Routledge Explorations in Energy Studies

CHINA AND GULF COOPERATION COUNCIL COUNTRIES

PARTNERSHIPS TOWARDS ECONOMIC AND ENERGY TRANSITION

Edited by
Dongmei Chen, Fuqiang Yang, Lei Yang
and Majed Alsuwailem

ROUTLEDGE

China and Gulf Cooperation Council Countries

This book investigates the evolving bilateral relations between China and the six Gulf Cooperation Council (GCC) countries as the global energy system undergoes a profound transformation and the architecture of international trade and investment continues to shift.

This book examines how China–GCC relations are evolving as they leverage their resource endowments, structurally transform their economies, and ramp up investments in clean technologies, low-carbon infrastructure, and resilient supply chains. It contemplates the synergistic potential of China–GCC cooperation around three overarching themes: (1) traditional energy, including hydrocarbons and associated petrochemical industries; (2) low-carbon energy sources such as renewables, energy efficiency, hydrogen, and nuclear energy; and (3) key enablers of the clean energy transition, including climate policy framework, sustainable financing, critical minerals, and digitalization. The authors of the book envision a future in which joint endeavors foster shared socioeconomic benefits and promote an inclusive, orderly energy transition, with potential spillover effects that improve economic integration and structural transformation across the Middle East and North Africa. Using evidence-based and structured analysis, the authors draw on case studies and lessons learned to propose policy recommendations that foster coherence, strategy, and effective coordination between China and the GCC in the areas of energy and sustainability.

This book will be an invaluable reference for researchers and academics studying international relations, energy policy and economics, energy geopolitics, and Asian and Middle Eastern studies. It will also be useful for policy analysts in academia and think tanks and advisors and decision-makers in government and private enterprises.

Dongmei Chen is Principal Fellow in the Oil and Gas Department at KAPSARC, Saudi Arabia. Her research focuses on China's overseas energy investment, energy trade, regional energy cooperation, and supply chain integration. With over 30 years of experience in energy and climate policy, she is dedicated to advancing the understanding of China's energy economic relations with the GCC region and the global community.

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Partnerships Towards Economic and Energy Transition

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Contents

Figures

Tables

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Preface

Over the past two decades, the relationship between the Gulf Cooperation Council (GCC) countries and China has evolved from a primarily hydrocarbon-based trade partnership into a multifaceted strategic one. While energy remains central to this relationship, the scope of cooperation has expanded to include industrial infrastructure, digitalization, clean technology, and sustainable finance. A pivotal moment in advancing this partnership came with the inaugural GCC–China Summit, held in Riyadh in December 2022, where the adoption of a joint five-year action plan underscored a broader framework of collaboration encompassing economic diversification, technological innovation, and energy security cooperation.

This volume, co-edited by KAPSARC and the Institute of Energy at Peking University, arrives at a critical juncture. As the global energy system undergoes a profound transformation and the architecture of international trade and investment continues to shift, China–GCC cooperation represents a forward-looking model of mutually beneficial engagement. The book offers a structured, evidence-based analysis complemented by original case studies to inform policy and investment decisions. It focuses on three overarching themes: traditional energy and associated industries; low-carbon energy such as renewables, energy efficiency, and hydrogen and geothermal energy; and key enablers of the clean energy transition, including climate policy frameworks, sustainable financing, critical minerals, and digitalization. Moreover, this volume addresses essential questions: What are the drivers and risks shaping China–GCC energy relations? And how are both partners adapting their policy frameworks, industrial strategies, and energy investments in response to evolving global developments?

This collaborative publication highlights the strategic value of combining KAPSARC's deep expertise in energy policy and regional dynamics in the GCC with Peking University's extensive knowledge of China's energy governance and institutional framework. By integrating region-specific insights from both institutions and combining different perspectives, the book provides a comprehensive understanding of the opportunities and challenges shaping cooperation between the GCC and China. It also offers practical recommendations for policymakers, business leaders, investors, and academics to advance the next phase of China–GCC relations in the areas of energy and economic integration and sustainable development.

Fahad Alajlan
President, KAPSARC

Preface

China and GCC countries share a long-standing history of collaboration. The Belt and Road Initiative, along with the inaugural China–GCC Summit in 2022, has laid out a new blueprint for deepening cooperation across multiple sectors, with energy at its core, elevating China–GCC relations to an unprecedented strategic level. In 2023, bilateral trade between China and the GCC reached an impressive USD 282 billion, representing over 20 times the volumes recorded in 2002.

Since its launch in 2013, the Belt and Road Initiative (BRI) has become a cornerstone of China's international economic engagement, significantly shaping the global energy landscape. The BRI has provided a framework for China and the GCC states to deepen infrastructure investment, energy cooperation, and industrial integration.

Energy cooperation between China and the GCC nations has yielded substantial achievements. China, as a major consumer of oil and natural gas, is also a global contender in the development and deployment of solar, wind, and nuclear energy technologies. The GCC member countries, home to some of the world's largest oil and gas reserves and production capacities, represent the most influential political and economic bloc in the Middle East and occupy a central role in the global energy market. Their collaboration has evolved beyond traditional oil and gas, refining, and petrochemical sectors to encompass renewables, energy storage, hydrogen energy, nuclear power, and sustainable mobility. China and the GCC bloc are steadily embracing an orderly, inclusive, and sustainable energy future. Furthermore, it has significantly contributed to the social and economic prosperity of both sides while playing a critical role in ensuring global energy security and facilitating the transition to sustainable energy systems.

In the face of intensifying challenges posed by global climate change, the energy transition is at a critical juncture. Although China and the GCC may have varied national contexts, their shared commitment to energy sustainability, green development, and climate action reflects a progressive and pragmatic approach. Building on their existing strategic ties, both sides are expanding into new frontiers of cooperation. A deepened partnership will not only accelerate the energy transition and enhance the sustainability of socio-economic development but also enable China and the GCC to jointly address pressing regional and global challenges, including geopolitical tensions, economic uncertainties, and trade complexities.

Since 2023, the Institute of Energy at Peking University and the KAPSARC have been collaborating on joint research pertaining to China and the GCC. This collaboration culminated in the publication of this volume. The book explores opportunities for integrated cooperation in strategic domains. China–GCC energy cooperation is increasingly centered on three key areas: the integration of traditional and low-carbon energy sources—including new forms of oil and gas collaboration, hydrogen, and nuclear power; the development of energy infrastructure and digital technologies to enhance efficiency and build resilient renewable energy supply chains; and the promotion of sustainability through joint efforts in carbon capture, geothermal energy, and securing critical minerals vital for the energy transition. The research is guided by the overarching objectives of energy security, economic growth, and low-carbon development. This book could serve as a valuable resource for academic researchers, policy analysts, decision-makers, think tanks, governments, and private enterprises across the globe.

I extend my heartfelt gratitude to all the authors, members of the editorial board, and supporters whose contributions made this book possible.

(Dr.) Zhijun Jin, President of the Institute of Energy, Peking University

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1 Reframing China–GCC Energy Economic Relations

Dongmei Chen and Fuqiang Yang

Introduction

Political and economic ties between China and the GCC states have deepened significantly over the past 10 years. All six GCC countries have endorsed cooperation agreements for the Belt and Road Initiative (BRI). Five GCC member states, including Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE) have been the founding members of the Asian Infrastructure Investment Bank, the China-led multilateral institute for BRI project financing. During the first GCC–China Summit held in Riyadh in 2022, both sides adopted a five-year joint action plan to deepen their partnerships in fifteen major areas, including comprehensive political and security dialogues, economic partnerships, and greater cultural engagement.

Trade and investment flows between the GCC and China continue to grow. Bilateral trade flows between China and the GCC reached \$282 billion in 2023, increasing more than 20-fold since 2002 (ITC 2024). The total stock of foreign direct investment (FDI) from China to the GCC region amounted to \$26 billion in 2023 (AEI 2024). The total stock of FDI from the GCC to China is only valued at \$5.3 billion, which has been limited mostly to petrochemical downstream projects. However, in recent years capital flows from the Gulf sovereign wealth funds (SWFs) have increased noticeably. Acquisitions by GCC SWFs in China jumped to more than \$2.3 billion in 2023, up from \$100 million the previous year (Bartenstein 2023). In the first nine months of 2024, GCC SWFs deployed \$55 billion across 126 transactions. Notably, \$9.5 billion of this capital was directed toward China, indicating a strategic pivot toward Asian markets as Western investors retreat (ZAWYA 2024). Historically these SWFs have maintained very light footprints in the Chinese equity market compared to elsewhere, with around 80% of their total outflows directed to North America and Europe.

Energy remains a cornerstone of China's relationship with the GCC, consistently highlighted in high-level meetings from the China-Arab States Cooperation Forum in 2014 to the GCC–China Summit in 2022. For GCC countries, securing their market share of oil and gas in China is an increasingly strategic priority as the world transitions to cleaner low-carbon energy sources. China has become an increasingly important major destination for GCC crude oil and gas. China has

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consistently imported around 30% of its crude from the GCC over the last decade. China's liquefied natural gas (LNG) imports from the GCC have also grown rapidly, from only 8% in 2009 to 26% in 2022.

Rapid progress in clean energy transition has catalyzed Chinese investment and technology transfer in the GCC region, resulting in the establishment of local supply chain networks for clean energy technologies. These networks span activities ranging from the extraction and processing of critical minerals to the manufacturing and assembly of wind, solar, and electric vehicle products. Chinese technology, resources, and cost advantages can further expedite the advancement of hydrogen and carbon capture, utilization and storage (CCUS) in the GCC region. Beyond energy production, the partnership has expanded into areas such as energy storage, grid modernization, and the development of smart energy systems.

China's engagement in the GCC region is also evident in the establishment of joint venture special economic zones (SEZs). These include the China–UAE Industrial Capacity Cooperation Demonstration Zone in Abu Dhabi, the China–Oman Industrial Park in Duqm, Oman, and the Sino-Saudi Jazan City for Primary and Downstream Industries (JCPDI) in Saudi Arabia. SEZs have been present in the GCC region since the 1990s with mixed success. These zones receive renewed mandates for their positioning and value propositions when industrial and logistic sectors are prioritized in GCC states' diversification plans. These joint venture SEZs serve as hubs for Chinese companies to access GCC markets, with a focus on sectors such as aluminum processing, machinery manufacturing, petrochemicals, building materials, energy, and logistics.

These developments are underpinned by the alignment of economic strategies and complementary strengths between China and the GCC states. China seeks to enhance its infrastructure and logistical connectivity while deepening trade and investment ties through the BRI. Meanwhile, the GCC states aim to diversify their economies and capitalize on emerging industries tied to infrastructure development and the global energy transition. As both sides pursue their domestic priorities and seek greater global influence, the GCC–China relationship will continue to evolve.

This paper explores how internal dynamics, external pressures, and their interaction may shape the future of GCC–China energy and economic relations. The internal analysis focuses on domestic economic growth drivers within both regions, while the external analysis considers geopolitical competition—particularly in infrastructure and technology supply chains. Additionally, the roles of China's BRI and the BRICS+ (Brazil, Russia, India, China, and South Africa) framework are examined to assess how these broader platforms may influence the trajectory of GCC–China engagement in the years ahead.

A Slowed Economic Growth in China

China has experienced rapid economic growth over the past few decades, emerging as the world's second-largest economy in 2010. This expansion has been closely tied to an investment-driven growth model that facilitated major infrastructure upgrades and the modernization of production technologies (ECB 2024). China is already the world's largest consumer of many clean energy technologies and is on course to surpass its 2030 Nationally Determined Contribution (NDC) target of 1,200 gigawatts (GW) of solar and wind capacity five years ahead of schedule. It currently leads global production of solar photovoltaics (PV), wind turbines, batteries, heat pumps, and hydrogen electrolyzers (IEA 2023a).

Since 2014, China has officially lowered its growth expectations, recognizing that an annual growth rate of around 7% or lower represents the country's "new normal," compared to the average 10% growth achieved in previous decades (Xinhua Net 2014). This deceleration was, in part, a deliberate policy choice aimed at addressing long-standing issues such as industrial overcapacity, rising debt levels, and environmental degradation, while shifting the growth model toward services, technological innovation, and domestic consumption.

However, the path to sustainable growth remains complex, challenged by persistent structural imbalances, external headwinds, and a fragile post-pandemic recovery. Excessive investment, particularly in infrastructure and real estate, has contributed to elevated debt levels among property developers, increased financial vulnerabilities for banks, and mounting fiscal burdens on local governments. Meanwhile, China's industrial policy focus has led to rising inefficiencies, including resource misallocation and persistent overcapacity in key sectors. Diminished corporate profitability has further strained labor market conditions, making it more difficult to rely on consumer spending as a stable driver of growth.

In response to these challenges, the Chinese government is stepping up efforts to expand its policy toolkit, advance market-oriented reforms, and stimulate technological innovation. Building on the "Made in China 2025" initiative, the government is promoting the development of "new quality productive forces," a concept introduced by President Xi Jinping in September 2023 that emphasizes cutting-edge sectors such as advanced manufacturing, artificial intelligence, quantum computing, and 6G technology (Xinhua News 2024). In 2024 alone, China invested over $500 billion in research and development, amounting to 2.68% of its gross domestic product (GDP), a share that continues to rise steadily (Government of China 2025a). This underscores the country's strong commitment to innovation as a key driver of future economic growth.

To stimulate domestic demand, the government has also launched a series of consumption-driven initiatives. Among the most prominent is a RMB 300 billion ($42 billion) subsidy program introduced in 2024, which encourages consumers to trade in outdated electronics and vehicles for new, energy-efficient alternatives, doubling the scale of the previous year's program (Government of China 2025b). In addition, a RMB 10 trillion initiative, equivalent to approximately 8% of GDP, was launched in 2024 to restructure local government off-budget debt through lower-cost, on-budget financing over a five-year period. Coupled with stronger-than-expected fiscal spending, more decisive efforts to stabilize the property sector, and targeted measures to boost employment, raise incomes, and ease financial burdens on households, these actions are expected to lift the economic growth.

Looking ahead, China continues to confront significant domestic and external challenges to sustaining long-term economic growth. The country's GDP grew by 5% in 2024 (NBS 2025), but without comprehensive structural reforms, potential growth is projected to decline—averaging around 3.8% between 2025 and 2030 and further falling to approximately 2.8% between 2031 and 2040 (IMF 2024a). This downward trajectory reflects the dual pressures of a shrinking labor force and slowing productivity gains. Compounding these internal challenges, rising geoeconomic fragmentation, including increasing global restrictions on China's access to high-tech imports and its ability to export green technologies, is expected to place persistent strain on the country's economic outlook.

Slower economic growth could result in China's total energy demand peaking around the middle of this decade. Despite its growing deployment of clean energy technologies, China is expected to remain the largest consumer of fossil fuels through 2050. Natural gas use is anticipated to grow strongly until 2030, before eventually peaking in 2040 at around 25% higher than today's level, and oil consumption is expected to peak at 16.6 million barrels per day (Mb/d) before 2030 and decline to 12 Mb/d by 2050 (IEA 2023b). Reduced oil imports by China could redirect oil flows to other regions, such as India or Southeast Asia, although these markets may not fully compensate for China's diminished demand.

Utilization rates across China's clean energy manufacturing sectors have declined sharply in recent years, dropping below 40% in 2022—well under the 70% benchmark typically seen as healthy for mature industries. While this excess capacity could accelerate the deployment of affordable clean technologies in emerging markets and developing economies, it may also heighten competition with new manufacturing hubs in the GCC, which are positioning themselves to serve the same markets.

A Diversified Development in the GCC

GCC countries have made notable strides in diversifying their economies beyond hydrocarbons. A combination of policy incentives to attract investment in emerging sectors, regulatory reforms to improve the business environment, and strategic efforts to build local competitiveness in priority industries have gradually fueled growth in the region's non-hydrocarbon sector. These diversification strategies aim to reduce reliance on the inherently volatile hydrocarbon markets and promote long-term economic stability. As a result, non-hydrocarbon activities are expected to become the primary drivers of growth across the GCC. GDP growth in the GCC is projected to reach 4.9% in 2025 before stabilizing at around 3.5% over the medium term (IMF 2024b). Deeper regional integration could further enhance these gains by linking domestic, regional, and international value chains to higher-value industries and net-zero related assets.

The global energy transition impacts the GCC states in two major ways, especially for oil and gas producers. On the one hand, economies that are heavily reliant on oil and gas revenues may be exposed to reduced demand for oil and gas from structural changes in energy supply and energy use and volatility from increased market competition. This will have an impact on fiscal stability and public spending, which is crucial to incentivizing the development of non-hydrocarbon economies. On the other hand, the prospect of falling oil and gas demand adds some urgency to the GCC states' economic diversification, creating a powerful incentive to accelerate these efforts. Ambitious plans were announced to promote the use of net-zero energy technologies across sectors. This includes increasing investment in building up local manufacturing capacity for renewable technologies, advancing the development of hydrogen and CCUS hubs, and establishing a pilot carbon trading system.

Despite the progress made, several challenges remain. Sustaining significant economic growth will require an adequate supply of skilled labor, a robust industrial ecosystem, and well-developed infrastructure. The GCC states also face growing competition from early movers that have already established cost and technological advantages in key sectors. Furthermore, heightened geopolitical tensions and ongoing conflicts in the Middle East present additional risks. Concerns over regional security and stability can affect the viability and cost of major shipping routes, influence market expectations regarding oil and gas supply, and undermine investor confidence.

Rising Competition in Infrastructure Diplomacy

As China marks the tenth anniversary of its largest infrastructure initiative, the BRI, the U.S., and its allies have pushed forward the development of alternatives that could contain China's influence. This has led to intensified competition in infrastructure investment globally.

The announcement of the Group of Seven (G7) Partnership for Global Infrastructure Investment (PGII) in 2022 signaled the largest move in infrastructure geopolitics. The PGII aims to mobilize up to $600 billion in private and public sector investments from the G7 countries by 2027 to promote investment in climate change, energy security, supply chain resilience, and infrastructure connectivity (Ministry of Foreign Affairs, Japan 2023). The PGII highlights shared standards among G7 countries and provides a single political umbrella that can consolidate existing infrastructure initiatives from the G7 partners, such as Japan's Partnership for Quality Infrastructure and the European Union's (EU's) Global Gateway. Under the G7 partnership framework, the U.S. pledged $200 billion for PGII projects, Japan pledged $65 billion, and the United Kingdom (U.K.) pledged 40 billion pounds. Through its Global Gateway program, the EU and its member states aim to mobilize €300 billion for connectivity and energy infrastructure projects during the period 2021–2027 (BMZ 2023). In only two years, the PGII has expanded partnerships and developed new initiatives in regions of strategic importance for energy, critical minerals, and supply chain security. Africa, the Middle East, and Southeast Asia, which have been critical for China's BRI, now become the hotspots for the PGII.

At the G20 Summit held in India in September 2023, the PGII announced the launch of a major initiative: the India–Middle East–Europe Economic Corridor

(IMEC). This multilateral project includes India, the UAE, Saudi Arabia, the EU, and others, with the U.S. playing a central role as a diplomatic convener and strategic coordinator.

The IMEC consists of two main corridors: an eastern corridor connecting India to the Arabian Gulf, and a northern corridor linking the Arabian Gulf to Europe. It envisions a new ship-to-rail transit network designed to complement existing maritime and road infrastructure, thereby facilitating more efficient trade flows among participating countries. Along the railway route, there are plans to lay cables for electricity transmission and digital connectivity, as well as a pipeline to transport clean hydrogen (The White House 2023).

IMEC aligns with the strategic and economic interests of all its participants. For the U.S., it serves as a diplomatic tool to offer a credible alternative to China's BRI and expand its influence in the Middle East. For the EU, it offers a means to diversify supply chains and strengthen trade ties with clean energy suppliers. The GCC states view the corridor as a way to advance their economic diversification agendas, particularly by enhancing infrastructure, logistics, and energy export capacity. India stands to gain from closer trade integration with the EU, potentially capturing a larger share of global value chains from China and strengthening its manufacturing competitiveness.

Another flagship initiative under the PGII was announced at the G20 Summit in India in September 2023: the Lobito Economic Corridor in Africa. With the EU and the U.S. playing central roles, the corridor is designed to strengthen transport connectivity among Zambia, the Democratic Republic of Congo (DRC), and Angola, while also promoting investment in local value chains (European Commission 2023). The core element of the project is the construction of a new Zambia–Lobito railway line, which will for the first time connect Zambia's copper belt to the Angolan port of Lobito on the Atlantic Ocean. This infrastructure development is expected to open up new westward trade routes, enhancing the efficiency and reliability of critical mineral and commodity supply chains from the DRC and Zambia (Geopolitical Monitor 2024).

In April 2024, the PGII announced its first project in the Philippines, the Luzon Economic Corridor, a trilateral initiative involving the U.S., Japan, and the Philippines. The corridor aims to strengthen connectivity among Subic Bay, Clark, Manila, and Batangas while enabling strategic investments in high-impact infrastructure projects. These include upgrades to rail and port infrastructure, as well as initiatives in agribusiness, clean energy, and semiconductor supply chains (U.S. Department of State 2024a). The Luzon Corridor is expected to generate economic benefits and bolster security resilience for the Philippines. For the U.S., the project represents a critical step in asserting economic credibility and political influence in Southeast Asia, offering a compelling alternative to China's expanding regional presence.

