments And Carbon Emissions," *Journal of Environmental Management* 306, (2022): 114495, https://doi.org/10.1016/j.jenvman.2022.114495.

64 Lotus Shaheen, "Seven I-REC Trends to Watch Out for in 2023," *First Climate*, March 30, 2023, https://www.firstclimate.com/post/7-i-rec-trends-to-watch-out-for-in-2023?lang=en.

65 Zhu et al., "Impact of Renewable Electricity Standard."

66 Wang et al., "Achieving a Sustainable Development Process," 13.

67 Ayub, "PM Removes 17pc GST on Solar Panels."

solar panels. However, days later, the SBP imposed de facto restrictions on the import of solar panels. The restrictions were later removed but, for a time, contributed to shortage and an increase in the prices of solar panels.[68]

Another example relates to the buyback rates for net metered electricity. At the time of writing, net metering users received PKR 21 per unit for the surplus solar electricity fed back into the grid.[69] However, multiple times the government considered slashing solar net metering buyback rates,[70] bringing uncertainty for solar participants. Moreover, at the time of the writing, speculations also existed regarding the government's consideration to potentially transition from net metering to a 'gross metering' system, under which solar energy generated by the end-users will be fed directly into the national grid, and the end-users will then draw electricity solely from the grid.[71]

Currency depreciation: Currency depreciation causes fluctuations in the price of solar equipment, thus posing challenges for advancing solar energy use in Pakistan. The country continues to depend heavily on imported solar equipment and technology to meet domestic demand,[72] particularly from China, due to limited

68 Mujtaba Raza, "Blunders vis-a-vis Solar Energy," *Dawn*, November 21, 2022, https://www.dawn.com/news/1722214/blunders-vis-a-vis-solar-energy.

69 "Govt Considers Cutting Buyback Rates from Rs 21 to Rs 11/unit for Net-Metering," *Profit*, April 25, 2024, https://profit.pakistantoday.com.pk/2024/04/25/govt-considers-cutting-buyback-rates-from-rs-21-to-rs-11-unit-for-net-metering/.

70 Mushtaq Ghumman, "Net Metering Power: Govt Mulling Bringing Buyback Rates Down to Rs 11/Unit From Rs 21," *Business Recorder*, April 25, 2024, https://www.brecorder.com/news/40300217.

71 "Govt to Shift from Net to Gross Metering for Solar Panels Amid IMF Talks," *Profit*, Accessed August 3, 2024, https://profit.pakistantoday.com.pk/2024/05/19/govt-to-shift-from-net-to-gross-metering-for-solar-panels-amid-imf-talks/.

72 Irfan et al., "Solar Energy Development in Pakistan," 13.

internal supply, although domestic production of these technologies and equipment has been gradually rising.[73] Any notable depreciation of the Pakistani Rupee can affect the progress of solar PV uptake by increasing the cost of imported solar technologies/equipment and reducing the return on solar PV uptake.

Pakistan's growing smog problem: Since the past few years, major Pakistani cities, particularly Lahore and its surroundings, have been experiencing recurring episodes of smog due to industrialisation and traffic pollution, causing smog to be labelled as the country's 'fifth season.'[74] Its intensity is expected to worsen if adequate measures are not implemented. Smog reduces the intensity of sunlight reaching solar panels, impacting the performance of solar energy systems. Research indicates that electricity output loss can reach up to 70% during heavy smog, while light smog can cause losses ranging from 20% to 30%.[75]

Independent Power Producers (IPPs) and capacity payments conundrum: Numerous reports suggest that there remains a persistent uncertainty among policymakers in Pakistan about whether to promote or discourage solarisation.[76] At the root of the uncertainty lies the concern that rapid solarisation is reducing demand for traditional grid-based power, which is increasing the

---

73 Syed Akhtar Ali, "Solar PV Indigenisation: Strategy and Scope," *Business Recorder*, August 10, 2022, https://www.brecorder.com/news/40257195.

74 Farah Naz and Abedullah, "Smog: The Fifth Season in Pakistan," *Policy and Research* 3, no.2 (2022), https://pide.org.pk/research/smog-the-fifth-season-in-pakistan/.

75 Wenjun Chen, Mengshi Yang, Sunfang Zhang, Phillip Andrews-Speed and William Li, "What Accounts for China-US Difference in Solar PV Electricity Output? An LMDI Analysis," *Journal of Cleaner Production* 231, (2019): 161-170, https://doi.org/10.1016/j.jclepro.2019.05.207.

76 Shahbaz Rana, "For Fourth time: Govt Stalls Solar Panel Policy," *Express Tribune*, June 23, 2024.

government's burden of idle capacity payments to private Independent Power Producers (IPPs) and the cost of electricity for the consumers. [77] For context, the state's contractual obligations with the IPPs require it to pay them for the entire installed capacity throughout the year, regardless of utilisation.[78] In FY 2025, the per-unit capacity payments have increased to PKR 17.31 per kWh from PKR 16.22 per kWh in FY24.[79] Unless a sustainable solution is implemented, the challenge of burgeoning capacity payments will continue to hinder implementation of stronger incentive policies for solar uptake and cloud the future of solarisation in Pakistan.

Discussion

Recent research has revealed a rise in overall awareness about the benefits of renewables.[80] Of the many means, 'word-of-mouth' has strongly influenced knowledge dissemination about solar PV. Likewise, there is a growing awareness of solar PV energy generation in the agricultural and industrial sectors. However, while awareness about solar PV is becoming more widespread, solar energy generation, including on-site solar generation by end-consumers, remains well below potential and desired levels.

Roger's innovation-decision process suggests that persuasion and decision-making phases that follow the knowledge phase and precede the implementation phase involve meticulous assessment of the relative advantages of adopting a technology by the decision-making unit. During these phases, the decision-making units also

77 "Govt to Shift from Net to Gross Metering for Solar Panels."

78 Fahd Ali and Fatima Beg, "The History of Private Power in Pakistan," (paper, Sustainable Development Policy Institute, Islamabad, 2007), https://sdpi.org/sdpiweb/publications/files/A106-A.pdf.

79 Malik, "IPPs and Capacity Payments.".

80 Abdullah, Deyi Zhou, Tariq Shah, Khalil Jebran, Sajjad Ali et al., "Acceptance and Willingness to Pay for Solar Home System: Survey Evidence from Northern Area of Pakistan," *Energy Reports* 3, (2017): 54-60, http://dx.doi.org/10.1016/j.egyr.2017.03.002.

seek out information very actively. The same applies to the confirmation phase, where technology adopters assess the decision to continue or expand the use of that technology based on whether or not it achieves the expected value. [81] Roger posited that incentives, specifically financial incentives, are key to increasing the relative advantage of a technology and serve as a cue to action. This is also corroborated by studies showing an association between the termination of incentives and a reduction in the adoption of an innovation and vice versa.[82]

The present SWOT analysis findings have highlighted strengths and opportunities to encourage positive attitudes towards adopting distributed solar energy systems. The federal and provincial governments have also introduced a few solar support schemes to boost the renewable energy sector. However, the slower-than-expected growth of solar energy generation[83] suggests that significant challenges and weaknesses must be addressed. Government incentive policies will need to be more robust to encourage greater adoption of distributed solar energy systems. For instance, at the time of this writing, the government was buying a unit of electricity from roof-top solar producers at PKR 22.9 compared to PKR 38.59 from the solar IPPs, and speculations still exist regarding possible reduction of the PKR 22.9 buyback rate.[84]

---

81 Lind and Åman, "Diffusion and Adoption of Renewable Energy Products."

82 Genevieve Simpson and Julian Clifton, "Testing Diffusion of Innovations Theory with Data: Financial Incentives, Early Adopters, and Distributed Solar Energy in Australia," *Energy Research and Social Science* 29, (2017): 12-22, http://dx.doi.org/10.1016/j.erss.2017.04.005.

83 Saleh and Upham, "Socio-technical Inertia."; Arif Habib Limited, "Pakistan Power Sector."

84 Bilal Hussain, "Net-metering: Turning Up the Heat on Pakistani People instead of IPPs," *Business Recorder*, May 23, 2024, https://www.brecorder.com/news/40304924.

Major incentive schemes other than net metering are non-existent.[85]

Conclusion and Recommendations

Pakistan possesses substantial solar energy resources, capable of meeting its high energy demand and reducing reliance on fossil fuels, which have dominated the country's energy market for decades. Distributed solar energy generation offers a promising pathway to harness this immense potential. However, the study highlights that developing a robust distributed solar energy market faces several barriers and threats that must be addressed.

Globally, advancements in solar technology and growing manufacturing capacity of firms have been playing a crucial role in increasing the efficiency of solar PV panels and decreasing their costs. Pakistan must seize this opportunity by passing on such benefits to consumers, particularly by reducing the pressure of additional costs on imported hardware for solar PV systems. This can be achieved through strategies including but not limited to streamlining and improving customs procedures and clearances, diversifying the market for imports, addressing economic fundamentals to boost confidence in the PKR with the aim of preventing excessive currency depreciation. The end goal should be to further reduce the costs of solar equipment and technology in the domestic market to mitigate price pressures for the uptake of solar PV systems. In addition, concessionary solar financing ought to be made more accessible to individuals and entities looking to acquire PV systems. Simultaneously, efforts to indigenise quality solar equipment and technology, which are already underway, must be accelerated to reduce excessive

85 Hamza Naeem and Lubna Riaz, "Renewable Energy-Based Distributed Generation in Pakistan: Status, Importance, and Electrification Opportunities," *Policy-Perspectives* 19, no. 1 (2022): 65-84, https://doi.org/10.13169/polipers.19.1.ra3.

dependence on imported technologies as a medium to long-term goal.

It is paramount that domestic policies for the solar sector remain continuous and stable and only adjusted when necessary. Furthermore, investments to enhance grid stability and reliability must be implemented to not merely facilitate solar PV uptake but also disseminate the benefits of distributed solar energy generation to the broader populace by facilitating the export of excess power to the electricity grid. The process of net metering should be made seamless to ensure that a larger number of distributed solar PV systems can be connected to the grid. A debate is ongoing that expediting net metered connections will lead to an additional pricing burden on consumers who do not have net metered systems, as the requirement to pay a large number of solar adopters will reduce the government's revenue generation in the power sector and lead to electricity price hikes to cater to the burgeoning capacity payments burden. While such concerns are valid, the way forward should be to address the root cause of the capacity payments burden rather than slowing down the pace of solarisation. Addressing the capacity payments burden necessitates renegotiating power purchase agreements with the IPPs, conducting a forensic audit of the latter to verify their claims, and transitioning to a competitive electricity market based on market dynamics of supply and demand. Furthermore, export of excess electricity produced by distributed solar energy systems, along with large-scale government-funded solar projects, can also help alleviate, if not wholly address, the adverse impacts of reducing commercial subsidies on non-adopters of solar energy.