Infrastructure initiatives often generate controversy, even in stable and well-governed societies. In contexts marked by weak government legitimacy, corruption, clientelism, limited adherence to the rule of law, and social instability, the risks and complexities are significantly heightened (Mariani 2023). Given the distinct comparative advantages of the BRI and the PGII, GCC states are strategically positioned to structure partnerships and prioritize infrastructure investments that support economic diversification and strengthen their roles as key connectivity hubs.

Derisking Technology and Supply Chains

Geopolitical competition is evident not only in infrastructure investment but also in technology and supply chains. China's dominance in clean energy technologies—ranging from critical minerals extraction to the manufacturing of wind turbines, solar photovoltaic systems, batteries, and electric vehicles—along with its rapid advancement in digital technologies and the Internet of Things, has raised significant concerns among the U.S. and its allies. In response, the U.S. has implemented a range of policies and actions to reduce reliance on Chinese supply chains.

One major step is the adoption of the Inflation Reduction Act (IRA), the largest policy incentive in U.S. history aimed at stimulating domestic production of clean energy, electric vehicles, and batteries. According to the final regulations on clean vehicle credits released by the U.S. Department of the Treasury and the Internal Revenue Service in May 2024, qualified manufacturers must demonstrate compliance with the Foreign Entity of Concern (FEOC) restrictions. A business is classified as an FEOC if it is incorporated in, headquartered in, or carries out relevant activities in a covered nation, which includes China, Russia, North Korea, and Iran. Additionally, businesses may also be classified as FEOCs if 25% or more of their board seats, voting rights, or equity interests are cumulatively held by the government of a covered region (CRS 2024a).

Moreover, the friendshoring policy is applied throughout the production process for clean energy vehicles. Manufacturers must conduct detailed supply chain tracing to determine the actual value-added from extraction, processing, and recycling sourced either domestically or from a free trade agreement (FTA) partner, and new clean energy vehicles must undergo final assembly in North America.

U.S.-led joint initiatives have also pursued similar de-risking strategies with their strategic partners. In 2017, the U.S., Japan, Australia, and India revived their Quadrilateral Mechanism (QUAD), which initially focused on national security and maritime cooperation and was updated to include critical supply chains, infrastructure investment, and health cooperation. In 2021, the U.S., the U.K., and Australia forged a trilateral security partnership (AUKUS). It aims to coordinate policy and strengthen cooperation in the Indo-Pacific region in the fields of submarine technology, artificial intelligence, quantum technologies, and cyberwarfare capabilities. In 2022, the U.S. launched the Indo-Pacific Economic Framework for Prosperity (IPEF) with 13 partners, including Australia, Brunei, Fiji, India, Indonesia, Japan, South Korea, Malaysia, New Zealand, the Philippines, Singapore, Thailand, and Vietnam. The U.S. expects the IPEF to result in higher standards and better governance in reshaping supply chains and reducing the reliance on China, especially in the digital economy and the manufacturing of semiconductors and electric vehicle batteries (CRS 2024b). This will lead to direct competition with the

Regional Comprehensive Economic Partnership (RCEP), the China-led free trade agreement with the Asia-Pacific Countries.

The EU has adopted a similar derisking strategy. It introduced the Foreign Subsidies Regulation and the Anti-Coercion Instrument, while also updating its inward and outward investment screening process as its de-risking strategy became more prominent in its dealings with China. A series of new policies and regulations have been announced to enhance economic security while pursuing climate goals. These include the Critical Raw Materials Act, the European Chips Act, the Net-Zero Industry Act, and the Carbon Border Adjustment Mechanism.

These evolving dynamics will require a more agile and strategic approach to risk management. In response to rising geopolitical tensions, many companies are adopting a "China Plus One" strategy, relocating segments of manufacturing or sensitive innovation activities outside China while increasing investment in markets that offer greater geopolitical stability, particularly those with FTAs with the U.S. Over time, this trend could erode China's dominance in global manufacturing.

For the GCC states, this shift presents a significant opportunity. With growing domestic demand and strategic geographic proximity to Europe, the GCC is well-positioned to develop into a regional hub for global supply chains. By capitalizing on the relocation of Chinese technology and production capacity, the GCC can strengthen its role in high-value segments of global trade and industrial integration.

Evolution of China's BRI

Over the past ten years, China's BRI has grown from a mere vision to an initiative with concrete deliverables. By 2023, more than 150 countries and 30 international organizations had signed BRI collaboration agreements with China. A series of landmark BRI projects such as the China–Laos railway, the Jakarta–Bandung high-speed railway, and the Mombasa–Nairobi railway, have been completed and put into operation.

Despite mounting domestic challenges, including slowing economic growth, rising financial pressures, and the need to preserve social and economic stability, China has reaffirmed its commitment to the BRI. Securing funding for large-scale infrastructure projects under the BRI has become more constrained, but China's overseas direct investment in non-financial firms in BRI countries has continued to rise steadily (Nedopil 2023). Underscoring this commitment, the Chinese government announced a new plan in 2023 to allocate an additional $100 billion to the BRI over the next decade. The updated strategy expands cooperation beyond the initiative's five traditional pillars—policy coordination, infrastructure connectivity, unimpeded trade, financial integration, and people-to-people ties—to include emerging areas such as green development, the digital economy, technological innovation, and healthcare (Global Times 2023).

To address growing international scrutiny and adapt to evolving global dynamics, the Chinese government has initiated a strategic recalibration of BRI governance. In response to concerns over transparency, debt sustainability, and governance standards, China has established two key multilateral-oriented institutions under the BRI framework: the Asian Infrastructure Investment Bank (AIIB) and the Multilateral Cooperation Center for Development Finance (MCDF). These institutions are designed to promote greater transparency, foster multilateral collaboration, and improve the overall effectiveness and sustainability of development financing within the BRI.

Notable changes have emerged in the BRI's lending, investment, and project implementation practices. The Chinese government has issued a series of new guidelines to reduce environmental, ecological, and climate risks. Chinese companies operating overseas are encouraged to adhere to international standards or Chinese regulations throughout the project lifecycle, particularly in cases where host country standards are absent or poorly enforced. This marks a shift from earlier BRI practices, in which Chinese enterprises were only required to comply with local regulations in host countries.

This shift is also evident in the types of projects now favored, moving away from large-scale, capital-intensive infrastructure, such as roads, railways, and ports, toward more targeted and manageable initiatives described as "small but beautiful" projects. While infrastructure and connectivity remain essential for promoting development in low-income countries, where China often remains the only willing financier due to high financial risks, several factors have prompted this strategic pivot.

The lengthy timelines required for infrastructure development, growing debt distress among some BRI recipient countries, and insufficient risk management frameworks among many Chinese firms have collectively elevated financing risks. In response, the BRI has broadened its scope, now emphasizing smaller, greener, and lower-risk projects across a more diversified range of sectors, including finance, healthcare, education, agriculture, mining, clean energy, and digital technology. This evolution can also partly explain the ongoing decline in China's overseas development financing. According to Ray (2023), China's two principal development finance institutions—the China Development Bank and the Export–Import Bank of China—committed only $10.5 billion in new loans in 2020 and 2021, continuing a downward trend from the 2016 peak of $87 billion.

The Implications of BRICS Plus

BRICS (Brazil, Russia, India, China, and South Africa) was initially formed in 2006 as BRIC, with South Africa joining in 2010 to make it BRICS. The inclusion of the UAE, Egypt, Ethiopia, and Iran as new members in 2024 made it BRICS Plus. Over the past decade, BRICS has gradually increased its influence on global governance. The establishment of the New Development Bank (NDB) and the Contingent Reserve Arrangement (CRA) in 2015 represents a significant effort by BRICS to provide alternatives to traditional finance and promote South–South cooperation.

The NDB has expanded its membership from the five founding members of BRICS to include Bangladesh, the UAE, Egypt, Algeria, and Uruguay. As of November 2024, the NDB had approved 96 projects across its member countries, with a cumulative commitment of approximately $32.8 billion (NDB 2024). These projects span several key sectors, including renewable energy, transportation, and water resources. Notable examples include green energy initiatives in India and urban transportation systems in China. In its four-year strategy for 2022–2026, the bank has planned to dedicate 40% of its total volume of approvals to projects contributing to climate change mitigation and adaptation (NDB 2022).

The CRA framework was designed to offer protection and support through liquidity and precautionary instruments in response to short-term balance of payment challenges. It created a substantial reserve pool totaling $100 billion, with contributions from each member country based on their economic size. The distribution of capital and access to funds is a clear testament to the collaborative effort of the CRA to foster financial resilience. In 2023, the CRA completed its sixth test run and amended the Inter-Central Bank Agreement to enhance the mechanism's credibility and operational efficiency (BRICS Today 2024).

BRICS has also developed several market mechanisms to reduce member countries' reliance on the U.S. dollar in global trade and finance. The yuan-denominated oil futures market launched by China provides an alternative to dollar-based oil pricing benchmarks like Brent and West Texas Intermediate (WTI). This mechanism allows oil-exporting countries to trade in Chinese yuan, enhancing the currency's international use while gradually reducing the dependence of oil transactions on the dollar. BRICS is also working on alternative payment systems to reduce member countries' dependence on the dollar-dominated SWIFT payments network. Russia has developed the System for Transfer of Financial Messages (SPFS), and China's Cross-Border Interbank Payment System (CIPS) facilitates transactions in RMB. These systems aim to insulate member countries from U.S.-led financial sanctions while encouraging the use of BRICS currencies for trade and investment. Another promising initiative is the BRICS Pay system, envisioned as a unified payment platform enabling seamless cross-border transactions in local currencies without the need for dollar conversions (Liu and Papa 2022).

Despite BRICS making notable progress in developing an alternative framework for global economic and political cooperation, significant challenges remain.

The first challenge is achieving cohesion within the expanded BRICS bloc. BRICS operates primarily through annual summits, ministerial meetings, and working group discussions. Its consensus-based decision-making process requires all member states to agree on a given course of action before it can be implemented. This can make it difficult to reach consensus on key issues, given the diverse political, economic, and social interests of the member countries and the complex nature of their interrelations (EPRS 2024). For example, ongoing tensions between China and India have hindered BRICS Plus and the NDB from supporting initiatives related with BRI. Meanwhile, U.S.-led sanctions on Russia and Iran may prompt these countries to adopt differing approaches to the West compared to other members. All these factors could limit the ability of BRICS Plus to perform as a unified bloc across economic and geopolitical fronts.

The second challenge is achieving an independent financial system aimed at reducing reliance on the U.S. dollar in international trade, finance, and economic transactions. Some BRICS economies are deeply integrated into dollar-based global markets, making a shift toward alternative systems complex and potentially costly (Liu and Papa 2022). Developing local currency payment systems and cross-border platforms requires significant resources. The limited financial capacity of the NDB restricts its ability to lead large-scale de-dollarization initiatives effectively. There are also conflicts of interest among BRICS members who hold significant U.S. dollar reserves.

As BRICS Plus continues to expand and evolve, it holds the potential to reshape global governance structures and economic systems. For the GCC countries, especially Saudi Arabia and the UAE, BRICS Plus presents an opportunity to diversify strategic partnerships beyond traditional Western allies. Enhanced engagement with fast-growing economies in Asia, Africa, and Latin America opens new venues for trade and investment, particularly in sectors such as infrastructure, renewable energy, and digital technologies. As major energy exporters, GCC states are well positioned to play a central role in shaping BRICS-led initiatives in global energy governance. Their sovereign wealth funds and experience in global capital markets make them attractive partners for institutions such as the NDB. Participation in such platforms may allow the GCC to co-create new mechanisms for development finance, thereby supporting their long-term economic diversification goals. However, the growing emphasis on using local and digital currencies within the BRICS framework introduces additional complexities, including institutional coordination challenges and the need to carefully balance emerging partnerships with long-standing Western alliances.

China plays a leading role in BRICS institutions such as the NDB and the CRA. It complements China's broader foreign policy objectives and enhances China's ability to build coalitions with emerging economies. However, deepening ties with emerging markets, many of which face political instability, high debt, or governance challenges, could expose China to financial risks, particularly in development lending and investment through BRICS institutions.

Conclusions

The GCC states and China have entered into a stage of close and integrated collaboration from infrastructure investment to technology supply chains. Their energy relations have transitioned from a traditional focus on oil and gas trade to a more diversified partnership encompassing renewable energy and net-zero technologies. This relationship will continue to evolve as both sides strive to achieve their domestic priorities and increase their global influence.

Slowed economic growth in China presents challenges for the government in expanding financial support for BRI projects, especially for capital-intensive infrastructure projects such as roads, railways, and ports. The shift in the BRI's investment strategy to smaller, greener, and less financially risky projects should encourage Chinese companies to prioritize opportunities in logistics, healthcare, education, agriculture, clean energy, and digital technology. This aligns well with the GCC states' economic diversification plans. Meanwhile, the competition between China's BRI and the U.S.-led PGII provides an opportunity for the GCC states to structure multipolar engagement. If there is no chance of the BRI and PGII collaborating directly in the region, the GCC states are well positioned to coordinate resources from both initiatives and prioritize the projects that best suit their needs.

To deal with the structural and demographic challenges in its economy, China has stepped up its efforts to unleash new growth from disruptive technology innovation. While its previous industrial policy efforts have mainly focused on achieving competence, self-sufficiency, or global market share in established technologies, the "new productive forces" will be unleashed through a new national system of centralized coordination and financial support to spur future technological development in manufacturing, information, materials, energy, space, and health. It is still too early to say whether this technology-driven development strategy will succeed in generating sustained GDP growth. But in a world where China can no longer rely on trade with and investment from U.S.-led alliances to meet its technology needs, all available domestic resources must be marshaled to support its domestic scientific progress (Kroeber 2024). The GCC states become more important for China as a hedge against this shift. China is also a crucial partner for the GCC in helping to develop this region into a new hub for global supply chains and capitalize on the relocation of Chinese technology production capacity.

As BRICS Plus expands and evolves, there is the potential for the GCC states to facilitate the growth of cross-border trade and investment with other BRICS Plus members through the use of local and digital currencies. However, this needs to be carefully designed in a way that balances their partnerships with existing Western alliances.

The future of GCC–China energy and economics relations is poised for deeper cooperation, driven by China's need for stable energy supplies and the GCC's diversification goals. While China's energy transition and slowing economic growth may temper long-term oil and gas demand, the GCC can leverage its strategic position to strengthen its ties with China through investments in renewables, hydrogen, and infrastructure under the BRI. Geopolitically, both sides need to maintain strategic flexibility, balancing their ties with the U.S. and its alliances while fostering trade, technology, and financial collaboration to navigate an increasingly multipolar world.

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2 China–GCC Trade and Investment Interconnections

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China–GCC Trade Dynamics

The economic and trade relationship between China and the Gulf Cooperation Council (GCC) dates back to the 1980s when China implemented opening-up policy. As it continued to integrate into the global economy it developed close economic and trade ties with all six GCC members. Over the past two decades, economic, trade, and energy cooperation between China and the GCC has made remarkable progress.

As shown in Figure 2.1, bilateral trade flows in nominal United States (U.S.) dollars ($) have grown more than 20-fold since 2002. The growth of imports from the GCC started outpacing Chinese exports to the region in the early 2000s, driven by China's increasing energy needs and higher global energy prices. This trend resulted in a record trade deficit with the GCC bloc in 2022 of $104.5 billion, which was reduced by 40% in 2023 due to lower global oil prices. The prevalence of energy in the GCC's exports to China also explains the significant volatility in the annual dollar values of bilateral trade observed in Figure 2.1.

During the last decade, GCC's exports have grown faster than its imports. China has become increasingly important to the foreign trade of GCC countries, overtaking the European Union (EU) as the bloc's primary trading partner in 2020. Given the substantial share of exports in the GCC economies, trade with China provides a notable contribution to their gross domestic product (GDP). Exports to China accounted for nearly 8% of Saudi Arabia's GDP in 2022, while nearly a third of Oman's GDP is directly tied to its exports to China. Since the COVID-19 pandemic, China's share of GCC foreign trade has plateaued, averaging 21.5% of the region's exports and 17.5% of its imports over the last three years (International Trade Centre 2024). Recent efforts and policy developments in the sphere of economic cooperation, along with the resumption of free trade agreement (FTA) negotiations, could provide a new impetus for the further development of bilateral trade.

In contrast, the share of GCC countries in China's foreign trade is relatively small, which is unsurprising given the size of the Chinese economy and the GCC's relatively small domestic market. Chinese exports to the GCC have been growing slowly but steadily, representing 3.3% of its total exports in 2023 (International Trade Centre 2024). The rise in the GCC's share of Chinese imports since the turn

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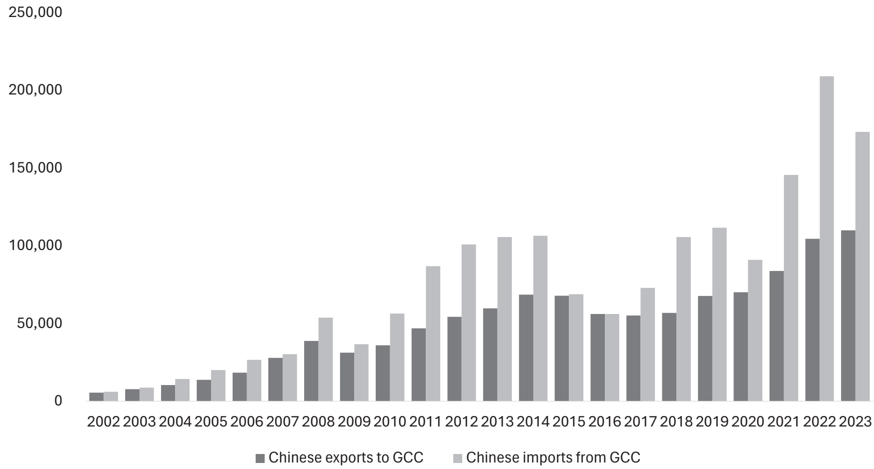

Figure 2.1 Trade flows between China and the GCC ($ million).

Source: International Trade Centre (2024).

of the century is largely attributed to developments in bilateral energy cooperation and increased reliance on oil imports from the region, in particular.

Despite the broadening scope of GCC–China economic cooperation, energy remains at its core. Based on 2023 statistics, crude oil and natural gas account for up to 85.9% of trade flows from the GCC to China (Figure 2.2). Interestingly, refined oil products (Harmonized System [HS] code 2710) only constitute 2.6% of these flows, as China retains a competitive edge in its downstream market and remains keen to protect it. Non-oil exports from the GCC are primarily represented by plastics and organic chemicals—representing 5.6% of total Chinese imports from the bloc.

China's imports from the GCC align with the overall structure of Chinese imports, which are also heavily dominated by crude oil—73.5% of the total import value in 2023. However, compared to the early 2000s, imports from the GCC have become even more petroleum-centric. Despite a broad range of bilateral economic cooperation initiatives, the share of non-petroleum imports decreased from 22.7% in 2002 to the current 11.5% in dollar terms. This trend can be partially explained by higher energy prices and a rise in energy demand in China compared to the base period. However, it is evident that energy increasingly dominates this trade flow. Six GCC nations comprise a formidable 35.8% of Chinese total crude imports, amounting to 202 million tons in 2023.

Exports to China represent about 30% of total GCC crude exports, with little variation among GCC members, except for Oman, which ships 80% of its crude oil exports to China. However, the export structures of the GCC countries vary greatly. While petroleum still dominates the exports of Oman and Kuwait—mirroring the structure of the GCC's exports to China—Saudi Arabia and the United Arab

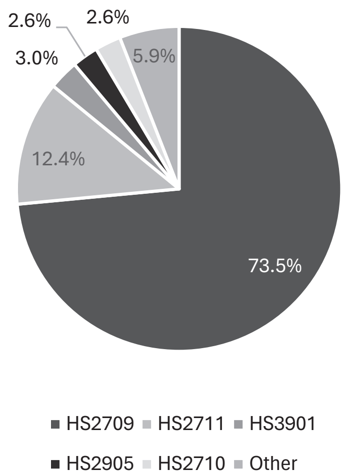

Figure 2.2 The structure of Chinese imports from the GCC by HS classification (Data for 2023).

Source: International Trade Centre (2024).

Notes:

HS2709—Petroleum oils and oils obtained from bituminous minerals, crude.

HS2711—Petroleum gases and other gaseous hydrocarbons.

HS3901—Polymers of ethylene, in primary forms.

HS2905—Acyclic alcohols and their halogenated, sulfonated, nitrated, or nitrosated derivatives.

HS2710—Petroleum oils and oils obtained from bituminous minerals, other than crude.

Emirates (UAE) have more diverse exports, with their relative shares of petroleum at 67.0% and 13.7%, respectively. This indicates a potential opportunity for other GCC countries to diversify their export offerings to China.