In addition, with the increase in overall awareness about the benefits of renewables and the social acceptability of solar energy use, the public must also be encouraged to towards solar PV uptake by transmitting information, including through 'word-of-mouth.' Government and solar industry professionals must also direct efforts towards disseminating technical information for solar

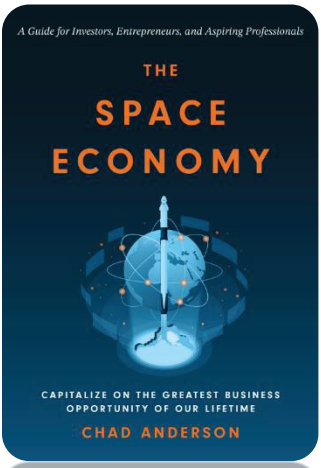
energy use among the population, such as information about routine maintenance, system performance monitoring, and backup power options.

As the global shift toward renewable energy accelerates, Pakistan faces a critical juncture. The country's ability to develop a thriving distributed solar energy market depends on effectively addressing existing weaknesses, such as policy gaps, financial constraints, and infrastructural challenges. Success will require capitalising its abundant solar resources and the growing demand for clean energy while proactively taking advantage of emerging opportunities, such as lowering international costs and technological advancements, to mitigate threats like market volatility and trust barriers. Falling behind in this transition risks exacerbating energy insecurity and economic vulnerabilities.

Zahra Niazi holds a Masters in Development Studies from the National University of Sciences and Technology (NUST), Pakistan. Her research interests include Sustainable Development, Peace and Development, and Development Economics. She can be contacted at: niazizahra98@gmail.com

Book Reviews

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 151-154



Chad Anderson, *The Space Economy: Capitalise on the Greatest Business Opportunity of Our Lifetime* (Hoboken, New Jersey: John Wiley & Sons, Inc., 2023).

Reviewed by Zahra Niazi

The Space Economy, written by venture capitalist Chad Anderson, is a multi-purpose resource that explores the tremendous potential of the space sector while providing actionable takeaways for entrepreneurs, investors, and aspiring professionals to embrace the vast array of opportunities within it.

Writing from his experience as the founder of the space venture capital fund, Space Capital, the author sends a central message that is clear: 'The space economy is on track to becoming the dominant source of growth across the global economy.' Defining space economy as 'any technological product or service that depends on orbital access in some way,' the author writes that over 90% of its value is driven by the satellite sector, including the Global Navigation Satellite System (GNSS), Global Positioning System (GPS), Geospatial Intelligence (GEOINT), and Satellite Communications (SatCom) (pp. 1-48). While GNSS and GPS are used for navigation and positioning and GEOINT for analysing and interpreting geospatial data, SatCom involves transferring data between various points on Earth. Within each of these stacks are companies focussed on one or more of the major competencies, including building, launching, and operating space-based assets; receiving, processing, storing, and delivering the data from those assets; and using the data to deliver products and services to customers. The author also devotes an entire section to featuring

the major companies and startups within the space industry, from Planet Labs, which provides high-resolution imagery of the Earth, and SkyWatch, which aims to make Earth-observation data accessible to the world to Arbol and dClimate, which have been making it possible for the agricultural industry to address the growing risks of climate change (pp. 49-72).

On the question of 'how and why to start a business in the space economy,' the author states that to venture into the space industry, one needs the skills, expertise, and experience to start a company, but the background doesn't have to align perfectly with domains such as aerospace, technology, or the like (p. 74). He then dives into the areas that are currently in demand within the space economy, including Next-generation Earth Observation (EO) applications, Augmented Reality (AR) applications, 3D data and development tools, GPS alternatives, ocean observation, and weather micro-forecasting (pp. 77-80).

The author further offers insightful guidance on the essentials of a successful venture in the space industry (pp. 91-107). He does this by combining his own insights and observations with accounts of experienced professionals in the field. The essentials for entrepreneurs include building a well-equipped founding team, identifying the right market and first customers, setting up the business in the right place, and pitching investors strategically. On the importance of government support to space businesses, he states that 'the very first dollars most new companies that launch in the space economy use to conduct early research and build their first prototypes come not from private investors but from public agencies' (p. 100). Even today, several major players within the space industry rely on or work closely with government agencies in one form or another. The author, however, also asserts that governments ought to give more reign to market forces to allow commercial space efforts to progress (p. 132). Offering motivation to aspiring professionals, he suggests that a wide array of roles is in demand within the space economy, for 'just as space increasingly touches on every part of

business, nearly every type of career touches the space economy' (p. 146).

Moreover, the author notes that although GPS, GEOINT, and SatCom dominate the market at present, four emerging industries are gathering momentum, including stations, lunar, logistics, and industrials (p. 180). As for 'stations,' hundreds of millions of dollars have already been invested in the idea of commercial space habitats. Activities in the lunar industry, including commercial efforts on and around the moon, are also gaining momentum. Additionally, the demand for the logistics industry, comprising space traffic management, on-orbit servicing, and debris mitigation, is growing fast. As for 'industrials,' pharmaceutical companies are already conducting Research and Development (R&D) abroad at the International Space Station (ISS), and ultra-high-quality fibre-optic cable is being manufactured there for specialised purposes. Given these developments, Anderson talks about an urgent imperative for intelligent policies, laws, and treaties that reflect the reality of today's space economy to ensure a profitable and peaceful use of space and its resources by every country (p. 192).

Anderson's passion for the space economy is visible in his writing throughout the book, making it both compelling and persuasive. He assures the readers with convincing arguments that there is room within the space economy for any entrepreneur or professional passionate about forward-looking industries. Hence, as a reader, one can confidently say that the book has the potential to convince at least some motivated investors, entrepreneurs, and aspiring professionals to consider exploring the plethora of opportunities within the space economy. With well-structured and easy-to-follow content and ample examples integrated into the main text, the book is engaging as well as a helpful self-study guide for newcomers to the field of space economy.

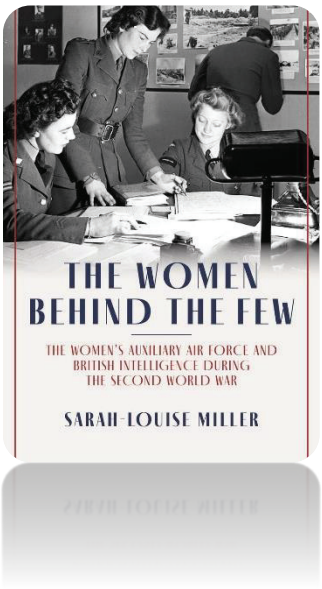
The discussion on the future of the space economy could, however, have been enriched if the author had also explored the potential risks to it, such as the ones highlighted by the World Economic Forum

(WEF). These include a potentially diminished demand for space-based solutions, constraining regulations, or maligned satellite activity that could limit the expansion of the space economy. Reduced demand for space-based solutions, for instance, could occur due to technological advancements on Earth, offering better alternatives to space-based solutions. Evidently, the book is written from the perspective of an author who has a stake in seeing a thriving space sector going forward.

Overall, the book is a useful read because it helps readers understand the current state of the space economy and its verticals, how to participate in them, and why they matter. The book should be integrated into the curricula not just for aerospace specialisations but also for other disciplines such as business administration, computer science, data science, and environmental studies, to name a few.

Zahra Niazi holds a Masters in Development Studies, with majors in Peace, Conflict and Development, from the National University of Sciences and Technology (NUST), Pakistan. Her research interests include Sustainable Development, Peace and Development, and Development Economics. She can be reached at: niazizahra98@gmail.com.

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 155-157



Sara Louise Miller, *The Women Behind the Few: The Women's Auxiliary Airforce and British Intelligence during the Second World War* (London: Biteback Publishing, 2023)

Reviewed by Ajwa Hijazi

The book 'The Women Behind the Few' offers an engaging insight into the role of the Women's Auxiliary Airforce (WAAF) - the female auxiliary of the Royal Air Force (RAF) formed in 1939 -against the backdrop of World War II. The author, Sara Louise Miller, lecturer at the Defence Studies Department, King's College London, and visiting scholar in the faculty of History at the University of Oxford, specialises in the history of World War II. In this book, she highlights the significant intelligence contributions of WAAF that assisted RAF during the war but had been previously overlooked in historical accounts.

In this captivating ten-chapter narrative, Miller recounts the inspiring journey of the women of WAAF who transcended the restrictive societal stereotypes of 'gossip and chatter' to carve out their indelible roles within the intricate network of British intelligence during World War II. At a time when women's expertise in high-level math, science, or engineering was not just rare but often dismissed, these remarkable women shattered expectations. They not only matched but often exceeded their male counterparts in providing crucial intelligence services for aerial warfare. Embedded deeply within bomber and fighter commands, they lived, worked, and, in many tragic instances, died alongside their fellow servicemen, proving their undeniable competency, patriotism and reshaping perceptions of women in

wartime roles. They were integral to radar operations and communication intelligence, and some were even parachute-dropped into Nazi-occupied territories as clandestine agents for the Special Operation Executive (SOE), an organisation formed to support resistance movements and gather intelligence across Europe. The bravery of these women was recognised through numerous medals of valor. Yet, one of their most cherished moments of recognition came when they received a rousing cheer from stationed airmen. This occurred as they marched back to their quarters after enduring a particularly intense raid that resulted in heavy casualties, highlighting the profound respect and admiration they garnered from their peers.

While describing WAAF members as the 'hidden few' (p.18), the author vividly captures their vital intelligence roles across various RAF departments, despite facing societal resistance and governmental skepticism (p.31). She highlights their critical involvement in the Dowding System during the Battle of Britain and the Blitz. This system was crucial for gathering radar intelligence and relaying essential information to the Fighter Command, enabling the timely interception of enemy aircraft (pp.102,112). These courageous women also served in the Y Service - an operation designed to intercept enemy communications. They played a key role in deciphering Luftwaffe codes, thus exposing enemy attack formations and significantly contributing to the Allied war effort (pp.112, 117).