China is expected to remain a lucrative market for GCC oil and gas exports in the foreseeable future. According to OPEC estimates, Chinese oil demand is set to increase by 2.5 million barrels per day (MMb/d) by 2050 from its 2023 level (OPEC 2024). While other analysts expect peak oil demand in China by the late 2020s, its further trajectory is more likely to plateau (Barron's 2024; Goldman Sachs 2024). The growth in China's domestic natural gas demand is forecast to be more prolonged, reaching 700 billion cubic meters (bcm) by 2050, representing an approximate 80% increase from current levels (GECF 2023).

It should be noted, however, that certain factors may impede the further growth of the GCC's market share in China's oil and gas imports. These primarily include the following:

- China's intention to maintain a certain level of import portfolio diversification.
- Security considerations: China favoring cross-border pipeline imports and seaborne imports that bypass the Malacca Strait.
- Shifts in import patterns due to geopolitical factors.

The reverse trade flow—from China to the GCC—is much more diverse, comprising such items as machinery, transport, electronics, metals, and consumer goods (Figure 2.3). This structure generally mirrors (with deviations of a few percentage points for certain items) the pattern of Chinese global exports, reflecting its diversified export-oriented economy. Over the last two decades, the share of consumer goods (clothing, apparel, footwear, etc.) in China's exports has declined in lieu of more advanced, higher value-added manufactured items. This trend can be observed both in exports to the GCC and to the global market in general, mirroring China's economic development trajectory during this period.

GCC countries import a broad range of products. In terms of their absolute value, these imports are led by machinery, transport, and equipment—a pattern resembling Chinese imports to the GCC. There are major opportunities for expansion in trade, particularly through reduced trade barriers and enhanced cooperation in emerging sectors such as green energy and electrification.

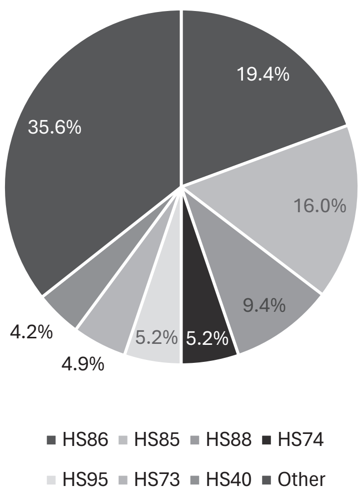

Figure 2.3 The structure of Chinese exports to the GCC by HS classification (Data for 2023).

Source: International Trade Centre (2024).

Notes:

HS86—Railway or tramway locomotives, rolling stock and parts thereof; railway or tramway track fixtures and fittings and parts thereof; mechanical (including electro-mechanical) traffic signaling equipment of all kinds.

HS85—Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles.

HS88—Aircraft, spacecraft, and parts thereof.

HS74—Copper and articles thereof.

HS95—Toys, games and sports requisites; parts and accessories thereof.

HS73—Articles of iron or steel.

HS40—Rubber and articles thereof.

Trade in services represents another important component of bilateral cooperation and economic development. In 2021, the trade in services between China and the GCC exceeded $45 billion, representing 20% of the total value of the bilateral trade in goods for that year. The balance of trade in services is marginally skewed toward China. In 2021, exports of services from the GCC to China accounted for $19.6 billion, while imports of Chinese services by the region stood at $25.7 billion (WTO 2024). Commercial services dominate the bilateral trade, representing 41.5% of total trade, followed by transport (15.5%) and travel (11.9%). In 2021, the GCC's share of Chinese foreign trade in services exceeded its share in the trade in goods, at 5.5% compared to 4.0%, respectively.

China–GCC Investment Flows

Following the increased bilateral trade between the GCC and China in the early 2000s, China started investing in the GCC economies in the early 2010s. In 2017, it started to ramp up its investments in the GCC. Chinese investments in the GCC are primarily focused on the energy sector (Figure 2.4). By the end of 2023, the sector accounted for $20.3 billion or 78.1% of China's total investment in the GCC. All other sectors combined comprised $5.7 billion. The $26 billion of total Chinese investment in the GCC is distributed across GCC members, roughly in line with their GDP.

Having accumulated significant reserves in national wealth and investment funds, GCC countries have also been expanding their outward investment activities. In 2022, the GCC's annual outward investment flows reached $48 billion. China is starting to attract substantial investment from the GCC. Its outward investment stocks in China reached $2.7 billion (GCC-STAT 2024). In 2023, GCC countries

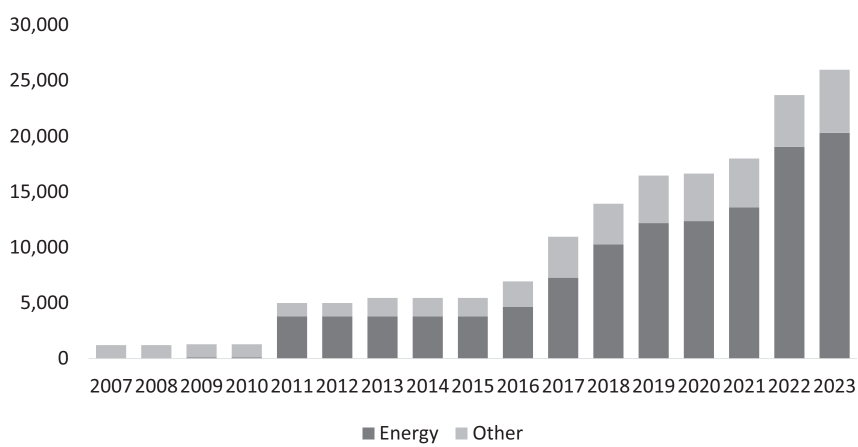

Figure 2.4 Chinese investment stocks in the GCC's major projects by sector ($ million).
Source: AEI (2024).

invested more than $2.3 billion in China, compared with just $100 million in 2022 (The Business Times 2024).

Based on recent announcements, one can expect a surge in bilateral China–GCC investment. In 2023, Chinese businesses announced a record 21 greenfield projects in Saudi Arabia alone worth an estimated $16.2 billion (FDI Intelligence 2023).

The majority (71.3%) of Chinese foreign direct investment (FDI) in the GCC region is allocated to the oil and gas sector, with $8.8 billion invested in oil and $5.7 billion in gas. By comparison, Chinese FDI in GCC alternative energy investments totals $3.3 billion (AEI 2024). Chinese investments have been distributed across the whole GCC oil and gas supply chain in both exploration and production. The China National Offshore Oil Corporation (CNOOC) and PetroChina obtained a stake in Abu Dhabi's onshore and offshore Lower Zakum, Umm Shaif, and Nasr concessions. China National Petroleum Corporation (CNPC) and Sinopec obtained a stake in Qatar's North Field East expansion project. Sinopec made a significant investment in oil and gas logistics, with a 50% stake in Fujairah's major terminal, and in the 400,000 barrels per day (bpd) Aramco Sinopec JV (YASREF) refinery in Yanbu, Saudi Arabia.

The GCC will remain a lucrative destination for oil and gas investment, for both China and other countries, as the regional economies plan significant capacity expansion. The UAE is ramping up its oil production capacity to 5 MMb/d by 2027, while Kuwait is planning an increase to 4.75 MMb/d by 2040 (S&P Global 2024). Saudi Arabia intends to increase its natural gas production by more than 80% by 2030 (MEES 2025), and Qatar is pursuing an 85% liquefied natural gas (LNG) capacity expansion by 2030, resulting in the production of 142 million metric tons of gas per annum (Boufarah et al. 2024). GCC countries have been leading global refinery capacity expansion since 2020. They are planning to further upgrade existing facilities (the Bapco Modernization Program in Bahrain and the Az-Zour Refinery in Kuwait) and greenfield projects (the Crude Flexibility Project in the UAE and the Ras Al-Khair and Jizan Refineries in Saudi Arabia). These developments will also require additional investment in logistics and supporting infrastructure.

Investment from GCC states in China's energy sector has been concentrated in the downstream segment. Saudi Aramco has been leading the GCC's advance into the Chinese market with a number of projects in refining and petrochemicals, some of them with crude offtake agreements attached. China's new open policy to foreign investment has led to the initiation of some new JV megaprojects with Saudi Arabia, including the $6.4 billion SABIC Fujian Petrochemical Complex in China's Fujian province (Xinhua 2024) and the $12.2 billion refining-petrochemical complex involving Saudi Aramco (Reuters 2023). Other major projects with GCC participation include the Sinopec-Aramco Fujian Refining and Petrochemical Company (FREP), the Sino-Qatar Taizhou Refinery, and the Sino-Kuwait Guangdong Refining and Chemical Integration Project.

While not as large or mature as the regional oil and gas market, the GCC's nuclear energy sector is also lucrative for foreign investors due to its growth potential. Bahrain, Saudi Arabia, and the UAE are at various stages of pursuing nuclear power development, while Oman and Qatar are currently abstaining, and Kuwait decided to withdraw its industry development plan after the Fukushima accident. China faces tough competition from other countries interested in developing the GCC's nuclear power sector. According to the King Abdullah City for Atomic and Renewable Energy, South Korea, Russia, China, the U.S., and France are among the contenders bidding to develop Saudi Arabia's nuclear program (NEI 2022). The same cohort will likely compete for nuclear projects in the UAE and Bahrain, should these nations decide to proceed with nuclear capacity expansion.

China dominates the GCC imports of solar components, and it has been steadily increasing its investments in other alternative energy sectors such as lithium batteries, wind power, and hydrogen. Chinese companies have invested in or undertaken significant projects, including the photovoltaic power plant in Qatar, the Abu Dhabi photovoltaic power plant, the 700 megawatt (MW) solar thermal power plant in Dubai, and the Al-Shuaiba power plant in Saudi Arabia. Mensha Ventures, a venture capital firm based in Dubai, has partnered with Chinese entities to invest up to $1 billion in clean energy. Companies from China, including Sinopec Group, the State Power Investment Group, and the China Energy Construction Group have also reached agreements with some GCC enterprises to cooperate on hydrogen energy and carbon neutrality, spanning markets in both China and the Middle East. Additionally, China and the GCC countries are actively engaged in global climate governance.

Despite its considerable potential, joint investment between China and the GCC in third-party markets has not yet gained traction. Joint investment vehicles, such as the $10 billion UAE-China Joint Investment Fund, primarily focus on the domestic GCC or Chinese markets, while major GCC and Chinese national oil companies and private oil and gas companies tend to negotiate their investment terms directly with their counterparts, whether in the GCC, China, or other markets. One successful third-party collaboration is a joint investment by China's Power Construction Corporation and Qatar's AWC in Pakistan's coal-fired Qasim Power Plant. Another is the broader participation of Saudi Arabia and the UAE in the China–Pakistan Economic Corridor infrastructure network project, particularly the "oil city" project and oil refinery in Gwadar port.

Impetus of Trade and Investment Facilities

Economic Cooperation Frameworks

The path to the current level of economic partnership between the GCC and China began in the late 1970s with the formal establishment of diplomatic relations. As trade ties developed, China had signed investment treaties with all GCC members by the end of the 1990s, even before its accession to the World Trade Organization (WTO) in 2001 (Table 2.1). Bilateral tax treaties ensued, although at different times for individual GCC countries, further facilitating business relationships.

China and the GCC established a strategic dialogue mechanism in 2010. Building on this, China signed comprehensive strategic partnership agreements with

Table 2.1 Major bilateral policy milestones between China and GCC countries

Country	*Diplomatic relations*	*Bilateral investment treaty*	*Tax treaty*
Bahrain	1989	1999	2002
Kuwait	1971	1985	1989
Oman	1978	1995	2002
Qatar	1988	1999	2001
Saudi Arabia	1990	1996	2006
UAE	1984	1993	1993

Sources: UNCTAD (2024c); China Briefing (2024).

Saudi Arabia (2016), the UAE (2018), and Bahrain (2024). Similar agreements were signed with Kuwait, Oman, and Qatar.

With major economic cooperation frameworks in place, the advancement of China–GCC ties has primarily occurred via joint summits and strategic dialogues. A designated GCC–China Summit framework has also been established for business collaboration, with the first China–GCC Countries Forum on Industrial and Investment Cooperation held in China in May 2024. The China–Arab States Cooperation Forum (CASCF), established in 2004, has also played a role in coordinating multilateral partnerships and enhancing China's cooperation with the GCC states. The declaration of the 10th CASCF was held in Beijing in May 2024 focused on joint approaches to regional crises and humanitarian efforts, while the Action Implementation Plan outlines specific collaboration initiatives in such areas as trade, investment, international finance, and resource management (MEPEI 2024).

BRICS could be another multilateral platform for China–GCC cooperation with an even broader scope. Several Arab nations have joined the bloc as member states, such as Egypt and the UAE. Upon their potential accession, GCC countries would be able to develop closer ties with China and other BRICS members in the areas of development finance (via the New Development Bank and other mechanisms), monetary policy coordination, deeper technological cooperation, and growing intra-bloc trade (BCG 2024).

GCC countries have also become an integral part of the Belt and Road Initiative (BRI). By 2019, all GCC members had formally joined the BRI. The BRI's "1+2+3" cooperation approach with the GCC was proposed by China in 2014 and reemphasized in 2016, where 1 represents energy cooperation, 2 infrastructure, trade and investment, and 3 high tech, nuclear power and renewables. It aligns well with the initial goals of the BRI, such as policy coordination, infrastructure connectivity, and unimpeded trade.

As the BRI continues to evolve in its scope and guiding principles, the GCC remains a key part of the initiative and of Chinese global trade and investment priorities. The newly proposed eight major steps to elevate BRI cooperation in terms of the quality and level of development undertaken will be aligned with the development strategies of GCC member countries, expanding collaboration into new areas, including the digital economy and sustainable development (Belt and Road Portal 2023).

Trade and Investment Agreement

The complementary structure of the GCC and China's economies and foreign trade patterns has facilitated the development of economic ties between the two, necessitating a comprehensive cooperation framework. In July 2004, the China–GCC FTA was launched, and 10 rounds of negotiations were held, followed by a suspension from 2009 to 2016. The rounds focused on rules of origin, market access, technical barriers to trade, trade remedies, free trade agreement texts, trade in goods, and preliminary offers on trade in services. After the negotiations were resumed, they focused on trade in services, economic and technological cooperation, investment, e-commerce, customs procedures, trade facilitation, and remaining issues surrounding trade in goods.

Once the China–GCC FTA is signed and in effect, the resulting free trade area will become the world's second largest after the Regional Comprehensive Economic Partnership. Given the potential for the FTA to reduce the import tariffs of both parties by up to 90%, bilateral trade flows are expected to receive a major boost. Initially, the most visible effect would be observed in key exports, such as energy exports from the GCC and machinery and equipment exports from China. The FTA is also expected to give significant impetus to bilateral cooperation in other sectors, such as petrochemicals and new energy, potentially doubling bilateral non-oil trade within three years (The National News 2023). Liberalizing trade in the petrochemical sector alone could yield additional benefits of over $260 million to GCC producers (GPCA 2023) and over $240 million in net welfare gains for China due to trade creation effects (Galkin, Bollino, and Shabaneh 2018).

The potential benefits for both parties extend beyond tariff elimination, as the FTA will foster a more conducive business environment and provide a robust foundation for future agreements in adjacent areas.

China could strengthen its competitive advantage by supplying intermediate goods to the GCC. Its domestic green sector—ranging from electrification solutions to electric vehicle production—could also get a boost from GCC trade as GCC countries strive to diversify their energy infrastructure. Finally, Chinese companies in new industries such as artificial intelligence (AI), big data, and 5G/6G services could establish themselves in the GCC market ahead of their global competitors.

From the GCC's perspective, exporters would gain preferential access to one of the largest global markets with significant growth potential. As major capital exporters, GCC economies would also benefit from investment opportunities arising from easier access to the financial markets of Shanghai, Shenzhen, and Hong Kong. Furthermore, deeper trade and investment cooperation with China would allow GCC countries to enhance their domestic infrastructure development and further establish the bloc as a global logistical hub. Moreover, the modernization and unification of regulations necessary to accommodate the execution of the FTA would accelerate domestic economic reforms, improve the GCC's business climate, and strengthen economic and foreign policy cohesion within the bloc.

Both parties overcame differences on a number of issues during the FTA negotiations and are keen to finalize the negotiations as soon as possible. An expedited agreement seems to be in the interests of both parties, as their counterparts advance economic cooperation with regional rivals. For example, China and Iran recently signed the Iran–China 25-year Cooperation Program, while the GCC recently signed an FTA with South Korea and resumed FTA negotiations with Japan and India.

Special Economic Zones

Special economic zones (SEZ) have been particularly instrumental in promoting China–GCC trade and investment. They can be established in various formats—domestic SEZ in GCC and China, designated China–GCC SEZ, and Chinese Overseas Economic and Trade Cooperation Zones (COCZ). SEZ also vary in scope (free trade zones, free economic zones, free ports, industrial parks) and in the incentives they provide.

Currently, there are up to 100 SEZ in six GCC states, over 40 of them in the UAE, with industrial development and logistics as key focus areas (PWC 2020). Similar SEZ arrangements have been established in direct partnership with China. These include the China–Oman Industrial Park in Duqm, the Jazan Industrial Cluster in Saudi Arabia, and the China–UAE Industrial Capacity Cooperation Demonstration Zone.

The SEZ format has greatly contributed to expanding the economic ties between China and the GCC. This is evident from the number of Chinese companies operating in SEZ, the influx of investments, and the launch of major projects. By the end of 2023, the Dubai Multi Commodities Centre free trade zone alone hosted 852 Chinese companies (Caixin Global 2024), representing close to 15% of all Chinese companies operating in the UAE. Over 20 Chinese companies have invested more than $1.7 billion in the China–UAE Industrial Capacity Cooperation Demonstration Zone. Chinese investment in Duqm Industrial Park in Oman amounts to $10.7 billion, and China has already committed more than $21.33 billion to the newly established Jazan SEZ in Saudi Arabia.

China recently intensified its domestic SEZ program to stimulate growth and attract foreign investment. The country has initiated 21 pilot free trade zones to test several innovative practices. These include pre-establishing national treatment and negative list management models, trade facilitation measures, opening the financial services industry, and institutional innovations like post-operational supervision. The SEZ also differs by industrial focus, for example, financial services in Beijing or AI, smart vehicles, and appliances in Anhui. This framework has significant potential for China–GCC investment cooperation, as GCC investor focus is gradually expanding from China's downstream petroleum sectors to green technologies, electric vehicles, and other emerging technologies and industries.

Financial Infrastructure

China and GCC countries have also made significant progress in developing their respective financial infrastructure to facilitate bilateral trade and investment. China has signed cross-border trade settlement arrangements with all GCC members and it has established yuan clearing centers in Qatar and the UAE. Bilateral currency swap lines have also been established between China and Qatar, Saudi Arabia, and the UAE. These measures could make the yuan a trade invoicing currency, reduce cumbersome processes and costs, and create a pool of liquidity in the yuan (Ali 2024).

At the retail and industry levels, major Chinese banks, including the Bank of China (BOC), Agricultural Bank of China, the Industrial and Commercial Bank of China (ICBC), and China Construction Bank, have established a presence in the Dubai International Financial Centre. The BOC and the ICBC also conduct operations in other GCC countries via offices in Bahrain, Kuwait, Qatar, and Saudi Arabia. Some GCC banks, including the National Bank of Kuwait, First Abu Dhabi Bank, and Qatar National Bank, have also opened branches in China.

Chinese and GCC financial institutions have recently collaborated on a number of projects in digital finance. The central banks of China, Saudi Arabia, and the UAE have been working on Project mBridge, testing the viability of central bank digital currencies (CBDCs) for instantaneous cross-border trade and other payments using the project's blockchain (CoinDesk 2024). Furthermore, the Dubai stock exchange, Nasdaq Dubai, and the Shanghai Stock Exchange signed a memorandum of understanding covering various areas of digital financial cooperation.

Significant progress has also been made in facilitating bilateral access to capital markets for public and private funds via investment flows to stock exchanges. The Abu Dhabi Securities Exchange and the Shenzhen Stock Exchange agreed to promote cross-border investment and exchange listings. Saudi Arabia's Tadawul Group also began talks on cross-listing with the Hong Kong, Shanghai, and Shenzhen stock exchanges. Two exchange-traded funds focused on Saudi Arabian stocks have already made their debut in Shanghai and Shenzhen (Bloomberg 2024b).

With the necessary financial infrastructure already in place, speculation about the possibility of settling payments for the GCC's oil and gas exports in renminbi (RMB) has intensified. In 2023, the first LNG cargo imported from the UAE was settled in the Chinese currency. China has explicitly called for regional oil trade to switch to the RMB, and Saudi Arabia is said to be considering this proposition (Wall Street Journal 2022). Given the significant share of Chinese imports in GCC foreign trade, such an arrangement would make sense from an economic standpoint. However, it would also likely have significant impacts on the global oil and gas market, as well as on the international financial system.

Impact of the Changing Global Landscape

The global trade and investment ecosystem seems to be undergoing significant shifts. The recent flurry of global shocks, from the COVID-19 pandemic to regional military conflicts, has amplified the accrued vulnerabilities and systemic problems of the current global economic structure. In order to remain competitive and capitalize on the unfolding transformations, economies need to consider the new risks and opportunities and reflect them accordingly in their international and domestic development strategies.

Risks affecting international trade and investment stem from both macroeconomic and geopolitical origins. The period after the Global Financial Crisis of 2008–2009 saw a slowdown in international trade and FDI, both in absolute terms and as a percentage of GDP, due to the slowing global economy. Meanwhile, public and private global debt continued to mount. It currently exceeds $300 trillion, or roughly three times the global GDP in 2023 (World Economic Forum 2023). These worrying fundamentals were exacerbated by the COVID-19 policy responses, which can be boiled down to the disruption of economic activities and the expansion of the monetary base. Unsurprisingly, this led to a spike in inflation and significantly higher costs of capital due to elevated interest rates. As analysts and institutions argue whether the global economy is poised for a "soft landing" or a full-blown recession, the environment for international trade and investment remains far from conducive.

The last decade was marked by escalating tensions between the U.S. and China, leading to the reinstatement of a variety of bilateral trade and investment barriers. The U.S. administration in 2018 followed the "trade conflict" path by expanding the list of goods imported from China that were subject to increased tariffs. The U.S. also tightened its regulations on inward FDI with the Foreign Investment Risk Review Modernization Act of 2018 (FIRRMA) and banned outward FDI in Chinese new technology industries, including advanced computing chips, microelectronics, quantum technology, and AI (The White House 2023).

China's countermeasures in response to the U.S. trade restrictions included tariff hikes on U.S. exports (generally matching the new U.S. import tariffs to avoid further escalation), increased sourcing of agricultural products from other regions, and anti-dumping investigations. Further potential countermeasures to recent U.S. and EU regulatory initiatives may comprise increased tariffs on automobile, food, and alcohol exports. China could also encourage import flows from other countries while continuing its longer-term strategy of import diversification into alternative markets (Bloomberg 2024a; Steinberg and Tan 2024).

Despite the GCC countries' neutral stance in the China–U.S. competition, their investment activities in the West also face increasing hurdles. To cite only few examples in the media: "U.S. Compels Saudi Fund to Exit AI Chip Startup" (Bloomberg 2023); "Alarm on Capitol Hill Over Saudi Investment in Twitter" (The Guardian 2022); "UAE-Backed Bid for Telegraph Group Dealt Fatal Blow by New Legislation" (The Guardian 2024); "Dubai Clearinghouse Barred From EU Access Amid Money Laundering Concerns" (Euronews 2024). The current structure of the GCC's exports to the U.S. and the EU does not induce significant trade impediments due to its complementary nature. However, as the GCC economies advance their diversification efforts, the issue of market access for their industrial exports will become increasingly pertinent.

The symptoms confirming the current trend of unfolding deglobalization[1] are increasingly spreading across the globe. Growing numbers of economies representing major global markets are increasing their barriers to entry for imported products by applying both tariff and non-tariff measures. At the same time, countries are trying to limit access to domestically developed technologies and scramble for limited resources and other inputs, such as microchips or rare earth elements. In the FDI domain, there is a growing suspicion of inward foreign investment in domestic infrastructure and other sectors of the economy deemed "sensitive." Many countries have also started prioritizing the development of domestic supply chains over promoting outward investment.

In addition to economic discord, the 2020s have already seen several armed conflicts, including the Russia–Ukraine conflict, Gaza offensive, and the Red Sea crisis. All of these have significant repercussions for international trade and investment flows, especially in energy, and exert further pressure on the global rules of engagement. The over use of sanctions and the weaponization of energy trade by the U.S and the EU further complicate the trade, FDI and the working of the international trade and payment systems.

It should be noted that, despite such significant pressures, international trade and FDI have not deteriorated. The 2023 values, while slightly lower than those recorded the previous year, significantly exceeded their pre-pandemic levels. In 2023, global trade amounted to $31 trillion—compared to $25 trillion in 2019 (UNCTAD 2024a). Over the same period, total outward FDI increased from $34.6 to $44.4 trillion (UNCTAD 2024b). Whether, how soon, and to what degree this trend is going to reverse remain to be seen, as the post-pandemic liquidity influx tapers off and new geopolitical and macroeconomic paradigms start to unfold.

Looking beyond the aggregate global numbers, these pressures are already reshaping trade and investment patterns at the regional and industry supply chain levels. Foreign direct investment and international trade pathways are becoming increasingly aligned along geopolitical lines. Trade flows between the U.S. and China, for instance, have been growing at a slower pace than their respective trade with the rest of the world, while trade relationships tend to strengthen within other regional blocs.

Global geoeconomic tensions have also led to the development of new trade corridors and supply chains that bypass direct links between rival economies and geopolitical blocs. For instance, since 2018, Vietnam has seen an 80% increase in imports from China, while its exports to the U.S. have surged by 159% (Deloitte 2024). It is uncertain, however, whether these "bypass" corridors will continue their spectacular growth. If the bigger players press on with protectionism, this may result in "secondary" trade barriers and sanctions. In any case, these new trade corridors indicate a new approach to global supply chains with a focus on diversification and resilience—rather than on costs and operational efficiency alone.

The emergence of new trade pathways and investment destinations is an example of the opportunities for developing economies that materialize from the global shifts described earlier. These economies can benefit from both the increased economic cooperation within respective trading blocs and the blocs' roles as global intermediaries.

China and the GCC countries exemplify this potential, as they are well positioned to take advantage of the ongoing shifts in global trade and investment. China is projected to overtake the U.S. as the world's largest economy in the 2030s (City Research 2023). Meanwhile the Middle East region could emerge as a major hub for global trade, potentially outpacing the global average trade growth by up to 4% by 2030 (Standard Chartered 2023).

In addition to the geographic and geopolitical opportunities presented earlier, significant development opportunities exist in emerging industries, such as clean energy and cleantech, biotechnology, and digital solutions across various sectors. Driven by innovation and technological development in such spheres as AI, blockchain, web3, and big data, these emerging industries could alleviate the potential decline in international trade and investment expected in some of the conventional sectors. Interestingly, unlike the global trade in goods, which fell by 5% year on year in 2023, the global trade in services grew by 8% over the same period (UNCTAD 2024a).

Visions of the Future

Over the past two decades, China and the GCC have been successfully developing economic ties. This is evidenced by significantly increased bilateral trade and investment flows and the establishment of a solid foundation for further cooperation, encompassing both physical (logistics, segments of industrial supply chains, SEZ) and soft (policy, financial, institutional) infrastructure. However, a sustained linear development trajectory may prove to be challenging to maintain, as both the global economy and individual countries face a new set of challenges.

The trend of global fragmentation and China-U.S trade and technology tensions may test the Chinese economy, given its dependence on key foreign inputs (energy, metals, minerals, and agricultural products, among others) and the more than 20% share of exports in its GDP. China's recent Global Development Initiative and Global Security Initiative indicate a shift in focus toward developing economies and the Global South. However, China's general intention seems to be to try and mend the current global systems by integrating Chinese development initiatives into existing (and seemingly deteriorating) global frameworks.

Despite the progress of the GCC countries in diversifying their economies, they are still heavily dependent on oil and gas exports. The increasing volatility in the global energy markets, the disruption of shipping routes, and the general reconfiguration of export portfolios and supply chains may significantly impact the performance of the GCC economies. GCC countries also need to maintain a careful balance in navigating between the competing global power centers that represent their key export markets. Given historical instances of GCC members lacking unity and a collective foreign policy approach to regional and global issues, this task may prove challenging.

In this environment, which presents challenges and opportunities that are increasingly different from the status quo of recent decades, what could be the focal points of trade and investment cooperation between China and the GCC?

Hydrocarbons are expected to remain at the core of bilateral economic relationships and provide a solid basis for cooperation in other areas. Relevant trade and investment flows ensure security of supply for China and security of demand and export revenues for the GCC economies. Cooperation in the energy sector has significant potential to grow in scale, scope (downstream industries and relevant value chain services such as transportation, insurance, finance) and breadth (joint projects in the domestic and global markets).

China and the GCC also appear to have a synergetic potential that could be utilized in the joint development of new energy industries. Their technological expertise, the availability of capital, and strong domestic demand driven by the restructuring of China's energy sector and the GCC's strategic development plans provide a strong foundation for establishing enterprises and industrial clusters. These clusters would cover domestic needs and help develop competitive advantages that could be applied to the global markets.

As many existing supply chains undergo transformation and new trade routes emerge, the logistics sector—both in the GCC and in China—can reap the benefits from these emerging global trends. In addition to handling increasing bilateral trade flows, the sector can serve as a bridge between the Association of Southeast Asian Nations/East Asia and Middle East and North Africa (MENA) regions. With the hard and soft infrastructure already established under the umbrella of the SEZ, the logistics hubs of the GCC and coastal China can become integral parts of the shifting supply chains and further cement their role as global logistics, processing, and re-export centers.

These developments in bilateral trade in goods could stimulate growth in related services such as construction, transportation, insurance, and finance. The global fragmentation of trade and emerging digital barriers present an opportunity for Chinese tech companies to establish their presence in the GCC with a view to capturing this promising market. Deeper cooperation in conventional and digital services (telecoms, data management, software and relevant intellectual property) can provide a solid base for joint developments in emerging technologies such as AI, big data, and blockchain solutions, which are essential for the future competitiveness of both China and the GCC's economies. Lastly, liberalizing the movement of people between China and the GCC would further boost growth in travel and other personal services.

Expanding bilateral trade in goods and services would require increased investment. Several factors could further stimulate investment flows between China and the GCC. First, established cross-border investment vehicles such as sovereign wealth funds, state-owned enterprises and development banks need to have unimpeded access to capital markets in China and the GCC. This includes access to stock markets, private equity, and derivatives, accompanied by the further development of cross-border financial services and infrastructure. Second, traditional recipient markets and perceived safe havens in the U.S. and Europe are becoming increasingly more restrictive to FDI inflows from certain jurisdictions, causing the redirection of existing and future investment flows. As investment flows from the West to China also face increasing hurdles, financial institutions in the GCC can position themselves as intermediaries providing access to Chinese markets. Finally, another opportunity lies in reshoring Chinese and GCC capital, especially given that major offshore jurisdictions are often located in or controlled by the U.S., the United Kingdom, and Continental Europe.

Both China and the GCC countries are embracing geoeconomic changes and the associated emerging opportunities, as demonstrated by their deeper and broader economic cooperation, which now covers institutional, financial, and policy domains and extends into emerging industries and technologies. Going forward, even more proactive approaches to maximizing their joint potential—both bilaterally and globally—may be required, as the unfolding geopolitical and macroeconomic trends advance the transformation of the global order, moving it further away from the conventional status quo.

Note

1 The term "deglobalization" is usually defined as decreasing interdependence and integration between entities around the world, primarily characterized by diminishing foreign trade and investment.

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3 China and GCC

Prospects for Upstream/Midstream Oil and Gas Cooperation

Colin Ward, Majed Alsuwailem, Lining Wang, and Kailei Liu

Introduction

The energy relationship between GCC countries and China is one of the most strategically significant developments in the twenty-first-century oil landscape. It is shaped by economic complementarity, geopolitical pragmatism, and shared priorities around energy security and sustainable development. At its core lies a powerful asymmetry: the GCC is a leading, cost-competitive producer of hydrocarbons, while China is the largest consumer and importer of hydrocarbons, with a heavy reliance on oil even as it advances a low-carbon transition.

Historically, the GCC–China engagement was primarily transactional, trading crude oil for manufactured goods. However, the accelerating energy transition, geopolitical uncertainty, and global supply chain shifts have prompted both sides to seek deeper integration. Today, the partnership includes joint investments in upstream and midstream infrastructure, technological collaboration, and aligned energy security and climate policies.

With around 30% of global oil and over 20% of natural gas reserves (Energy Institute 2024), the GCC has built a low-cost, low-carbon extraction model enabled by world-class infrastructure and governance. Meanwhile, China is expanding domestic production through deep, offshore, and unconventional sources, yet its liquids consumption continues to outpace supply, driving its need for diversified, secure imports.

This chapter explores the changing dynamics of the China–GCC energy relationship, emphasizing upstream and midstream cooperation. It is structured into three key sections. The first section examines the economic basis of GCC energy production. It then delves into China's strategic energy policies and the growing role of cross-investments and technological collaboration. The chapter concludes by assessing how these joint efforts enhance mutual energy security and contribute to a more resilient and stable global energy system.

GCC Energy Production and Economic Outlook

The GCC countries remain foundational to the global oil and gas markets due to their exceptional resource base, low-cost production profile, and strategically

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developed export infrastructure. Collectively, these states continue to anchor a significant share of the world's hydrocarbon output, even as the global energy landscape undergoes structural transformation driven by decarbonization, diversification, and technological change. In this evolving context, the outlook for oil and gas production in the GCC is shaped by both enduring economic advantages and adaptive strategies to align with emerging energy trends.

Hydrocarbon Reserve Base and Production Scale

As of the end of 2020, GCC countries collectively held 527.5 billion barrels of proven oil reserves, representing nearly 30% of the global total, along with 39 trillion cubic meters of natural gas, or approximately 21% of global reserves (Energy Institute 2024). Among these, Saudi Arabia possesses the largest share of oil reserves, followed by Kuwait and the United Arab Emirates (UAE). Qatar dominates in gas reserves, with substantial holdings also in Saudi Arabia and the UAE. This concentration of conventional hydrocarbon wealth underpins the region's long-standing dominance in global energy supply.

In 2023, the GCC countries produced an estimated 21 million barrels (MMb) of oil per day and 41 billion cubic meters of natural gas per day, accounting for approximately 22% of global oil output and approximately 10% of global gas production (Table 3.1). All GCC members are net exporters of crude oil, with the bulk of their exports destined for Asian markets, including China, India, South Korea, and Japan. This export orientation reflects the structural energy dependence of Asia's industrial economies and their limited domestic hydrocarbon resources.

Table 3.1 Oil and gas output and proven reserves in China and GCC countries

Country	*Oil production (1,000 barrels daily) in 2023*	*Proven oil reserves (billion barrels) at the end of 2020*	*Oil consumption (1,000 barrels daily) in 2023*	*Natural gas production (billion cubic feet per day) in 2023*	*Proven gas reserves (trillion cubic feet) at the end of 2020*	*Gas consumption (billion cubic feet daily) in 2023*
Bahrain	190	0.09	No data	1.62	2.3	No data
Kuwait	2,908	101.5	411	1.31	59.9	2.2
Oman	1,049	5.4	233	4.18	23.5	2.9
Qatar	1,772	25.4	370	17.51	871.1	4.3
Saudi Arabia	11,389	297.5	4,052	11.04	212.6	11
UAE	3,922	97.8	1,139	5.38	209.7	6.5
GCC countries	21,055	527.53		41.03	1,379	
China	4,198	26	16,577	22.67	296.6	39.2
World	96,376	1,723.4	100,221	392.74	664.8	388

Sources: Energy Institute (2024), OPEC (2023), and OAPEC Data Bank (2025)

Gas Market Dynamics and Power Generation Impact

In the GCC countries, excluding Qatar, natural gas production primarily consists of "associated gas," a byproduct of oil extraction. This creates a structural dependence on oil, as gas output is directly linked to oil production levels. OPEC+ quotas, which cap oil output, add further complexity by indirectly limiting the volume of associated gas that can be economically recovered. These constraints pose challenges for energy diversification and long-term economic planning in the region. To address this issue, GCC countries are increasingly developing non-associated gas fields. These new resources are expected to reduce reliance on oil-linked gas production, support more flexible energy use, and advance national sustainability goals by enabling cleaner energy for both domestic consumption and exports.

The role of natural gas within the GCC varies significantly. Export-oriented countries such as Qatar, Oman, and the UAE have invested heavily in liquefied natural gas (LNG) infrastructure, positioning gas exports as central to their economies. In contrast, nations like Saudi Arabia, Kuwait, and Bahrain primarily utilize natural gas to meet their growing domestic electricity demand and to support industrial development.

Qatar had the world's third-largest proven reserves of gas in 2020, estimated at 871.1 trillion cubic feet (Table 3.1), most of which are in its non-associated gas production from the North Field jointly shared with Iran. The country exported nearly 3.8 trillion cubic feet of natural gas it produced via LNG carriers to international markets, including East Asia and Europe and about 671 billion cubic feet via pipeline to Oman and the UAE (Energy Institute 2024; Al Suwailem and Aldayel 2020).

Saudi Arabia is the largest consumer of gas in the GCC, and it currently neither exports nor imports gas. The Kingdom has increased its gas production by 8% per annum since 2013, reaching 17.51 billion cubic feet per day in 2023 (see Table 3.1). Historically, Saudi Arabia's power generation relied heavily on liquid fuels due to the availability of oil and the limited domestic gas supply. However, current policy prioritizes the replacement of oil with 50% natural gas and 50% renewables to free up valuable crude for export and to reduce the carbon footprint of the power sector. This policy shift has spurred major investments in domestic gas development, with particular emphasis on unconventional sources. A key example is the Jafurah Basin, estimated to contain around 229 trillion standard cubic feet (tscf) of gas and 75 billion stock tank barrels (STB) of condensates in place (Aramco 2024). Development strategies for the Jafurah Basin include horizontal drilling and multistage hydraulic fracturing technologies (Shabaneh and Al Suwailem 2020).

In 2023, Bahrain and Kuwait produced 1.62 billion cubic feet per day (bcf/d) and 1.31 bcf/d of natural gas, respectively (Table 3.1), with all production consumed domestically to generate electricity and support water desalination industries (Al Suwailem and Aldayel 2020). The Durra field, located offshore from the Partitioned Neutral Zone (PNZ) between Kuwait and Saudi Arabia, is estimated to hold substantial natural gas reserves of up to 1 trillion cubic feet. However, its development has faced significant delays due to long-standing territorial disputes and disagreements over resource ownership and exploitation rights involving Iran (Hagagy 2023). While Bahrain benefits from its domestic natural gas production, the country lacks sizeable proven natural gas reserves, which limits its long-term self-sufficiency. As a result, Bahrain has been compelled to adopt strategies such as opening LNG receiving and storage facilities with regasification capabilities. A prominent example of this is Bahrain's LNG terminal, completed in 2020, which can receive and store 173,400 cubic meters with a regasification capacity of up to 800 million standard cubic feet per day (Bahrain LNG 2025).

Oman and the UAE's gas production is more complicated, with foreign oil companies operating in their countries under concession agreements that entitle these firms to sell a portion of the gas domestically and abroad. This has helped both countries price the gas they produce according to international market values. It has also helped them assess the feasibility of developing more gas fields (Al Suwailem and Aldayel 2020). Abu Dhabi is a net exporter of gas, with most of the UAE's oil and gas fields located there. Meanwhile, Dubai and the other emirates are dependent on domestic gas supplies and imports (Al Suwailem and Aldayel 2020). As of year-end 2023, the UAE and Oman exported 7.7 and 15.3 billion cubic meters of LNG, respectively (Energy Institute 2024).

Production Costs and Economic Efficiency

Overall, the GCC states enjoy a globally unmatched cost advantage in crude oil production, derived from geological, technological, and logistical factors. High porosity and permeability reservoirs, shallow depths, and large field sizes reduce exploration and development costs (Sorkhabi 2010). This translates into higher per-well productivity than their peers elsewhere.

Compared to other major oil producers, such as the United States (U.S.) shale sector, Canadian oil sands, or offshore African and Latin American operations, GCC producers are better positioned to sustain output during periods of price volatility due to their low development costs. Figure 3.1 shows the average well costs in GCC countries, encompassing lifting, transportation, processing, and decommissioning costs, estimated by the authors based on Rystad Energy data. Saudi Arabia maintained the lowest weighted average cost globally, driven by a very low lifting cost. Kuwait, the UAE, and Qatar also operate at highly competitive levels, with costs under $21 per barrel. Oman and Bahrain face relatively higher production costs, averaging just over $40 per barrel (Rystad Energy 2025). This is largely due to smaller reserve bases, more complex geology, and a greater reliance on enhanced oil recovery (EOR) methods. Nonetheless, these figures remain below many non-OPEC producers, preserving a meaningful degree of competitiveness for the entire region.

The GCC's competitiveness is further bolstered by its highly integrated upstream, midstream, and downstream infrastructure. This includes extensive pipeline networks and world-class export terminals located on the Arabian Gulf, Arabian Sea, and the Red Sea (el-Shaeri 2025) as well as strategically positioned

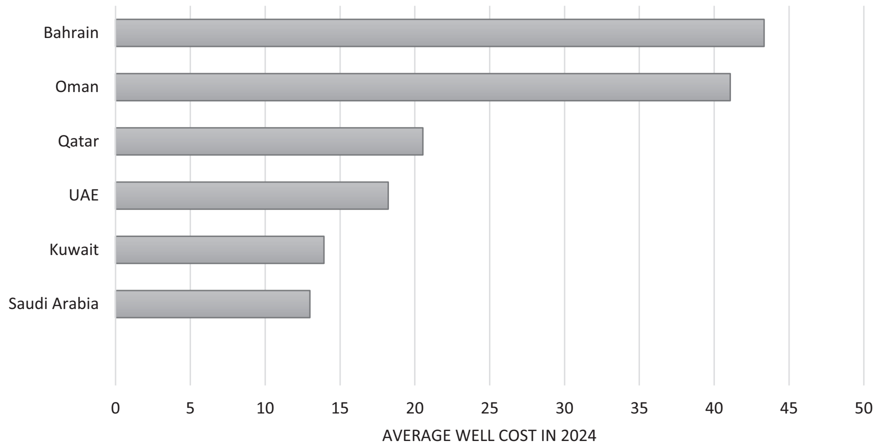

Figure 3.1 Estimated average well costs for GCC countries in 2024, $ per barrel.
Source: Authors' calculations based on Rystad Energy (2025).

separation plants, refineries, and petrochemical complexes near major shipping lanes. The bloc's ability to leverage economies of scale is a key driver of its competitiveness, while effective risk mitigation and structural efficiency serve as critical differentiators, particularly in an era of heightened scrutiny over investment returns and growing attention to future requirements such as lifecycle emissions.