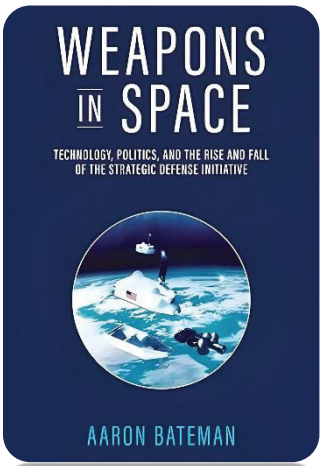
Miller also details how WAAF facilitated the seamless transfer of information to and from Bletchley Park, home of the Government's Code and Cypher School (p.260), and their deployment behind enemy lines in France to train and support the French Resistance, bolstering the Allied landings (p.198). She concludes how the WAAF became indispensable to the RAF's combat capabilities, and consequently, the Women Royal Air Force was established in 1949 as a peacetime counterpart. However, she notes a historical oversight: it was not until 1994 that women were formally integrated as full-time members of RAF, marking a significant milestone in their recognition (p.257).

Using gripping first-hand accounts of WAAF members, including radar operators (pp.55, 84), plotters (pp.56, 89), filter officers (p.88), code breakers (p.133), etc., Miller presents their perspective of war-time contributions and how they were inducted into the intelligence role out of necessity due to insufficient manpower. But still, they charted their territory from doing peripheral administrative work to being vital collectors, analysers, and disseminators of decisive information that paved the way for the overall Allied victory in the war. It is rather ironic and sad that the author discusses Britain's historical skepticism towards women's capabilities in intelligence roles during the World Wars which are prevalent even today according to her, instead of applauding their technical skills and critical contributions.

One significant issue in Miller's book is her frequent use of emotionally charged, hyper-nationalistic language, which can sometimes detract from an objective analysis of historical events. Despite this, the book is an insightful and well-crafted exploration of the often overlooked yet crucial contributions of the Women's Auxiliary Air Force, whose efforts were pivotal in securing air victories for the Allied forces during the war. This work is particularly valuable for academics, researchers, and students specialising in international relations, gender studies, and sociology, as well as anyone interested in the nuanced historical accounts of the World Wars.

Ajwa Hijazi has done her MPhil in Peace and Conflict Studies from the National Defence University (NDU), Islamabad. Her research interests include traditional and non-traditional security with a focus on internal security, human security, and electoral politics. She can be contacted at: hijaziajwa@gmail.com

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 158-161



Aaron Bateman, *Weapons in Space: Technology, Politics, and the Rise and Fall of the Strategic Defence Initiative* (The MIT Press, May 2024)

Reviewed by Mustafa Bilal

In 1984, the Reagan administration in the United States (US) warned allies about Soviet military space activities. In international politics, sometimes history repeats itself; forty years later, 2024 started with US defence officials warning allies of Russia's potential deployment of a nuclear weapon in space. The stark parallels between the present and the past raise the question of why space weaponisation has again become an international concern. Aaron Bateman seeks to grapple with this fundamental question in his first book, which builds on his doctoral thesis.

The author, a former U.S. Air Force (USAF) Intelligence officer and an Assistant Professor of history and international affairs at George Washington University delivers an illuminating historical account of the Strategic Defence Initiative (SDI), which President Reagan envisioned as a space-based missile defence shield. Bateman explores the technological debates sparked by SDI and its political and international dimensions. He analyses the intensified space militarisation in the final two decades of the Cold War by offering an archive-driven account of SDI's meteoric rise, rapid descent and enduring legacy on astropolitics and contemporary debates concerning space security. The book can be scrutinised in three ways: central theme, style of expression and key takeaways.

The central theme, which cuts across all the chapters, is divisions. Whether it be divisions in the Reagan administration on the technological foundations of SDI (pp. 52-110), divisions between Western European states both over SDI and the extent of their participation (pp. 110-142) and the overarching divisions between the US, its European allies and the former Soviet Union over the limits on military space activities and the ABM treaty (pp.144-174). Bateman situates these divisions in the context of the contentious space arms control negotiations by stressing the inextricable technological linkage between ASATs and SDI (p. 146). He posits that because of such disagreements, the issues left unresolved in the space arms control dialogue of the late Cold War are gaining renewed international concern, such as the debates over space weaponisation (pp. 220-226).

As for the style of expression, the book is narratively engaging. History can sometimes be boring, but Bateman supports his arguments by referencing intriguing unclassified conversations between officials across the US, Western Europe and the former Soviet Union. Despite placing 'technology' at the start of the book's title, the technical aspects of SDI are largely overshadowed by the politics surrounding its rise and fall. Bateman does examine the technological challenges accompanying the first phase of SDI deployment in the latter half of the book (pp. 181-216), but he does so without dry, lengthy technical descriptions. The lack of technical details might disappoint readers from a purely military-technical background. However, it would improve comprehension for most general audiences, who would also appreciate the absence of complex vocabulary.