Institutional and Strategic Models

The GCC's oil and gas industry is deeply intertwined with the history and development of its member states. The industry's roots trace back to Bahrain, where oil was first discovered in 1932, marking the beginning of a transformative era for the Gulf. This initial discovery was soon followed by others across the region, with Saudi Arabia uncovering vast reserves with the help of Standard Oil of California (which later became Chevron), and British Petroleum (BP) in Kuwait marking a new era of oil production in the region (Yergin 1990). Oman was the last among the GCC countries to make a commercially viable discovery, launching significant oil production in the late 1960s (Middle East Business Intelligence 2009).

While the early decades of oil and gas exploration and production in GCC countries were directed by international oil companies (IOCs), the establishment of OPEC in 1960 marked a turning point. Over the ensuing decades, GCC countries nationalized their oil assets, setting the tone for future production governance. Today, the GCC's exploration and production sectors are predominantly governed by national oil companies (NOCs), such as Saudi Aramco, Kuwait Oil Company, and QatarEnergy. These institutions serve as stewards of national hydrocarbon wealth and are central to economic policy. However, institutional models vary. The

UAE and Oman have adopted hybrid structures involving joint ventures with international partners, enabling technology transfer and capital inflows. For instance, the Abu Dhabi National Oil Company (ADNOC) collaborates with major global firms such as ExxonMobil and the China National Petroleum Corporation (CNPC) under concessionary and joint-venture frameworks.

Saudi Arabia remains largely committed to a state-dominated model but has selectively permitted foreign participation, such as Chevron's role in the onshore fields in the Partitioned Neutral Zone (PNZ) shared with Kuwait and the use of service companies. At the same time, a growing number of GCC energy firms, notably ADNOC and QatarEnergy, are expanding their international presence, investing in upstream assets abroad to diversify their portfolios and secure market access in high-growth regions.

Looking at the overlap of GCC and Chinese overseas upstream investment in the table below, we can see that while there may be zero direct foreign investment into Saudi Arabia, Kuwait, and Bahrain currently, the other GCC members have quasi-liberal upstream markets. Most notably, the UAE has a large external portfolio in locations including Iraq, Egypt, Russia, and Turkmenistan. Kuwait, Qatar, and Oman have smaller holdings in locations including Brazil and Kazakhstan. Saudi Arabia and Bahrain have not yet pushed into external exploration and production, but there are ongoing efforts to expand investments into Africa and the U.S., with a focus on gas and downstream projects (Procopio and Cok 2025) (see Table 3.2).

The UAE and Saudi Arabia have been actively pursuing investments in LNG projects in recent years to secure a foothold in the growing global LNG market. In 2024, Aramco acquired a minority stake in U.S.-based MidOcean Energy, which is in the process of acquiring four Australian LNG projects (Saba 2024). ADNOC also acquired a minority stake in the NextDecade's U.S.-based Rio Grande Project (Tani and Moore 2024).

Table 3.2 Production by ownership in 1,000 barrels of oil equivalent per day (kboe/d) (2025)

		Company Headquarters						
		China	*Saudi Arabia*	*UAE*	*Qatar*	*Kuwait*	*Oman*	*Bahrain*
Physical Production	China	7,852	—	—	—	—	—	—
	Saudi Arabia	—	12,092	—	—	—	—	127
	UAE	269	—	3,162	—	—	—	—
	Qatar	—	—	253	2,828	—	—	—
	Kuwait	—	—	—	—	2,942	—	—
	Oman	12	—	12	—	—	1,021	—
	Bahrain	—	—	—	—	—	—	328

Source: Rystad Energy (2025).

Note: The rows indicate geographical production, while the columns indicate production allocated according to company headquarters (e.g., 269 kboe/d in the UAE is produced by a Chinese company).

Role in Market Management and Stability

Saudi Arabia, Kuwait, and the UAE play crucial roles in OPEC as swing producers. Their ability to adjust their output in response to market conditions underpins their strategic influence and supports global price stability. Meanwhile, Oman and Bahrain, though not OPEC members, participate in the OPEC+ alliance under the Declaration of Cooperation (DoC), contributing to broader supply management efforts. This coordinated approach has proven effective in addressing market stability, including those caused by the COVID-19 pandemic and recent macroeconomic volatility.

These core swing producers maintain substantial spare production capacities, which can be deployed into the oil market within 30 days and sustained for at least 90 days (EIA 2023). This ability to rapidly increase output provides a crucial buffer against unexpected supply disruptions, whether due to geopolitical tensions, natural disasters, or technical outages in other producing regions.

These additional barrels have historically played a key role in stabilizing the global oil market. By responding swiftly to supply shocks or demand surges, swing producers help mitigate price volatility and maintain a degree of predictability in global energy markets. According to a study conducted by Almutairi, Pierru, and Smith (2021), OPEC's spare capacity plays a critical role in reducing global oil price volatility, generating substantial economic benefits for the world economy. The annual value of OPEC's spare capacity to the world's economy was estimated to be $193.1 billion in 2019 (Almutairi, Pierru, and Smith 2021).

Saudi Arabia's spare capacity has typically ranged between 1 and 3 million barrels per day (MMb/d) (with the levels during COVID-19 going beyond this). These excess volumes are distributed across many oilfields and different crude types (Considine et al. 2023). Similarly, the UAE contributes significantly to OPEC's strategic framework by officially maintaining up to 500,000 barrels per day (kb/d) of spare capacity, but their actual spare capacity is likely to be higher as they head toward a target of 5 MMb/d total output capacity by 2027 (IEA 2024).

Outlook: Navigating Transition With Resilience

The GCC countries maintain a unique and strategic position within the global crude oil market, underpinned by their vast hydrocarbon reserves, exceptionally low production costs, and advanced infrastructure that facilitates efficient extraction, processing, and export. As global oil demand evolves in the context of energy transition and climate imperatives, the comparative advantages of GCC crude will remain economically and geopolitically significant far into the future. These advantages, anchored in both natural resource endowment and institutional capacity, position the bloc as a key supplier in a more selective, carbon-conscious global oil economy.

Rather than fully pivoting away from hydrocarbons, an unrealistic expectation in the short and medium terms, given the economic centrality of energy rents, the GCC countries are pursuing a strategy that integrates sustainability into existing structures. This includes enhancing the environmental performance of their oil production, expanding the use of alternative energy, and reinforcing economic diversification, as outlined in broader national development programs such as Saudi Vision 2030, among others across the bloc, and their pledges to address climate change as outlined in their United Nations nationally determined contributions (NDCs).

A key aspect of this transformation lies in the concerted effort to reduce the carbon intensity of oil production. For instance, significant strides have been made in reducing routine gas flaring, which has historically been a major contributor to Scope 1 emissions in oil-producing regions. Saudi Arabia, Kuwait, and the UAE now rank among the lowest globally in flaring intensity due to their investment in gas recovery systems, process optimization, and flaring mitigation technologies. These efforts are also aligned with international frameworks, such as the World Bank's Zero Routine Flaring by 2030 initiative (Figure 3.2).

At the same time, carbon capture, utilization, and storage (CCUS) technologies are becoming a core part of the GCC's strategy to ensure the long-term viability of its oil. These systems not only support the bloc's climate objectives but also extend the commercial relevance of oil assets by making them more compatible with emerging environmental regulations and global trade frameworks. CCUS investments, while capital-intensive, are increasingly framed within long-term industrial strategies, often co-financed through sovereign wealth funds to reduce the financial burden on NOCs.

Beyond upstream decarbonization, GCC countries are also seeking to minimize domestic oil consumption by shifting to alternative energy sources for electricity generation. One example is Saudi Arabia's Jafurah project, which aims to replace oil-fired power generation with unconventional gas. This kind of fuel switching

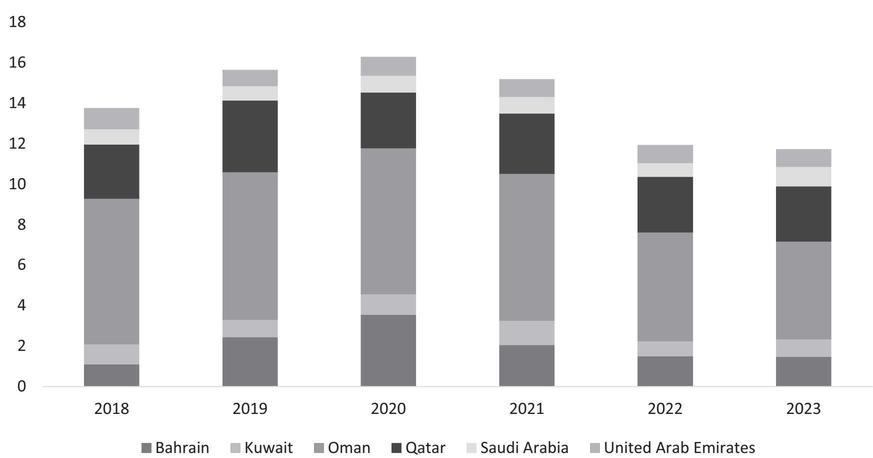

Figure 3.2 Upstream flaring intensity of GCC members, in cubic meters per barrel.

Source: Author's calculations based on Energy Institute (2024) and OAPEC Data Bank (2025).

not only reduces domestic emissions but also frees up crude oil for export or higher-value applications, thereby improving both economic and environmental outcomes. Formerly wasted byproducts, such as associated gas, are now being monetized through reinjection or power generation, reflecting a shift toward more efficient and sustainable resource use.

These developments also reflect a broader strategic adaptation to emerging trade and regulatory realities. The European Union's Carbon Border Adjustment Mechanism (CBAM) and similar policies increasingly impose tariffs or market access limitations on products with high embedded emissions. As a result, lower-emission crude oil is expected to command a competitive advantage in key markets, in terms of both pricing and access. GCC producers, by differentiating their crude as "greener" barrels, aim to preserve and even enhance their market share in regions such as Europe and Asia, where carbon-conscious procurement is gaining traction.

The outlook for GCC oil demand remains relatively robust in the near to medium term. Although global oil demand growth is expected to slow due to energy transition measures, efficiency improvements, and weak global economic growth, it is projected to continue increasing modestly until at least 2030, according to the International Energy Agency (IEA) and other major sources. Notably, jet fuel and petrochemical feedstocks such as naphtha are expected to drive this residual growth, even as gasoline and diesel demand plateau. Jet fuel demand is projected to grow by 24 million tons and naphtha by 18 million tons by 2030 (850 kb/d), accounting for 41.1% and 32.1% of the global demand increment, respectively. The Asia-Pacific region will remain the engine of global oil demand growth, accounting for 54.9% of net global demand increases, with India replacing China as the largest incremental consumer by 2030 (CNPC ETRI 2024).

As global demand becomes more selective, differentiated barrels, particularly those with low carbon intensity, will become increasingly important. The GCC's relatively low greenhouse gas emissions per barrel and investments in emissions reduction technologies (e.g., flaring reduction, CCUS, digital optimization) support the competitiveness of its crude oil in carbon-sensitive markets such as Europe and, increasingly, Asia, as discussed earlier.

While total demand for oil may decelerate and eventually decline, the pivot to these premium barrels is already underway. The IOCs and energy majors in OECD countries are increasingly pivoting toward gas and offshore assets. They are also reducing their oil investments in problematic locations like onshore Nigeria and are becoming more cautious about upstream development in general. This shift enhances the role of traditional, low-cost producers like the GCC, which can continue supplying oil economically at lower breakeven thresholds. In 2020, the Middle East accounted for 48.3% of global recoverable oil reserves, with a reserve-to-production ratio of 82.6, far exceeding the global average of 53.5 (Energy Institute 2024).

Partnerships with major consumers such as China are also evolving in the context of the energy transition. As China pursues its 2030 peak emissions target and its 2060 carbon neutrality goal, it has a growing interest in sourcing lower-carbon crude. This alignment creates a strong basis for long-term energy cooperation, including areas like hydrogen, CCUS, and low-carbon industrial development. For the GCC countries, securing such relationships ensures market stability while also embedding them in the broader global decarbonization agenda.

China's Market Positioning and Strategy

China's crude oil market is undergoing a structural evolution shaped by the dual imperatives of economic development and energy transition. As the world's largest crude oil importer and a top-tier oil producer, China faces the challenge of ensuring energy security while simultaneously pursuing decarbonization and industrial transformation. The policies guiding this balancing act reflect the country's long-term strategy to maintain energy supply stability, reduce import dependence, reduce negative environmental impacts, and promote technological innovation across the energy sector.

Economic Development and Energy Demand Outlook

China's ambition to double its gross domestic product (GDP) per capita by 2035, from approximately \$13,500 in 2024 to nearly \$30,000, implies a sustained increase in energy demand. Per capita energy consumption growth typically peaks at income levels between \$20,000 and \$30,000, indicating that China has yet to reach saturation. While improvements in energy efficiency are projected to reduce China's energy consumption per unit of GDP by 25% by 2035, its total energy consumption is expected to rise by 1.5 billion tons of standard coal equivalent, reaching around 7.5 billion tons (CNPC ETRI 2024). Demographic changes in China can also influence this trend in the long term, but the final impact here is considered on a total consumption basis.

Transitioning Energy Mix

Historically reliant on coal, China is actively rebalancing its energy mix to reduce environmental degradation and meet its climate commitments. Coal's share of the country's primary energy supply has decreased from 66% a decade ago to 54% in 2024, but it remains far above the global average. By 2035, the government aims to reduce coal's dominance further, increasing the share of non-fossil energy to over 30%. However, oil and gas will remain indispensable components of the energy system through at least 2040, together accounting for over 27% of primary energy consumption (CNPC ETRI 2024).

The Evolving Role of Oil and Gas

China is a major oil and gas producer. In 2023, it produced 4.2 million barrels of oil per day, surpassing the output of all GCC countries except Saudi Arabia. Its natural gas production reached 22.7 billion cubic feet per day, exceeding that of Qatar, the GCC's leading gas producer and exporter (see Table 3.1). Despite this substantial output, China consumes its entire domestic oil and gas production, as it remains a significant net importer of fossil fuels.

While oil consumption for transportation is nearing its peak, the strategic importance of oil is shifting toward petrochemical feedstocks and industrial uses. Demand is expected to peak at 770 million tons (~15.5 MMb/d) around 2025, before declining slightly to 730 million tons (~14.7 MMb/d) by 2030. During this period, the share of oil used for transport will fall below 40%, while the share of oil used in the chemical sector is projected to grow to approximately 27% of China's total demand (CNPC ETRI 2024).

Natural gas, the cleanest burning fossil fuel, is emerging as a transitional bridge in China's energy strategy. China's demand for natural gas is projected to reach 552 billion cubic meters by 2030, driven by its increased use in industry, power generation, and urban energy supply. Gas-fired power generation is particularly significant as a means of balancing intermittent renewable energy due to its responsiveness and low carbon profile.

Supply Trends: Domestic Production and Imports

Domestically, China is aiming to stabilize its crude oil production at or above 200 million tons (~4 MMb/d) per year through continued investment in reserve replacement and enhanced recovery. However, its refining capacity is set to reach approximately 960 million tons per year (~19.25 MMb/d) by 2030, exceeding domestic demand and reinforcing its position as a major exporter of refined products.

Natural gas production is also expected to rise to 300 billion cubic meters by 2030, supported by the ongoing implementation of the national Seven-Year Action Plan for energy security. Simultaneously, natural gas imports, particularly LNG, are expected to increase, reaching a projected 252 billion cubic meters. This dual approach ensures supply redundancy while enabling flexibility in sourcing and price hedging.

Strategic Reserves and Infrastructure

China has developed one of the world's largest strategic petroleum reserves (SPR), though its precise size remains opaque due to unreported inventories, extensive commercial holdings, and underground storage. Since the early 2000s, China has systematically built strategic and commercial oil stockpiles to enhance its resilience against supply shocks and price volatility. The integration of these reserves into a flexible, responsive midstream system further supports the country's energy security objectives.

Green and Low-Carbon Transition in the Oil Sector

China's oil and gas sector is undergoing a significant transformation to support national climate goals. Advanced technologies in deep-earth drilling, shale oil recovery, and offshore development have expanded domestic resource availability. Concurrently, investments in CCUS, the chemical recycling of plastics, and smart energy systems underscore the country's commitment to green innovation. These technologies will play a critical role in reducing Scope 1 and 2 emissions from the oil sector and in integrating fossil fuels into renewable energy systems.

Strategic Implications

China's crude oil policy is not solely domestic in orientation. The country's large-scale overseas investments, made through state-owned enterprises such as CNPC, CNOOC, and Sinopec, reflect a strategic approach to externalizing energy security. These investments span upstream, midstream, and downstream assets globally, including critical partnerships with producers in the GCC, Africa, and Central Asia. Such diversification helps mitigate geopolitical risks and enhances supply chain stability.

Ultimately, China's oil market development is characterized by a pragmatic duality: the imperative to secure traditional energy supplies in the short- to medium-term while building the foundations for a lower-carbon, innovation-driven energy system. The trajectory of this strategy has profound implications for global energy markets, particularly in reinforcing bilateral energy cooperation with the GCC.

GCC/China Areas of Collaboration

Cross-Investments in Crude Oil Production and Export

The trajectory of China–GCC energy relations has expanded markedly over the past two decades, progressing from simple trade in crude oil to a complex architecture of cross-investment and co-development across the oil value chain. This evolution reflects both China's strategic pursuit of energy security and the GCC states' desire to diversify their export outlets, attract foreign investment, and maximize the long-term value of their hydrocarbon resources in an increasingly decarbonized global market.

China occupies a unique dual role in the global energy system. It is simultaneously one of the top ten crude oil producers, producing 4.2 million barrels per day in 2023, and a top crude importer (Energy Insitute 2024). This paradox arises from its developmental model, which transforms vast quantities of imported raw materials and energy into high value finished and intermediate goods for global export. China's drive to secure long-term energy access is underpinned by its substantial overseas investments and trade frameworks, most prominently through the Belt and Road Initiative (BRI), which has linked Chinese capital with energy infrastructure development across Asia, Africa, and the Middle East.

This expansive approach to energy diplomacy has positioned China as a significant external stakeholder in oil-producing regions, including the GCC. Chinese NOCs, particularly CNPC and Sinopec, have pursued equity investments, joint ventures, and strategic partnerships across both upstream and downstream operations in the Gulf. In parallel, Chinese engineering, procurement, and construction (EPC) firms and oilfield service companies such as China Oilfield Services Limited (COSL) have executed contracts related to drilling, seismic surveys, and storage development, further embedding Chinese technical capacity within the GCC's oil sector.

China's direct investments in the GCC are growing. Among the GCC states, the UAE has emerged as the most open to Chinese upstream investment. ADNOC's hybrid operational model has enabled foreign firms, including CNPC, to participate in exploration and production (E&P) through long-term concession agreements. Oman has set a precedent for shared operational control, with Petroleum Development Oman (PDO) structured as a joint venture with IOCs, including Chinese entities. For other nations, however, access to upstream has been limited until now.

Saudi Arabia, while traditionally reliant on its state-owned champion Aramco, has permitted selective foreign involvement in upstream activity. A notable example is Chevron's joint operation with Kuwait in the PNZ. Although direct Chinese upstream access in Saudi Arabia remains limited, cooperation in downstream refining is more developed. The Yanbu Refinery, jointly developed by Sinopec (which holds a 37.5% stake) and Aramco, represents a flagship example of industrial integration and co-investment, with a total capital outlay exceeding $8 billion.

While not all GCC nations provide equal levels of upstream access, cross-investment dynamics are growing in their sophistication and scope. Chinese equity oil production from GCC countries, particularly the UAE and Oman, is already significant, and the scope for expansion remains considerable as trust, strategic alignment, and mutual benefits deepen.

Chinese oil production outside its borders, both in GCC states and elsewhere, is increasingly material to global supply balances. According to Rystad Energy, China's overseas equity production surpasses 7 MMb/d, representing nearly half of its current domestic demand. While this production spans a wide geographic spectrum, including major stakes in Iraq, Brazil, and Kazakhstan, its concentration in the Arabian Gulf is particularly notable. Chinese-associated production in the region alone exceeds 50 million tons annually (~1 MMb/d), underscoring the region's strategic weight in China's energy calculations. China's share of Iraq's oil production has grown as a percentage of total production from less than 5% in 2010 to approximately 25% currently (Rystad 2025).