What takes away from the reading experience is how the book doesn't proceed chronologically. Despite Bateman stating in the beginning that the events would follow chronologically (p. 20), the timeline in the book is not linear until the last few chapters, which narrate events post-Cold War. Thus, it eventually becomes hard to keep track of the specific dates (which are, of course, plenty). Additionally, throughout the book, ideas and concepts are repeated. Some of it can be excused for emphasising key aspects, such as Reagan's utopian conceptions

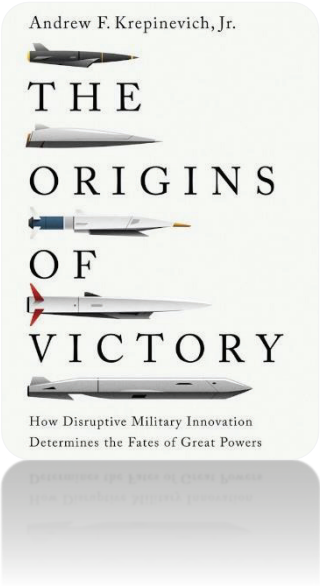
of SDI (p. 53) and his conviction that SDI would make nuclear weapons obsolete (p. 67), but it is hard to ignore in most cases.

However, looking past these issues, one can see that Bateman's work has many insightful takeaways, especially from the present lens. Bateman's first assertion is that 'technological innovations and cooling superpower relations created the conditions for expanded space militarisation in the 1970s' (p. 51). In the present context, ongoing technological breakthroughs in Artificial intelligence (AI) and miniaturising electronics combined with deteriorating Sino-US ties could similarly lead to a new phase in the militarisation of space. Indeed, throughout the book, one can notice glaring similarities between US-Soviet and Sino-US great power competition in space. Bateman also highlighted a conviction deeply held by the US that space technologies were linked with security and prosperity (p. 82). Presently, this conviction is underscored by the increasing cooperation between commercial space firms and the US space force. Bateman has also noted how idealistic public perceptions of the cosmos were at odds with the expanding militarisation of space (p.153); this is true even today, partly explaining the growing opposition to space weaponisation. Bateman also asserted that the fear of being technologically left behind diluted the opposition of major European states towards participating in SDI and militarising space (p. 141). This eventually culminated in space now being designated by NATO as an 'operational domain.' Perhaps the most significant takeaway from the book is that while there were undoubtedly technological uncertainties surrounding the deployment of SDI, the lack of political will to deploy space-based weapons played a key role in the downfall of the SDI (p. 206). Therefore, one cannot help but wonder if we will soon see a revival of the SDI with significantly lower launch costs and rapid technological innovations. Considering Donald Trump is once again set to take charge of the Oval Office, it's possible since he had alluded towards 'space-based missile defence' in his first term, as noted by Bateman in the conclusion (p. 223).

To sum up, the book is a timely and highly relevant publication that provides an enlightening history of space arms control and SDI in the late Cold War without explicitly supporting or condemning it. It certainly has issues with style and expression. Still, they can be overlooked as readers can derive valuable insights from Bateman's key takeaways and his narration of historical events, which draw parallels with the present. Hence, the book is worth reading for anyone who seeks to understand how the more things have changed in astropolitics, the more they have remained the same.

Mustafa Bilal has done his BS in International Relations from the National Defence University (NDU), Islamabad. His research interests include technopolitics, astropolitics, military aviation and warfare. He can be contacted at:
mustafabilal27924@gmail.com

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 162-165



Andrew F. Krepinevich, *The Origins of Victory: How Disruptive Military Innovation Determines the Fates of Great Powers* (New Haven: Yale University Press, 2023).

Reviewed by Shah Muhammad

Emerging technologies are driving transformative shifts in the character of warfare, underscoring the urgent need to evolve operational concepts and military strategies. In *The Origins of Victory*, Andrew F. Krepinevich provides a scholarly and insightful exploration of this critical subject. Drawing on his expertise in the higher echelons of the U.S. Department of Defense, Krepinevich essentially argues that militaries that master new technological revolutions are likely to have a decisive edge over their rivals.

The book is divided into two parts. In the first, the author constructs his arguments within the framework of the reconnaissance-strike complex. Reconnaissance refers to the ISR (intelligence, surveillance, and reconnaissance) or scouting forces of a military, while strike represents the combat forces. Krepinevich argues that technology-driven Revolutions in Military Affairs (RMA) enhance the effectiveness of this complex, as militaries aim to optimise their scouting and strike capabilities to gain a decisive advantage. The United States (US) military spearheaded a revolution in precision warfare during the First Gulf War, demonstrating its global dominance in the reconnaissance-strike complex through precision-guided munitions, stealth aircraft, and advanced battle networks (p. 8). However, Krepinevich argues that the growing scouting and strike capabilities of China and Russia

have increasingly challenged US supremacy in the precision warfare domain. Additionally, to keep pace with disruptive variations in the character of warfare, militaries prioritise speed, range and precision as compared to armour and firepower of the weapons systems (p. 41). In the same part, Krepinevich casts an analytical glance at emerging technologies such as Artificial Intelligence (AI), additive manufacturing, quantum computing and synesthetic biology. For instance, he offers a commentary on AI-enabled swarms which could integrate scouting, command and control, and strike elements, thus materialising the prospect of an AI-driven reconnaissance-strike complex (p. 94).

The second part of the book examines four case studies to uncover common patterns of achieving strategic advantage on the battlefield. The first case explores how the British Royal Navy, in the late 19th century, proactively addressed the emerging threats of submarines and torpedoes by developing innovative capabilities, thereby ensuring its continued dominance in naval warfare. Krepinevich next examines the German military's adoption of mechanisation and aviation during the interwar period, which culminated in the devastatingly effective Blitzkrieg strategy. This mechanised and concentrated air-land assault shattered Allied defences, delivering significant German victories in the early years of World War II. The author highlights that Blitzkrieg's success stemmed primarily from Germany's emphasis on speed and range, contrasting with France's reliance on armour and firepower (p. 287).