This growing portfolio reflects more than just physical supply acquisition. It signals China's intent to shape global energy flows and mitigate geopolitical risks as a stakeholder, with technical influence and long-term off-take agreements. In countries such as Iraq, Chinese companies have become dominant players in upstream development, often entering where Western IOCs have reduced their exposure. Such expansion is frequently facilitated by state-backed financing and diplomatic support, enabling Chinese firms to undertake projects with significant capital and operational demands.

For the GCC, welcoming Chinese capital and technical engagement presents both opportunities and challenges. On the one hand, it secures access to the world's most dynamic oil-consuming market, supports national diversification goals, and allows for the development of large-scale infrastructure projects. On the other hand, it requires a careful balancing of sovereignty, operational control, and long-term strategic interests, particularly considering regional security dynamics and global decarbonization pressures. Nevertheless, the GCC possesses considerable leverage. Unlike many other countries where Chinese oil investments flourish, often characterized by political instability, capital scarcity, or higher geological risk, the GCC states are relatively wealthy, politically stable, and technically advanced. As a result, they are able to negotiate as peers, shaping project design, and enforcing high environmental and operational standards.

On the other hand, GCC nations are increasingly looking towards China as a location for their investments, with a significant acceleration in the last few years (ISPI 2024). Diversification is a positive strategy to safeguard against regional and currency-based uncertainty, with China offering some attractive options in the energy space. Downstream investments appear to be most prominent in refining and petrochemicals, but they could easily extend into more upstream-related areas such as technology and midstream logistics (see the following sections).

Looking ahead, China–GCC cross-investments in crude oil production and export are poised to deepen further. With global demand patterns shifting and environmental standards tightening, partnerships that can deliver not only secure but also low-carbon and competitively priced crude will be increasingly valuable. In this context, GCC oil, characterized by low production costs and relatively low carbon intensity, combined with Chinese capital and technological capability, constitutes a powerful axis in the evolving global oil economy (Gibbon 2023).

Technology and Diversification

The evolving energy partnership between the GCC countries and China has extended beyond traditional crude oil trade into technology transfer, innovation, and industrial diversification (Zheng 2024). This cooperation increasingly reflects the shared strategic priorities of both parties: for the GCC, to modernize its hydrocarbon sectors and reduce its economic dependence on oil exports; for China, to enhance its energy security and advance its technological self-sufficiency. Together, their collaboration has laid the foundation for a deeper, more diversified relationship encompassing joint research, technical partnerships, and the co-development of advanced energy systems.

A distinguishing feature of the China–GCC relationship lies in the structural similarity between their energy governance systems and philosophies concerning long-term strategy. Both are anchored in NOCs with strategic mandates, long investment horizons, and insulation from short-term shareholder pressures. This contrasts with the operational frameworks of IOCs, which are often constrained by concession limitations and the demand for rapid financial returns. As a result, GCC and Chinese state-owned entities (SOEs) can align around shared objectives, such as maximizing reservoir longevity, pursuing enhanced recovery methods, and integrating energy operations into national development goals such as climate targets.

This long-term perspective enables both sides to undertake complex and capital-intensive technological initiatives that may be unattractive to private-sector actors with shorter planning cycles. Notably, the two parties are engaging in collaborative projects across upstream, midstream, and downstream domains, ranging from EOR applications to integrated refining and petrochemical complexes.

More practically, technical expertise is highly valued by both parties. GCC producers have adopted advanced technologies to enhance oil recovery rates and extend the life of mature reservoirs. Aramco and the Kuwait Oil Company have implemented peripheral water injection in giant fields such as Ghawar and Burgan, respectively, while gas injection for reservoir pressure maintenance has been used extensively in Saudi Arabia's Shaybah Oil Field. Oman's Marmul field demonstrates the use of chemical EOR, including alkaline–surfactant–polymer (ASP) injection, to increase mobility in otherwise inaccessible reserves.

These sophisticated recovery strategies align with China's technological evolution in upstream exploration. Faced with geologically complex and fragmented reserves, Chinese NOCs such as CNPC and Sinopec have invested in high-resolution seismic imaging, automated drilling systems, and ultra-deep well completions, including shale oil and tight gas development. Their technical advancement has made them globally competitive and attractive partners for GCC firms seeking innovative E&P solutions.

Chinese oilfield service providers, such as BGP, a CNPC subsidiary, have become increasingly prominent in the GCC. BGP has carried out seismic surveys in Saudi Arabia and Oman, demonstrating a growing level of mutual technical engagement. Likewise, COSL has executed drilling and well completion contracts across the Gulf, indicating the operational maturity of Chinese service firms.

In addition to conventional technologies such as drilling, digital technologies have become much more prominent in Chinese operations. A core area of mutual interest is the development of digital oilfield technologies, including real-time reservoir modeling, intelligent completions, and predictive maintenance using artificial intelligence (AI). GCC NOCs have actively pursued digital transformation to enhance their operational efficiency, reduce their emissions, and optimize their production. China's parallel progress in data analytics, machine learning, and industrial automation provides fertile ground for joint research and application.

Strategic cooperation in digitalization, joint ventures, and research centers could become critical pillars in building a digitally and technologically advanced energy ecosystem. One notable example is the Aramco Beijing Research Center. Founded in 2015, it is dedicated to developing innovative technologies across the petroleum value chain. Key areas of focus include advanced oilfield chemicals, seismic imaging, processing, and interpretation powered by AI and machine learning, alongside other cutting-edge technologies aimed at enhancing efficiency and performance in hydrocarbon operations (Aramco 2025).

The development of integrated supply chains, from upstream to downstream, leveraging economies of scale and flexibility, is also a strategy shared by both parties. Beyond upstream technologies, China and the GCC have partnered in refining and petrochemical ventures aimed at securing markets, enhancing value capture, and promoting industrial diversification. Projects such as the Yanbu Aramco Sinopec Refining Company (YASREF) demonstrate the strategic integration of Chinese capital into and market access to GCC feedstock and refining capacity. These facilities are often designed for complex conversion processes, aligning with the global need for versatile input sources and high-specification outputs.

Moreover, China's large-scale investments in plastics and chemical manufacturing provide downstream synergies with GCC producers seeking to move beyond crude exports. Petrochemical exports to China from the GCC have been increasing steadily, while joint ventures in China are also on the rise, with examples such as Huajin Aramco Petrochemical Company (HAPCO) and others (GPCA 2024). This supports the broader diversification efforts articulated in the aforementioned GCC national strategies. This also extends to new hydrocarbon-related technologies. As both entities face the dual pressures of energy transition and decarbonization, future cooperation is likely to intensify in fields such as carbon capture, utilization, and storage (CCUS), clean hydrogen, and the integration of renewables into hydrocarbon operations. These areas align with national goals to reduce carbon intensity while maximizing hydrocarbon value and are prime candidates for joint research and development.

Finally, there are opportunities for collaboration and joint investment outside of the GCC–China context in third markets. The growing presence of both parties in Iraq, Brazil, Kazakhstan, and Africa reflects a shared appetite for international expansion and a willingness to pool technical, financial, and diplomatic resources. These efforts can support broader global development needs while helping diversify supply chains for the regional markets. Such third-market engagements could include the co-development of infrastructure, shared service contracts, and parallel downstream investments.

In sum, China–GCC initiatives in technology and diversification transcend transactional energy trade. They reflect a structural alignment of state-led development models, long-term investment logic, and shared ambition for global competitiveness in energy technology. The deepening of this partnership has the potential to reshape not only bilateral energy relations but also the future contours of the global oil and gas industry.

Midstream: Crude Oil Storage and Transport

As global energy systems become more interconnected and subject to heightened geopolitical risk, the importance of robust and flexible crude oil storage and transport infrastructure has grown significantly. These midstream capabilities are not merely logistical necessities but serve as critical enablers of energy security, market stability, and international trade continuity. For major energy importing and exporting nations, most notably China and the GCC countries, investments in storage capacity and transport networks have become strategic imperatives within a complex and evolving global oil market.

China's approach to crude oil storage has undergone a profound transformation over the past two decades. Before 2004, oil storage in China primarily served operational and commercial functions and was managed by enterprises for short-term supply turnover. The first formal recognition of the strategic necessity of China's national oil storage came with the Tenth Five-Year Plan (2001–2005), which led to the initiation of a national strategic reserve in 2003.

The Medium- and Long-Term Plan for National Oil Reserves, approved by the State Council in 2008, envisioned a three-phase development process aimed at establishing a reserve capacity equivalent to 100 days of net imports. This plan included a total investment exceeding 100 billion yuan and targeted a cumulative reserve of 40 million tons (~290 million barrels), with 12 million tons in the first phase and 28 million in subsequent phases. In parallel, China adopted supportive fiscal policies, such as tax rebates for corporate participation in commercial stockholding, further integrating commercial and state storage systems.

Today, China's crude oil stockpiles comprise three primary components: national strategic reserves, commercial stocks, and enterprise production inventories. While official data on aggregate reserve levels remain undisclosed, estimates suggest that China has accumulated one of the largest strategic reserves globally, distributed across both above-ground terminals and extensive subsurface caverns. This infrastructure has been designed to shield the economy from external supply shocks, mitigate price volatility, and facilitate market intervention when necessary.

The GCC countries, as key global oil exporters, maintain sophisticated transport and export infrastructure that underpins their role as reliable suppliers to world markets. The bloc benefits from its close proximity to major maritime trade routes, particularly the Strait of Hormuz, and from decades of investment in pipeline networks, terminal capacity, and port development. Saudi Arabia, the UAE, and Qatar operate large-scale energy export terminals, integrated with upstream and refining operations to maximize efficiency. Key assets such as Saudi Arabia's East–West Petroline and the UAE's Habshan–Fujairah pipeline reduce reliance on the Strait of Hormuz, which presents as a significant chokepoint for 20% of the world's crude. Having alternative routes to the Red Sea and the Gulf of Oman is an insurance policy for the nations and global consumers involved.

The GCC is also home to a growing number of storage terminals aimed at enhancing commercial flexibility, supporting spot market trading, and enabling the re-export of crude and refined products. Notably, the Fujairah Oil Industry Zone (FOIZ) has emerged as a regional hub for storage and trading, leveraging its strategic location and regulatory framework to attract international investment.

Midstream Synergies Between China and the GCC

Cooperation between China and GCC countries in the midstream sector has intensified in recent years, reflecting their shared interests in securing stable trade flows and mitigating transport risks. Chinese firms, including Sinopec and CNPC subsidiaries, have been involved in the development and operation of midstream infrastructure in the GCC, contributing technical expertise and financial capital. In turn, GCC producers have expanded their participation in China's domestic infrastructure through joint ventures in storage terminals, refining complexes, and logistics hubs. These projects are designed to anchor long-term supply agreements and ensure priority access to Chinese markets (Aramco 2022). These initiatives also contribute to China's broader strategic objective of diversifying import routes and sources, an increasingly critical consideration in a fragmented and volatile global environment. Furthermore, both parties recognize that midstream investments are integral to managing the increasing complexity of crude oil markets, where differentiated products (e.g., low-carbon barrels) and regional imbalances in seasonal demand patterns (e.g., heating in Europe versus cooling in the Middle East) require highly responsive supply chain capabilities.

Technical and policy innovations are also having an impact on this midstream collaboration. Advances in transport and storage, including automated loading systems, digital monitoring of storage levels, and enhanced leak detection, are improving the efficiency and environmental performance of midstream operations. Regulatory coordination on safety standards, emissions control, and cybersecurity is also becoming more important as cross-border energy trade increases. On a policy level, the institutionalization of strategic petroleum reserves and the use of midstream assets for market stabilization have become common practices among major economies. For China and the GCC, enhanced coordination in these domains, including information sharing, harmonizing technical standards, and joint emergency response mechanisms, could serve as a foundation for broader strategic cooperation in global energy governance.

Challenges and Opportunities for Cooperation

The evolving partnership between the GCC states and China has created a dynamic framework for cooperation in energy trade, investment, and technology. While this relationship offers significant mutual benefits, ranging from energy security to economic diversification, it also faces a series of geopolitical, economic, and structural challenges that must be managed strategically. Understanding these tensions and opportunities is key to deepening bilateral energy cooperation and ensuring long-term resilience in the face of global energy system transformation.

Strategic Opportunities

Complementary economic and energy goals: The energy partnership between China and the GCC is built on shared long-term objectives. China seeks dependable energy supplies to support its industrial growth and energy transition, while the GCC is focused on securing consistent demand and attracting foreign capital. China's timeline for peaking carbon emissions by 2030 and achieving neutrality by 2060 increases its need for lower-carbon oil and gas, a category in which GCC producers are well positioned to deliver.

Expanding cross-investment and joint ventures: What began as a straightforward trade relationship has developed into a more complex web of joint ventures and equity partnerships. Chinese investments in upstream assets in the UAE and Oman, as well as downstream partnerships like the Yanbu Aramco

Sinopec Refining Company (YASREF), illustrate this trend. Future cooperation could extend into storage, petrochemicals, and shared infrastructure development in regions such as Africa and Central Asia.

Mutual focus on low-carbon technologies: Both sides are investing in technologies that reduce the environmental impact of oil and gas production. Carbon capture and storage, hydrogen development, and the integration of renewables into energy systems are all areas of active interest. These shared priorities open the door to collaborative research, knowledge exchange, and the co-development of scalable decarbonization solutions.

Cooperation in midstream and energy security: China has developed extensive strategic petroleum reserves and storage infrastructure to protect against supply shocks. In parallel, GCC countries are investing in diversified export routes and commercial storage hubs, such as the FOIZ. These initiatives serve shared interests in energy security and supply chain flexibility. Closer policy coordination in stockpiling, logistics, and emergency response could further enhance market stability during supply disruptions.

STRUCTURAL AND GEOPOLITICAL CHALLENGES

Sovereignty concerns and investment barriers: While the UAE and Oman have opened parts of their upstream sectors to foreign investors, other countries remain more cautious. In countries like Saudi Arabia and Kuwait, concerns over national control continue to limit foreign equity access. This uneven openness may require alternative investment models that preserve domestic control while enabling foreign participation.

Regulatory and technical integration: Differences in legal frameworks, safety protocols, and reporting standards can create challenges for Chinese firms operating in the region. While these firms bring growing technical capability, particularly in exploration and seismic services, greater alignment with local operational requirements will be needed. Stronger partnerships with domestic firms and targeted capacity-building efforts can help bridge these gaps.

Fragmented trade and carbon policies: New trade measures focused on environmental performance, such as the European Union's Carbon Border Adjustment Mechanism, are reshaping global energy trade. To remain competitive, both China and the GCC will need to strengthen their environmental, social, and governance (ESG) frameworks and build transparent, traceable supply chains that comply with evolving regulations in key markets.

Strategic Imperatives Going Forward

To unlock the potential of their partnership, China and the GCC should work together to:

- Establish coordination mechanisms for managing strategic reserves, trade logistics, and emergency responses.

- Build joint platforms for research and development focused on emissions reduction, upstream efficiency, and energy storage.
- Form investment partnerships in third countries, particularly in frontier markets with shared interests.
- Harmonize policies on environmental compliance, emissions tracking, and carbon accounting to enable smoother trade under new regulatory systems.

Through focused cooperation on these fronts, the China–GCC partnership can evolve into a long-lasting alliance that enhances energy security, supports economic diversification, and contributes to global stability throughout the energy transition.

Conclusion

The strategic partnership between China and the GCC countries constitutes an increasingly influential axis within the global crude oil and gas market. This relationship has evolved beyond traditional trade dynamics into a comprehensive, multi-dimensional framework encompassing upstream exploration, midstream logistics, and downstream distribution. As the global energy system transitions toward decarbonization and supply chains become increasingly complex, cooperation between China, the world's largest crude oil importer, and the GCC, an alliance possessing approximately 30% of global proven oil reserves, emerges as a stabilizing force in the international energy landscape.

A central pillar of this partnership is the mutual interest in ensuring energy security and economic resilience. China's continued economic expansion, coupled with its policy goal of doubling per capita GDP by 2035, necessitates reliable and diversified sources of energy. Despite an accelerating energy transition and a forecast peak in domestic oil consumption by the mid-2020s, China is projected to remain heavily reliant on crude oil imports to meet both its industrial and petrochemical demand. In 2023, GCC countries accounted for 36% of China's total crude oil imports (General Administration of Customs of the People's Republic of China (GACC) 2024), a figure that exceeds 50% when including Iraq and Iran, underscoring the strategic relevance of the Arabian Gulf as China's primary supply corridor.

From the GCC's perspective, this partnership aligns closely with member countries' national economic transformation agendas, such as Saudi Vision 2030, the UAE's Centennial 2071, and Qatar's National Vision 2030. These initiatives aim to maximize the value of hydrocarbon resources, attract foreign investment, and enable economic diversification, while reducing carbon intensity. Partnering with China could enhance market certainty and provide a critical outlet for the GCC's relatively low-carbon, cost-competitive crude oil. China's increasing demand for environmentally sustainable oil, motivated by its carbon peaking and neutrality targets, makes the GCC's decarbonized barrels particularly attractive.

Strategically, this partnership offers broader geopolitical and commercial benefits. It provides China with enhanced energy security through preferential access and diversified supply routes, while the GCC secures stable demand amid global uncertainty over fossil fuel consumption. Joint ventures, such as Sinopec's investment in the Yanbu Refinery with Saudi Aramco, demonstrate the potential of integrating both upstream and downstream operations across borders. Furthermore, initiatives such as China's BRI have facilitated capital inflows from China into GCC infrastructure, deepening both parties' economic interdependence and enabling collaborative energy logistics.

Beyond bilateral cooperation, the China–GCC partnership serves as a launchpad for engagement in third-country markets, particularly in Asia, Africa, and Latin America. Through coordinated investments in infrastructure, refining, and petrochemicals, the two actors can jointly develop new markets while advancing technological collaboration. Moreover, their aligned interests in stabilizing crude oil markets and coordinating policies on strategic petroleum reserves and energy transition technologies, such as hydrogen and carbon capture, position China and the GCC as central players in shaping global energy governance.

In an era marked by heightened geopolitical tensions, energy protectionism, and fragmented global institutions, the China–GCC strategic relationship offers a pragmatic and long-term approach to energy cooperation. By reinforcing supply and demand stability, promoting technological exchange, and jointly navigating the complexities of the energy transition, this partnership has the potential to significantly influence the structure and direction of the global energy market over the coming decades.

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4 Advancing the China–GCC Strategic Partnership in the Refining and Petrochemical Industries

Abdulwahab Al-Sadoun, Guanglian Pang, and Shuang Wang

Introduction

Since its beginnings in the mid-nineteenth century, oil refining technology has evolved in a continuous process of adaptation to the demands of society, in matters as vital as the supply of energy, lighting, transportation and producing chemicals to improve the quality of life. In that time, this has been one of the greatest examples of how the technological innovation of an industry contributes to the welfare and development of society (Larraz 2021).

As of 2024, there were 825 active oil refineries worldwide, with a total capacity of 103.5 million barrels per day (MMb/d) (EIA 2024). Global refinery capacity has nearly doubled over the past 50 years, experiencing the largest incremental growth during the 1970s (Energy Institute 2024). Asia is projected to have the highest refining capacity by 2027, followed by North America and the Middle East (GlobalData 2024).

An increasing number of refiners are strategically shifting production from fuels to petrochemicals. This transition is driven by anticipated declines in fuel demand due to the growing penetration of electric vehicles and the power sector's increasing reliance on renewables. Additionally, there are expectations of significant global petrochemical demand growth. In response, new oil refineries are being constructed worldwide with integrated petrochemical capabilities to meet this rising demand while maximizing returns across the hydrocarbon value chain. Integrated refinery-petrochemical sites are increasingly recognized as having a competitive edge over their fuel-only counterparts.

This overarching mega-trend promotes refinery-petrochemical integration and significantly influences the establishment of new facilities worldwide. More than 30% of the world's refineries are now integrated with commodity petrochemicals (Wood Mackenzie 2025). Such integration provides these sites with a diversified product slate and the potential to unlock greater value by exploiting economies of scale and operational cost synergies, reinforcing the strategic importance of integration in the evolving energy landscape.

In the latter half of the twentieth century, the variety of refined end-products from crude processing increased significantly. This expansion was primarily driven by technological advancements that enabled the conversion of heavy and

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sour crude into lighter, more desirable products, in response to market demand for high-quality fuels that comply with stricter emission regulations. Concurrently, the use of byproducts from the refinery's fuel processes to produce other chemical products fueled growth in the petrochemicals industry. The shift from standalone to integrated refineries reflects how markets have diversified and technologies have advanced.

The integrated refining and petrochemicals sector in China and the GCC states, particularly Saudi Arabia, exhibits distinctive characteristics shaped by regional strategies and global market dynamics. In China, robust industrial policies aim for self-sufficiency in commodity and specialty petrochemical products, resulting in significant investments in integrated refining-petrochemical complexes. Conversely, the GCC states, rich in hydrocarbon resources, have historically focused on oil extraction and refining. However, under initiatives like Saudi Vision 2030, these nations are diversifying their economies with a strong emphasis on expanding the petrochemical sector to create value-added products and reduce their economies' heavy reliance on volatile oil revenues. Embracing vertical integration is crucial for GCC members to add value further down the petroleum production chain, allowing them to transform from being merely crude suppliers to significant players in the global chemical markets.