The third case focuses on the U.S. Navy's recovery after the losses at Pearl Harbor. By revitalising its battleships and aircraft carrier task forces, the Navy achieved major victories in World War II, reshaping naval warfare. Finally, Krepinevich explores how the U.S. Air Force adapted after its setbacks in the Vietnam War, shifting its focus to speed, range, and precision rather than firepower. This transformation culminated in Operation Desert Storm, a landmark of the precision warfare revolution. The campaign decisively neutralised Iraq's integrated air defence system, solidifying American aerial superiority and redefining the modalities of modern aerial warfare (p. 393).

The book is well-researched and coherently written, drawing extensively from the works of past military strategists. Its strength lies in its avoidance of a reductionist view of military technologies. Instead, the author frames technologies as enablers and stresses key factors essential for maximising their strategic potential: a guiding vision, extended tenure for senior officials, new operational concepts, and exercises.

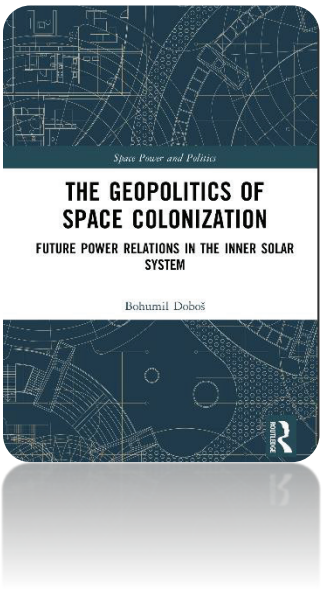
A guiding vision provides military strategists with a clear, forward-thinking direction, while the extended tenure of senior military officials ensures continuity in implementing military revolutions. New operational concepts enable militaries to adapt to the evolving character of warfare by informing analysis, wargaming, and experimentation, while also offering insights for developing new doctrines and structural reforms (p. 406). For example, the British Royal Navy in the late 19th Century adopted the operational concept of Flotilla Defence, employing smaller, more agile vessels to counter the torpedo threat. Similarly, Germany focused on mobility and maneuverability over positional warfare to amplify the impact of Blitzkrieg during World War II. In the precision warfare era exemplified by Operation Desert Storm, the US adopted a strategy of suppressing, rather than bypassing, Iraq's integrated air defence system, ensuring the success of its aerial campaigns.

On the other hand, there are a few glaring shortcomings that afflict the comprehensive nature of the book. There is no mention of robotics in the chapter on emerging technologies. The author could have discussed emerging trends in this regard while highlighting the US military's large-scale robotic exercises under Project Convergence which have been underway since 2020. Moreover, since the book was published in 2023, the author fails to touch upon the ongoing Russia-Ukraine War. The preliminary commentary on the technological aspects of this war could have significantly widened the reception of this book amongst different circles.

All in all though, it is a well-articulated and scholarly work that does not deviate from its central premise. It is highly recommended to the students as well as scholars and practitioners of military strategy.

Shah Muhammad has done MPhil in Peace and Conflict Studies from the National University of Sciences and Technology (NUST), Islamabad. His research interests include emerging technologies, national security, defence modernisation and global governance.

Journal of Aerospace & Security Studies
2024 | Volume III | pp. 166-168



Bohumil Doboš, *The Geopolitics of Space Colonization: Future Power Relations in the Inner Solar System* (New York: Routledge Publishing, 2024)

Reviewed by Uswa Khan

The concept of space colonisation, previously limited to science fiction writings, has made significant progress towards becoming a tangible possibility due to notable advancements in rocket propulsion, design, astronautics, astronomy, and robotics. The central theme of the book 'The Geopolitics of Space Colonisation: Future Power Relations in the Inner Solar System' by Bohumil Doboš explores the future colonisation of celestial bodies in the upcoming decades. The author is an Assistant Professor at the Institute of Political Studies at Charles University.

The book spans 158 pages and is divided into eight chapters. The first chapter provides a concise introduction to the subject, sparking a debate on this highly relevant topic. Its central thesis posits that decisions about proposed and potential missions to establish settlements or extract resources from celestial bodies in the inner solar system are shaped by geographical considerations and carry significant political implications, best analysed through the lens of geopolitics. Following the introduction, the second chapter lays the groundwork for understanding the historical, conceptual, and procedural dimensions of the topic. The author connects traditional geopolitics to astropolitics, tracing the term 'geopolitics' back to its 19th Century German origins (p.6). He explores the Anglo-Saxon

school of thought, highlighting Halford Mackinder's Heartland Theory and Alfred Mahan's Command of the Sea theory, categorising them under classical geopolitics (pp.8-11). The discussion then transitions to post-classical, critical, and systematic geopolitics. Dolman's seminal work is positioned as an essential guide to understanding astropolitics, asserting that dominance in low-Earth orbit and near-Earth space translates to control over Earth and, ultimately, humanity's destiny (pp.24-25).

Building on this, the third chapter shifts focus to the key players vying for dominance in space colonisation. During the early Cold War, the competition was limited to the US and the Soviet Union. Since the 1990s, however, state and non-state actors have entered the fray, including China, Russia, Japan, South Korea, North Korea, the UAE, Israel, India, the EU Agency for Space Programme (EUSPA), and SpaceX (p.33). Doboš predicts that these actors will continue to vie for control of strategic locations in near-Earth and outer space. The fourth chapter tackles the environmental challenges that complicate space exploration, emphasising how planetary conditions differ from Earth's. Moving into the normative realm, the fifth chapter examines the role of international law in regulating great-power competition in space. Doboš underscores the significance of the Outer Space Treaty as a potential framework for maintaining order and accountability. Finally, the concluding chapter explores the key decision points and contentious areas shaping the future of inner solar system colonisation. It reflects on the choices that will define humanity's long-term prospects in deep space, offering insights into the critical consequences of these decisions.

The book is a timely and valuable contribution to the literature on space, offering a geopolitical analysis of the impending human colonisation of stellar objects within the inner planetary system. It examines the political and strategic factors influencing missions to celestial bodies such as the Moon and asteroids, presenting forward-looking scenarios that highlight critical concerns for future operations beyond terrestrial orbits. By systematically analysing the medium-term prospects for establishment and mining operations, the book

identifies key focal points likely to shape power distribution in the inner solar system. It predicts an intensifying competition among states and non-state actors, such as Elon Musk's ventures, for control over nearby planets and moons.

On the policy front, Doboš urges both major and minor powers to establish a new framework for space exploration. Given the increasing involvement of non-state entities, he advocates for the creation of a treaty inspired by the Outer Space Treaty (OST) to prevent geopolitical conflicts and regulate activities in outer space. He also envisions non-human outposts, likely established by robots on the Moon or Mars, as precursors to eventual colonisation; and stresses the urgency of international consensus to manage this new frontier responsibly.

This book will especially engage students exploring the intersection of space power and international relations, providing them with essential insights into the evolving dynamics of space politics.

Uswa Khan has done her Bachelors in Strategic Studies from National Defence University, Islamabad. Her area of interest lies in counterterrorism, geopolitics of the South Asian region and emerging security threats.

ISSN 2790-7139
E-ISSN 2958-082X

GUIDELINES FOR SUBMISSION

Journal of Aerospace & Security Studies

Research Scholars/Practitioners are invited to contribute Original, Unpublished manuscripts to the annual Journal of Aerospace & Security Studies.

Submission Criteria

- Must be unpublished and not under review elsewhere.
- ***Word Limit:*** 5000 words, including a 150-200-word abstract, footnotes.
- ***Citation Format:*** Chicago Manual of Style 17th Edition (Full Note)

Scope of Journal

Primary Themes

- Aerospace and Emerging Technologies
- Security and Defence Strategies
- Cyber and Space Security

Secondary Themes

- International Relations
- Political Economy

Review Process

1. All submissions will undergo a rigorous desk review, including similarity and plagiarism analysis, and an AI-assisted text evaluation.
2. Manuscripts should be concise, well-structured, and interconnected, employing academic writing rather than journalistic styles.
3. High-quality and innovative research must include sections such as an introduction, methodology, theoretical framework/background, findings, analysis/discussion, policy proposals, and conclusion. The conclusion should also explore broader impacts and implications of the findings.
4. Submissions meeting the journal's scope and quality criteria will undergo a minimum of two double-blind subject expert peer reviews that will evaluate whether it offers theoretical/analytical insights, robust argumentation, relevant academic citations, and well-substantiated conclusions.
5. A common issue with submissions is the lack of theoretical integration. Merely citing a theory without proper application or integration does not constitute a theoretical contribution or a sound theoretical basis. Similarly, replication or summaries of prior work without offering novel insights are insufficient. While replication studies have value, JASS prioritises innovative contributions.

Submission Procedure

Author/s are required to email soft copies in MS Word format, along with their brief introduction, complete contact details, and electronically signed Authorship, Conflict of Interest, & Originality Declaration downloadable from the journal website.

Deadline:
End of April

Authors of published articles will be paid a modest honorarium.

Submission Email: cass.editor@gmail.com

Note: CASS holds the right to reject a submission at any stage from being published.

Journal of **Aerospace & Security Studies (JASS)**

The *Journal of Aerospace & Security Studies* (JASS) is Pakistan's first annual international, multidisciplinary, peer-reviewed publication that focuses on Aerospace and Security. The Journal recognises the growing interlinkages between emerging technologies with security and defence issues within the larger context of globalisation. This is, especially important for Pakistan since Research and Development in areas from cyber, space, Artificial Intelligence to hypersonics and biotechnology etc., is at a nascent stage. JASS hopes to fill this critical knowledge gap and publish research that looks at current as well as future AeroSec trends, their application and implications for the global community and Pakistan.

Vision

To publish high quality, original and innovative research that showcases CASS' work as well as encourages scholars to explore aerospace and security issues from a multidisciplinary, policy-driven lens.

Aim

To become a leading voice from Pakistan on aerospace and security issues.

Scope

Primary Themes

- Aerospace and Emerging Technologies
- Security and Defence Strategies
- Cyber and Space Security

Secondary Themes

- International Relations
- Political Economy

CENTRE FOR AEROSPACE & SECURITY STUDIES, ISLAMABAD
Independence. Analytical Rigour. Foresight

Old Airport Road, Islamabad, Pakistan
+92 051 5405011
www.casstt.com
cass.editor@gmail.com/

Centre for Aerospace & Security Studies
cassthinkers
@CassThinkers
cass.thinkers