The potential for synergy between China and the GCC in the integrated refining and petrochemical sector is vast and promising. Both parties stand to benefit from complementary strengths—China's vast market and technological advancements complement the GCC's hydrocarbon resource availability and strategic location. This chapter explores the state of refining and petrochemicals in China and the GCC countries, identifying opportunities and challenges for collaboration in this sector.

It analyzes recent dynamics in the refining and petrochemical industries in China and the GCC, the strategic shift toward integrating refineries with petrochemical complexes, and the implications for a further strengthening of the bilateral strategic partnership in cross-border investments and relevant technological advancements.

The GCC Oil Refining Industry's Landscape

Endowed with abundant hydrocarbon reserves, the GCC countries have well-developed oil production and refining sectors. In 2023, GCC oil production constituted 22% of global output, underscoring its importance on the world stage. Furthermore, the bloc contributed 6.8% to global refining capacity, indicating a substantial presence in the downstream sector (Energy Institute 2024).

The GCC's oil refinery industry is characterized by advanced capabilities, as reflected in its Nelson Complexity Index (NCI), which ranges from 7.1 to 11.9 (GlobalData 2024). This index denotes the complexity and sophistication of refineries, which are capable of processing a wide variety of crude oils into different products. In 2023, the GCC boasted 21 full-conversion refineries, collectively offering a refining capacity of approximately 7 MMb/d, highlighting the region's capacity to meet both domestic and international demands.

Table 4.1 Contribution of GCC countries to global oil production and refining capacity (2023)

GCC country	*Oil output*		*Oil refining*	
	Oil production (1,000 b/d)	*Share of global production (%)*	*Refining capacity (1,000 b/d)*	*Share of global refining capacity (%)*
Saudi Arabia	11,389	11.8%	3,289	3.2%
United Arab Emirates	3,922	4.1%	1,259	1.2%
Qatar	1,772	1.8%	429	0.4%
Oman	1,279	1.2%	435	0.4%
Kuwait	2,908	3.0%	1,309	1.3%
Bahrain	200	0.2%	260	0.3%

Source: Energy Institute (2024).

As outlined in Table 4.1, GCC countries such as Saudi Arabia, Kuwait and the United Arab Emirates (UAE) stand out as key players in both crude oil production and refining capacities, solidifying the bloc's critical position in the global oil industry.

GCC refineries produced 6.9 MMb/d of the four key petroleum products: gasoline, diesel, kerosene, and fuel oil. Table 4.2 provides detailed insights into the key refineries across the GCC, highlighting their capacities, start-up dates, and ownership structures. The strategic goal of the GCC countries is to align their upstream capacities with enhanced refining capabilities regionally and globally. The bloc is renowned for its numerous mega refineries, with Saudi Arabia, the UAE, and Kuwait leading in oil refining capacity.

Saudi Arabia, in particular, has a substantial domestic refining capacity of approximately 3.3 MMb/d and aims to expand this to between 8 and 10 MMb/d by 2030, facilitated by strategic investments and partnerships (Saudi Aramco's Annual Report 2024). As a pivotal player in the global oil market, Saudi Arabia holds 17% of the world's proven oil reserves (Facts & Figure, OPEC 2024). By 2024, the country's oil refining capacity had reached 3.3 MMb/d, processed across nine refineries, as documented in Table 4.2.

Among these nine refineries, Petro Rabigh and Duqm, situated on the coasts of the Red Sea and the Arabian Gulf, respectively, stand out as integrated refining and petrochemical complexes. Petro Rabigh was established in 2005 as a joint venture between Saudi Aramco and Japan's Sumitomo Chemical, and it was recognized as the largest single-phase refining and petrochemical complex globally at that time. Duqm Refinery and Petrochemical Industries Company (OQ8) is a joint venture between OQ and Kuwait Petroleum International (KPI), situated in Al Duqm, Oman. The refinery was commissioned in 2024 with a daily processing capacity of 230,000 barrels of crude oil (S&P Global 2024). OQ8 is a $9 billion refinery, with plans for a petrochemical project close by.

To further expand its operations, in 2018, Saudi Aramco and Total announced plans for an $11 billion petrochemical complex, Amiral, which will be integrated with the existing SATORP refinery in Jubail. This complex aims to produce

Table 4.2 The GCC's oil refining sector (2024)

Refinery	*Capacity (b/d)*	*Location*	*Start-up*	*Ownership*
Saudi Arabia refineries				
Ras Tanura	550,000	Ras Tanura	1945	Aramco (100%)
Riyadh	126,000	Riyadh	1975	Aramco (100%)
Yanbu	245,000	Yanbu	2016	Aramco (100%)
SAMREF	400,000	Yanbu	1984	Aramco (50%) Mobil (50%)
YASREF	400,000	Yanbu	2014	Aramco (62.5%) Sinopec (37.5%)
SASREF	305,000	Jubail	1985	Aramco (100%)
Petro Rabigh	400,000	Rabigh	2008	Aramco (37.5%) Sumitomo (37.5%)
SATORP	460,000	Jubail	2008	Aramco (62.5%) TotaleEnergies (37.5%)
Jazan	400,000	Jazan	2019	Aramco (100%)
UAE Refineries				
Abu Dhabi Refinery	85,000	Abu Dhabi	1976	ADNOC (100%)
Ruwais Refinery	817,000	Ruwais	1982	ADNOC (65%) Eni (20%) OMV (15%)
Jebel Ali Refinery	140,000	Jebel Ali	1999	ENOC (100%)
Qatar Refineries				
Um Said Refinery	147,000	Al Wakrah	1958	QE (100%)
Laffan Refinery 1 (LR1)	146,000	Ras Laffan Industrial City	2009	QE (51%) ExxonMobil (10%) Total (10%) Idemitsu (10%) Cosmo Oil Company (10%) Mitsui (4.5%) Marubeni (4.5%)
Laffan Refinery 2 (LR2)	146,000	Ras Laffan Industrial City	2016	QE (84%) Total (10%) Idemitsu (2%) Cosmo Oil Company (2%) Mitsui (1%) Marubeni (1%)
Kuwait Refineries				
Al Zour Refinery	615,000	Al-Zour	2023	KNPC (100%)
Mina Al-Ahmadi Refinery	466,000	West of Ahmadi	1949	KNPC (100%)
Mina Abdullah Refinery	270,000	Al Jahra	1958	KNPC (100%)
Oman Refineries				
Mina Al Fahal	106,000	Muscat	1982	OQ (100%)
Sohar Refinery Company (SRC)	116,000	Sohar	2007	Oman Oil Company (20%) Government of Oman (80%)

(*Continued*)

Table 4.2 (Continued)

Refinery	*Capacity (b/d)*	*Location*	*Start-up*	*Ownership*
Bahrain Refineries				
Bapco Refining	267,000	Sitra	1936	BAPCO (100%)
Overseas Refineries				
Motiva	630,000	Port Arthur, Texas	1903	Aramco (100%)
S-Oil	650,000	Ulsan, South Korea	1980	Aramco (63.45%)
Showa Shell	445,000	Japan	1976	Aramco (14.96%)
Fujan	280,000	China	1993	Aramco (25%)
RAPID	300,000	Malaysia	2019	Aramco (50%) Petronas (50%)

Source: GPCA, 2024.

2.65 million tons of petrochemicals annually and is expected to commence operations in 2027. The JV will be the first mixed feed cracker in region to be integrated with a refinery (Aramco, 2022).

Saudi Arabia is also home to the first Chinese investment in the GCC refining sector. In 2014, the Yanbu Aramco Sinopec Refining Company (YASREF), a joint venture between Saudi Aramco and Sinopec, was commissioned in Yanbu by the Red Sea. This full-conversion integrated cocking refinery is designed to process 400,000 b/d of heavy crude to produce high-value refined products, and has a Nelson Complexity Index (NCI) of 10.1 (Globaldata 2024).

Notably, of the 21 operating refineries in the GCC, 18 are located on the east coast of the Arabian Peninsula, close to the oil fields. Aramco and other GCC oil producers are the sole suppliers of crude oil to all domestic refining operations under long-term supply agreements. The remaining three West Coast refineries are supplied through Aramco's pipeline and terminal systems.

In alignment with their strategy to bolster their refining capabilities, GCC countries have significantly expanded their refining operations in high-growth economies overseas. By 2023, the refining capacity of GCC-affiliated refineries abroad had reached 3.6 MMb/d, constituting 54% of the GCC's domestic refining capacity, as noted in Table 4.3. These overseas refineries receive approximately 50% of their crude oil from GCC sources, ensuring a secure and stable supply chain for GCC oil producers.

Table 4.3 GCC's overseas oil refiners as of year-end 2024

Overseas Refineries	*Capacity (bpd)*	*Start-up*	*Location (Country)*	*Ownership*
Saudi Aramco's Affiliates				
Motiva	630,000	1903	USA	Aramco (100%)
S-Oil	650,000	1980	South Korea	Aramco (63.45%)
Showa Shell	445,000	1976	Japan	Aramco (14.96%)
Fujan (China)	280,000	1993	China	Aramco (25%)
RAPID	300,000	2019	Malaysia	Aramco (50%); Petronas (50%)

(*Continued*)

Table 4.3 (Continued)

Overseas Refineries	*Capacity (bpd)*	*Start-up*	*Location (Country)*	*Ownership*
Abu Dhabi—Mubadala Investment Affiliates				
CEPSA Gibraltar-San Roque	240,000	Spain	1967	Mubadala (63%), Carlyle Group (37%)
OMV Schwechat	200,000	Austria	1960	ADNOC (24.9% stake in OMV)
OMV Burghausen	70,000	Germany	1967	ADNOC (24.9% stake in OMV)
OMV Petrobrazi	90,000	Romania	1934	ADNOC (24.9% stake in OMV)
Kuwait Petroleum Affiliates				
Milazzo Refinery	200,000	Italy	1961	Kuwait Petroleum (50%) Eni (50%)
Nghi Son Refinery (NSRP)	200,000	2018	Vietnam	Kuwait Petroleum (35.1%) Idemitsu Kosan (35.1%) PetroVietnam (25.1%) Mitsui Chemicals (4.7%)
Zhanjiang	300,000	China	2020	Kuwait Petroleum (50%) Sinopec (50%)

Source: GPCA, 2024.

Oil Refining Landscape in China

China is the world's largest crude oil importer, relying on imports for nearly three-quarters of its needs. The country has been investing to maintain its domestic crude oil production at approximately 4.1 MMb/d. As of 2023, China also had the world's largest oil refinery capacity, nearing 18.8 MMb/d. In alignment with the "14th Five-Year Plan" strategy, China's primary production capacity experienced a compounded annual growth rate (CAGR) of 1.59% from 2019 to 2023. Centralized production through refining and chemical integration has been the main driver of its rapid capacity growth. By 2023, the integration among oil refining enterprises became more evident, leading to the idling and dismantling of outdated multi-regional refining capacities. Overall, production capacity in 2023 remained consistent with the previous year.

China has long prioritized systematic, policy-driven industrial development, particularly in strategic sectors such as petroleum and chemicals. This approach emphasizes comprehensive planning and centralized coordination, especially for large-scale projects like oil refining, which are guided by long-term national strategies and sector-specific roadmaps. This structured framework ensures alignment with the broader goals of industrial modernization, environmental sustainability, and global competitiveness.

China has implemented a series of strategic policy measures aimed at enhancing the development of and promoting high-quality growth within its petroleum and chemical industries. These include the "Petroleum and Chemical Industry '14th Five-Year Plan' (2021–2025)," which focuses on improving the quality of the industry's development. Additionally, the "2024 Guiding Catalogue for Industrial

Structure Adjustment" emphasizes the integration of high-quality refining and chemical processes. This strategy involves restricting the scale of traditional refining units while encouraging investments in the high-value-added chemical sector. The upcoming "15th Five-Year Plan (2026–2030)" is pivotal for transforming the sector. China's refining policies drive industrial transformation through technological innovation and value chain upgrades, prioritizing advanced refining technologies and high-value chemical production. The policies actively phase out inefficient capacities while incentivizing investments in specialty chemicals and green processes to enhance global competitiveness.

These policies are further reinforced by the "Action Plan for Carbon Peaking Before 2030," which sets binding targets to cap domestic crude oil processing capacity at 1 billion tons by 2025. Notably, China is pursuing a dual-track strategy, advancing capacity consolidation and technological upgrades of its domestic refineries while simultaneously developing export-oriented refining complexes. This structural shift aims to optimize cost efficiencies through scale effects, enhance the competitiveness of value-added products in international markets, and align China's refining output with its evolving domestic demand patterns under energy transition imperatives.

China's Primary Refinery Operations

China's refining sector has undergone strategic restructuring, propelled by regulatory-driven efficiency mandates that boosted export-oriented capacity expansion and reoriented domestic demand toward high-value petrochemical feedstocks.

Domestic Demand Reorientation

While the apparent consumption of refined products grew at 1–3% annually through 2022, structural shifts emerged in 2023. Gasoline demand declined by 1.2%, contrasting with a 15% rebound in aviation kerosene as international travel resumed. Diesel consumption plateaued at 3.4 MMb/d post-2020, reflecting progress in industrial decarbonization.

Export Sophistication

Refined product exports reached 1.0 MMb/d in 2023 (+13% year on year [YoY]), with high-value products (low-sulfur bunker fuel, aviation kerosene) constituting 60% of shipments. Diesel exports surged 26% to 280,000 b/d, strategically absorbing surplus capacity.

Feedstock Globalization

Crude oil imports hit a record 11.3 MMb/d in 2023 (+11% YoY), primarily fueling petrochemical expansion. Naphtha and liquefied petroleum gas (LPG) imports for ethylene production grew by 8% YoY, supporting China's 18% global share in chemical derivatives.

This tripartite restructuring positions China's refining sector at the nexus of global energy transitions. As the International Energy Agency (IEA) notes, China's demand for petrochemical feedstocks (projected to rise by 1.7 MMb/d from 2019 to 2025) now drives over 40% of global oil demand growth.

Refining Capacity and Regional Distribution

In line with its "14th Five-Year Plan" strategy, China is focused on reducing refined oil production while bolstering capacities for high-value products such as ethylene and propylene. Consequently, the growth of the country's refining supply has moderated, and the expansion rate of its overall refining capacity has slowed compared to previous decades.

From 2019 to 2023, China's primary refining capacity experienced a CAGR of 1.59%. This period saw rapid capacity growth driven by centralized production through refining and chemical integration. By 2023, the integration effect among oil refining enterprises became more pronounced, leading to the elimination of outdated refining capacities in multiple regions. Overall, production capacity in 2023 remained consistent with the previous year (Figure 4.1).

China's refining industry can be geographically categorized into seven regions, as illustrated in Figure 4.2, with East China (EC) remaining the largest hub for oil refining. In 2023, East China had the highest refining capacity in the country at 8.1 MMb/d, accounting for 43.4% of the country's total refining capacity. Following East China, the Northeast and South regions had refining capacities of 3.0 MMb/d and 2.7 MMb/d, respectively.

From a provincial standpoint, Shandong, Liaoning, and Guangdong collectively provide a refining capacity of 8.3 MMb/d, contributing to 44.5% of the nation's overall refining capacity. Additionally, provinces such as Zhejiang, Jiangsu, and Hebei achieved a combined capacity of 3.7 MMb/db/d, representing 20.0% of China's national refining capacity (Figure 4.2).

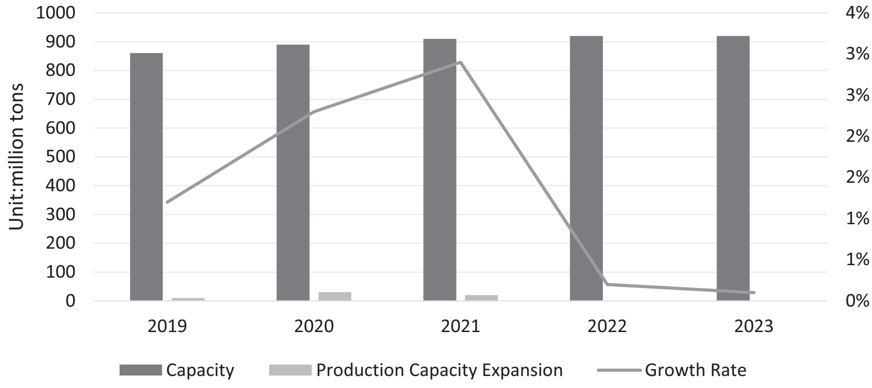

Figure 4.1 China's primary processing of refining capacity (2019–2023).

Source: China Petroleum and Chemical Industry Federation.

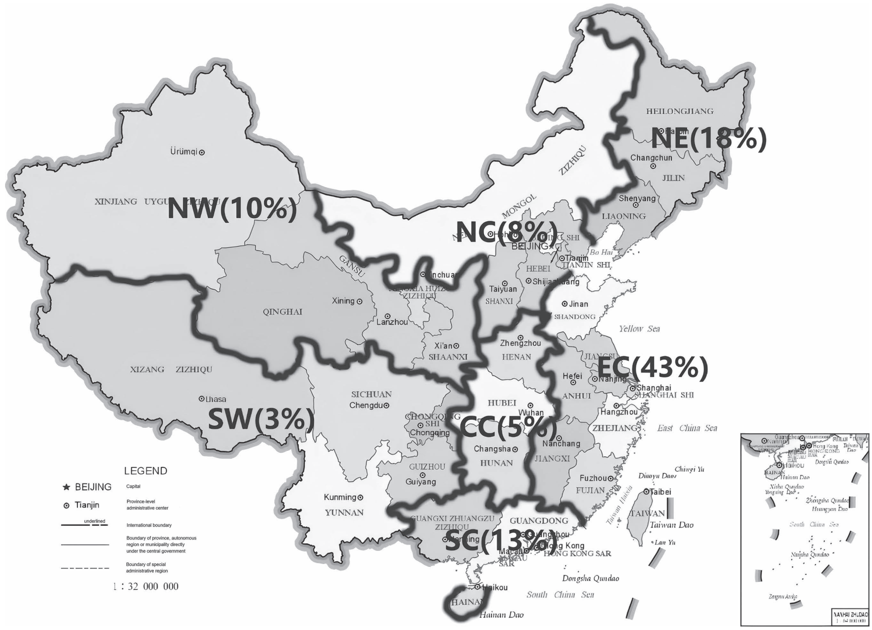

Figure 4.2 Regional contributions to China’s refining capacity in 2023.

Source: China Petroleum and Chemical Industry Federation (CPCIF).

In terms of coastal distribution, China’s refining industry is concentrated in three major clusters: Bohai Bay, the Yangtze River Delta, and the Zhujiang River Delta. Together, these regions boast a refining capacity of 13.6 MMb/d, accounting for 72.6% of the country’s total refining capacity (Figure 4.2).

China has established a robust global network, with key projects in Russia, Central Asia, the Middle East, and South America. The country’s global footprint in oil refining is evident through its dispersed overseas refining projects, which have a combined capacity of 1.6 MMb/d. Notable projects include the Yanbu Refinery in Saudi Arabia, a joint venture between Sinopec and Saudi Aramco, which boasts a capacity of 0.4 MMb/d (Chen and Han 2019).

Growth Dynamics of China’s Refined Oil Products Trade Flows

China’s refined product trade exhibits a distinctive import-export pattern. As the world’s largest crude oil importer, with 11.3 MMb/d in 2023, it maintains minimal product imports while strategically optimizing its exports through value-added processing.

After three consecutive years of contraction (2020–2022), China’s refined product exports rebounded to 41.5 million tons (equivalent to 1.03 MMb/d) in 2023, representing a 21.6% YoY increase in volume and a 9.2% growth in export value to US$35.3 billion (GACC 2024; CPCIF 2024).

Table 4.4 Export volume and value of refined oil products in China (January–June 2024)

Year 2024	*Export volume (kb/d)*	*Export value (million $)*	*YoY change in volume (%)*	*YoY change in value (%)*
January	627.5	3,475,887	−28.9%	34.3%
February	571.6	3,135,686	−32.5%	−36.4%
March	821.3	4,648,022	10.7%	14.1%
April	613.9	3,441,396	21.3%	22.0%
May	729.9	4,061,777	9.5%	17.6%
June	732.6	3,935,026	19.0%	26.7%

Source: General Administration of Customs of China 2024.

Note: kb/d, 1,000 barrels per day.

The export product mix underwent significant changes compared to 2022 (Blue Book on the Development of China's Petroleum Circulation Industry). Aviation kerosene exports rose to 37.8% of total shipments (up from 31.7% in 2022), driven by the recovery of international travel post-pandemic (global aviation fuel demand increased by 18% YoY [IATA 2024]). The share of gasoline exports declined to 29.3% (down from 36.6%), reflecting domestic inventory management and saturation in the Association of Southeast Asian Nations (ASEAN) market. Diesel maintained a 32.9% share, supported by strategic stock releases to Asia-Pacific partners.

This reconfiguration aligns with China's refining modernization strategy. The rebound in kerosene exports strategically leverages the recovery in global aviation, while the decrease in gasoline exports reflects refinery upgrades that prioritize chemical feedstock production. The disparity between export value growth (9.2%) and volume expansion (21.6%) emphasizes the need to enhance global market share through competitive pricing and advancing certification of premium products, such as European Union Emissions Trading System (EU-ETS)-compliant bunker fuels, to secure premium market access. This trend continued into 2024. From January to June 2024, China exported 4.1 MMb/d of refined oil products, a decrease of 166,400 b/d compared to the same period in the previous year, reflecting a YoY decline of 3.8%. The export value during this period was US$2.26 million, representing a reduction of US$1.22 million from 2023, equating to a YoY decrease of 4.1%. Specifically, in June 2024, the export volume of refined oil products from China was 732,600 b/d, with an export value of US$3.94 billion (see Table 4.4). The total export volume of refined oil products for the entire year is projected to exceed that of 2023, indicating a pattern of higher exports in the latter half of the year.

When viewed under a narrow definition (gasoline, diesel, and kerosene), China's imports of key refined products declined in 2023 amid rising domestic production and a supply surplus. Gasoline imports were fully suspended, while diesel imports fell by 70% to approximately 2.4 mb/d, and kerosene imports decreased by 61% to about 6.3 mb/d. In contrast, the total import volume of refined oil products under the broader national statistical definition (which includes fuel oil, naphtha, etc.) increased significantly by 80.3% year-on-year, primarily driven by a surge in fuel oil imports.

Table 4.5 Import volume and value of refined oil products in China (2019–2023)

Time	*Import volume (kb/d)*	*Import value (million $)*	*YoY change in volume (%)*	*Year on year change in value (%)*
2019	416.9	17,076	−8.7%	−15.2%
2020	386.8	11,793	−7.2%	−30.9%
2021	369.9	16,694	−4.0%	41.3%
2022	360.8	19,604	−2.5%	17.3%
2023	650.6	27,932	80.3%	42.3%

Source: General Administration of Customs of China 2024.

Note: kb/d, 1,000 barrels per day. *Note:* The statistical scope of "refined oil products" in this table refers to the consumption tax taxable items in China, primarily including gasoline, diesel, kerosene, naphtha, solvent oil, lubricating oil, and fuel oil.

Global Petrochemical Market Dynamics

Petrochemical demand is driven by growing populations, the growth of the middle class, and urbanization. The global petrochemical market was valued at US$649.16 billion in 2024 and is projected to grow to US$900.91 billion by 2032, with a CAGR of 4.2% (Fortune Business Insights 2024).

Global chemical production is anticipated to grow by 3.5% in 2025 (First Research 2024). As the world's largest chemical market, China is expected to achieve the highest growth rate of 4.8%. At the end of 2022, the country accounted for 45% of global chemical production capacity, which is projected to rise to 62% by 2035 due to market share expansion through export leadership and innovation (Falter and Pflug 2022). The exponential growth in China's production of fine and specialty chemicals, with an efficiency driven by economies of scale, will significantly impact future chemical supply chains and pricing.

Paradigm Shifts in the Global Petrochemicals Market

The global petrochemicals landscape is undergoing a strategic rebalancing, with China and the GCC states led by Saudi Arabia capturing 65% of new capacity additions since 2020. North America and Europe retain their technological leadership in high-value specialty chemicals. From 2000 to 2023, China's share of global chemical sales surged from 7.2% to 43.1%. In contrast, North America and the EU-27 saw notable declines in their market shares, with North America's share dropping from 27.5% to 22.1% and the EU-27's share falling from 28.7% to 12.6% during the same period. The GCC has maintained a stable global sales share, increasing modestly from 1.4% in 2007 to 1.5% in 2023 (GPCA 2024). This trend is reinforced by China's leadership in global chemical sales. Concurrently, GCC states exhibit strategic resilience through energy-integrated industrial expansions. In contrast, economies such as the United States, Europe, and Japan face negative growth rates as traditional production models encounter mounting pressures from shifting demand patterns and competitive repositioning (Table 4.6).

The paradigm shift in the global petrochemicals industry is underscored by the emergence of new players from China and the GCC among the top 10 global

Table 4.6 Global petrochemical industry overview: change in regional sales (2000–2023)

Country/region	*2000*	*2016*	*2023*	*Change in global share (+/−)*
EU-27	28.7%	14.5%	12.6%	−16.1%
North America	27.5%	15.6%	12.9%	−14.6%
Asia (excluding China)	27.8%	21.7%	22.1%	−5.7%
China	7.2%	39.2%	43.1%	+35.9%
GCC	1.4%	2.0%	1.7%	+0.3%
Rest of the world	7.3%	7.0%	7.6%	+0.5%

Sources: GPCA analysis; CEFIC (2025).

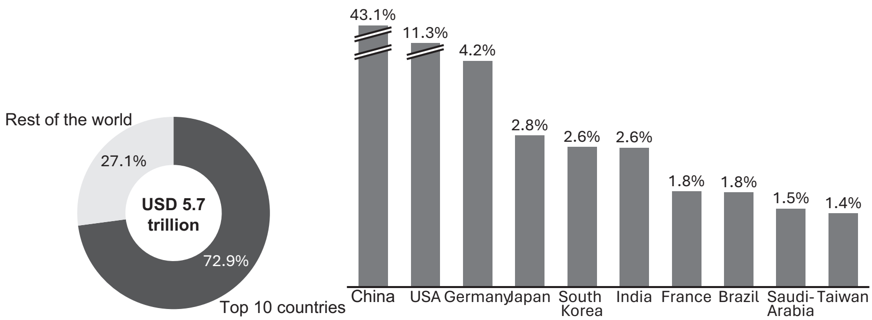

Figure 4.3 Market share distribution (a) and top 10 economies in global chemicals in 2023 (b).

Note: Taiwan, China

Source: GPCA, 2024.

chemical producers, as illustrated in Figure 4.3b. China contributes 43.1% of the US$5.7 trillion in global chemical revenues (see Figure 4.3a), while Saudi Arabia holds a 1.5% share, reflecting their strong positions in the global petrochemicals industry. The top 10 economies accounted for two-thirds of global chemical industry revenues in 2023.

The global prominence of China and the GCC in the chemicals industry is also reflected in the rankings of Saudi Arabia's SABIC and China's Sinopec, Rongsheng Petrochemical, and Wanhua Chemical among the top 10 global chemical manufacturers in 2023 (ICIS 2023). Meanwhile, several international chemical companies have ceased to exist due to consolidation or acquisition by new players.

Petrochemicals in China: A Drive Toward Global Dominance

China's petrochemical industry has undergone transformative growth over the past five years, establishing itself as the global leader in commodity chemical production and trade. This dominance is a result of strategic state investments, targeted industrial policies, and a deliberate shift toward high-value-added products, which has reshaped global supply chains and competitive dynamics.

China's petrochemical sector accounted for 46% of global industry investments in 2022 (Atkinson 2024). This expansion solidifies China's position as a leading exporter of bulk petrochemicals, with exports reaching US$254.8 billion in 2023 (China Customs 2024). Key product categories include polyethylene (28% of export value), polypropylene (PP) (22%), and methanol (12%), collectively representing 62% of total bulk petrochemical exports.

Conversely, China remains dependent on imports for high-end specialty chemicals, spending US$185 billion in 2023 on advanced materials such as engineering plastics, semiconductor-grade polymers, and precision additives (UN Comtrade 2024). This export–import profile reflects China's global leadership in commodity chemicals while highlighting its dependency on technology-intensive imports.

China's petrochemical sector has solidified its dominance in global markets, driven by massive capacity expansions and vertical integration. The country now accounts for 45% of global petrochemical sales, with over 50% of new global petrochemical capacity additions since 2015 originating from Chinese projects. This expansion is supported by vertically integrated supply chains, from crude oil imports to refining and chemical production, allowing for a reduction in operating costs by 15–20% compared to Western counterparts (Wood Mackenzie).

China's dual focus on commodity scale and high-value innovation presents collaboration opportunities in Crude Oil to Chemicals (COTC) technologies and carbon-intensive feedstock processing. However, China's push for self-sufficiency in critical materials, such as semiconductor-grade chemicals, requires partners to align investments with its innovation priorities. The country's petrochemical industry has transitioned from a volume-driven growth phase, dominated by low-end commodities, to a technology-intensive powerhouse, driven by policy mandates for industrial upgrading and global market competitiveness.

In 2023, China accounted for approximately 55% of global acetic acid capacity, about 50% of global carbon black capacity, and around 45% of global titanium dioxide capacity. China also produces nearly 65% of new ethylene capacity and is set to triple its domestic paraxylene (PX) capacity, a key raw material for producing polyester (EPC 2024).

By 2025, China's ethylene capacity is projected to reach 50 million metric tons (a 50–60% increase), and its plastics production could hit 120 million tons annually (a 30–35% increase over the last five years). This resulting oversupply will reshape global petrochemical market dynamics. By 2025, China's production capacity in all major segments (methanol, PP, polyethylene) is expected to exceed consumption levels. This increase is driven by domestic demand and a strategic goal to reduce import dependency. In the first quarter of 2024, China's PP exports reached 619,000 tons, a year-on-year increase of 95%. At the same time, PP imports were about 310,000 tons, leading to net exports for the first time. In 2023, China's new PP production capacity was projected at 5.6 million tons/year, a YoY increase of 13.9%, accounting for more than 80% of the world's new production capacity (EPC 2024).

The GCC—A Global Commodity Petrochemicals Production Hub

The GCC industry's product portfolio predominantly comprises commodity chemicals, with a strong focus on basic chemicals, agri-nutrients, and polyolefin polymers (Al-Sadoun 2015). Saudi Arabia accounts for over 74% of regional production. The country has emerged as a leading global producer of commodity petrochemical products, primarily through state-driven investments aimed at capturing the value of flared associated natural gas (see Figure 4.4).

In the broader context of the GCC, Saudi Arabia is an important example of the development of the chemical industry in the region. The liberalization of the sector in the 1990s spurred similar reforms in other GCC states, allowing greater involvement of private and state-run companies in chemical manufacturing. This diversification, with Saudi Arabia alone accounting for a substantial share of total production, has contributed to making the GCC one of the world's largest chemical-producing blocs.

Throughout its growth trajectory, the GCC's chemical industry has pursued strategies that can be classified into two main categories: organic and inorganic growth strategies. On the organic front, the industry has demonstrated consistent, exponential growth, significantly expanding its production capacity over the past decades, increasing from 76 million tons in 2007 to 156.2 million tons in 2023. During this time, the industry's product portfolio has also consistently broadened, evolving from primarily C1 and C2 value chains to a more balanced mix, with notable growth in C3 and aromatics value chains.

Given the small domestic market in the GCC, the petrochemical industry was compelled to adopt an export-oriented strategy to benefit from economies of scale. In 2023, the GCC petrochemical industry exported petrochemicals valued at US$85.8 billion to various countries (GPCA 2024). The industry's adaptability and proactive response to market dynamics have enabled it to expand its market share and enter new markets. Data indicate an annual growth rate of exports from

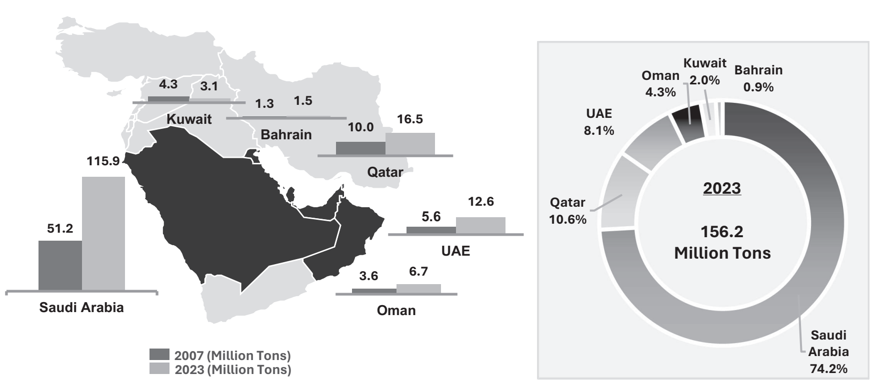

Figure 4.4 GCC chemicals production capacity by country (2007–2023).

Source: GPCA, 2024.

the GCC to China of 12.5% over the last 20 years, with China receiving 25% of the GCC's chemical exports in 2023.

GCC companies in Saudi Arabia, Qatar, and Oman have embarked on consolidating their in-country assets to enhance their global competitiveness. A significant milestone in this drive occurred in Saudi Arabia in June 2020 when Saudi Aramco completed its acquisition of a 70% stake in SABIC, valued at US$69.1 billion (Rashad et al. 2020). In 2019, ORPIC Group merged with the Oman Oil Company in 2019, and the combined entity was named OQ. Earlier, in 2013, Qatar Energy consolidated its interests in three companies: Qatar Chemical (Q-Chem I), Qatar Chemical II (Q-Chem II), and Qatar Vinyl (QVC). Consolidations were also observed in the GCC private sector, with a notable example being the merger between Saudi International Petrochemical and Sahara Petrochemical in 2019, forming Sahara International Petrochemical (SIPCHEM) with assets worth US$6.3 billion and a market value of around US$5.3 billion. To secure feedstock and market access, SABIC pursued joint ventures in China, starting in 2003 with a partnership to expand the China National Petroleum Corporation's (CNPC's) naphtha cracker. Although this project stalled, SABIC successfully launched a world-class naphtha cracker in Tianjin with Sinopec in 2007. This joint venture expanded to include a polycarbonate production unit in 2011. Meanwhile, SABIC enhanced its distribution network in China and opened a US$100 million technology center in Shanghai in 2013.

Portfolio diversification is the second most compelling driver of consolidation, maximizing value creation by developing new downstream industries that, in turn, create more job opportunities for locals. Opening new revenue streams and reducing concentration risk has become crucial, especially for GCC commodity producers. Product portfolio diversification has been particularly desirable in GCC countries, enabling companies to tap into new markets and industries, ensuring their long-term growth and stability, with the number of petrochemical products projected to grow by 3.2% annually between 2010 and 2027.

GCC–China Partnership—Unlocking Value Creation Opportunities

The GCC and China have developed strategic partnerships in the refining and petrochemical industries, driven by China's growing demand for energy and chemical products and the GCC's goal to diversify its markets and strengthen its ties with one of the world's largest economies. While Saudi Arabia has been a major player in these partnerships (through Saudi Aramco and SABIC), other GCC countries have also established substantial ties with China. These partnerships focus on strategic alliances, joint ventures, and supply contracts that strengthen the economic ties between the GCC and China, leveraging both parties' natural resources and manufacturing capacities.

GCC–China Oil and Petrochemicals Trade Pattern

Trade ties between China and the Middle East trace back 1,500 years to the time of the Silk Road. The economic axis between China and the GCC nations strengthens as both regions diversify beyond oil and deepen their financial and commercial ties. A rise in transactions between China and the GCC countries has been noted. Figures from HSBC Global Research show that the two-way payment flows between China and the GCC have grown by more than 20% YoY. It forecasts the annual two-way goods trade will increase from US$950 billion in 2022 to over US$1.9 trillion by 2035 (HSBC Global Investment Outlook 2024). Oil remains a significant part of the trade story. In 2023, China imported about 201 million tons of crude oil and 18 million tons of LPG from the GCC nations, along with substantial imports of byproducts from the oil industry, including plastics and chemicals.

Saudi Arabia accounts for 25% of the total trade volume between China and Arab countries, reaching US$106 billion in bilateral trade in 2022—a 30% increase from 2021 (Middle East Briefing 2023). The cooperation between China and Saudi Arabia in the oil refining and chemical industries is a critical component of their energy cooperation. China represents nearly 20% of Saudi Arabia's total oil export volume, excluding China's significant imports of plastics and other crude oil derivatives. Data from the General Administration of Customs of China shows that in 2023, China imported 85.96 million tons of crude oil from Saudi Arabia, which represented 77% of its total imports from the country. In 2024, China's crude oil imports from Saudi Arabia totaled 78.64 million metric tons (1.57 million barrels), a decrease of 8.5% from 2023. As China's largest supplier of crude oil in the GCC, Aramco delivered 85.96 million tons (1.72 million barrels) in 2023 (Hayley 2024). From 1995 to 2023, China's total imports from Saudi Arabia amounted to US$787.3 billion, with crude oil accounting for 76%. During the same period, China's key exports to Saudi Arabia were valued at US$370.8 billion, primarily consisting of machinery, goods, and clothing (UN Comtrade Analytics 2024).

China is the GCC's leading destination for chemical exports, while Saudi Arabia is China's primary source of chemical imports. In 2023, China accounted for 29% of the total GCC exports of oil, refined oil, and chemical products, while the GCC represented 12% of China's imports. GCC chemical exports to China constituted 22.5% of the industry's total export value in 2023. This shows the pivotal role of the chemical sector in defining the trade dynamics between the two parties, highlighting the significant and enduring nature of their trade relationship. Furthermore, they have managed to maintain a positive trade balance. Between 2010 and 2023, GCC exports to China more than doubled, rising from US$89 billion in 2010 to US$180 billion in 2023. This reflects a growing partnership that is expected to strengthen further with the Belt and Road Initiative (BRI) enhancing exports due to their shared economic interests.

From 2004 to 2023, China's chemical imports from the GCC grew sixfold in volume and fivefold in value, with polyolefins and organic chemicals (glycol) accounting for over 96% of total GCC exports (Table 4.7). In 2004, GCC chemical exports to China were 3.35 million tons, valued at US$2.55 billion, which increased to 21.96 million tons worth $14.23 billion in 2023. In 2004, China exported 560,000 tons of specialty chemicals to the GCC, valued at US$700,000, increasing to 6.5 million tons valued at US$10.8 billion in 2023. This growth in GCC chemical exports to China reflects an expanding partnership, poised to strengthen further

Table 4.7 GCC–China chemical trade pattern (2004–2023)

Bilateral Chemical Trade Metrics	*GCC's chemical exports to China*			*China's chemical exports to the GCC*		
	2004	*2023*	*Multiplier (X)*	*2004*	*2023*	*Multiplier (X)*
Volume (million tons)	3.35	21.96	6.5	0.56	6.53	11
Value ($billion)	2.55	14.23	5.5	0.70	10.78	15.4

Source: GPCA analysis, using data from ITC (2024).

with the BRI enhancing exports. Conversely, the volume of GCC petrochemicals imported by China has more than quadrupled since 2008, with imports primarily consisting of inorganic and specialty chemicals (dyes/pigments, caustic soda, synthetic rubbers, plates, sheets, solvents, and thinners).

Over the past decades, China has made significant strides toward achieving self-sufficiency in key chemicals. Today, China is a net exporter of ammonia and urea, and with the startup of crude-to-chemicals projects, it is on track to achieve self-sufficiency in aromatics. Despite current economic challenges, China is expected to approach balanced positions on key petrochemical products by 2030. Foreign producers have aided China's self-sufficiency drive, with several GCC players, such as Aramco and SABIC, establishing joint ventures in China.

According to the CNPC's Economics and Technology Research Institute, China's energy self-sufficiency rate reached 85% in 2024, a 5% increase compared to a decade ago. By 2060, this rate is expected to reach 95%, driven by accelerated innovation in exploration and the scaling up of renewable energy systems. Given China's self-sufficiency strategy, the GCC–China trade pattern is set to evolve, as the Chinese petrochemicals market continues to exhibit diversification and stable growth. China is poised to become the world's largest producer of ethylene, a building block for over 75% of petrochemical products. The planned addition of chemical and fertilizer capacity may contribute to a broader global overcapacity scenario. This shift has significant implications for the export-oriented GCC chemical industry, necessitating strategic adaptation to navigate evolving trade dynamics and leverage emerging opportunities in burgeoning alternative markets.

GCC–China Investment Pattern in the Downstream Oil Sector

The Sino-Saudi relationship is founded on "stable long-term energy cooperation" (Ministry of Foreign Affairs of the People's Republic of China 2016) and supported by steadily increasing bilateral investments. Aramco has secured annual supply deals with six Chinese refiners, including Sinopec, CNPC, the China National Offshore Oil Corporation (CNOOC), Sinochem, Noringco, and private refiner Zhejiang Petrochemical. In 2023, Saudi Arabia supplied approximately 1.61 MMb/d per day of crude oil to China (Tan 2024), fostering strong ties with Chinese national oil companies and major private players. Additionally, the joint petrochemical projects between Aramco and SABIC in China have yielded significant results, with an estimated total petrochemicals volume of 14.4 million tons per annum.

Collaboration in the development of integrated refinery-petrochemical complexes in China, supplied with crude oil from Aramco. This initiative began in 2009 with the Fujian Refining and Petrochemical Company (FREP), a joint venture involving Aramco, ExxonMobil, and Fujian Petrochemical Company. Other notable examples include the SINOPEC SABIC Tianjin Petrochemical Company (SSTPC), which features Asia's first polycarbonate plant and is currently expanding its production capacity; the Zhejiang Petroleum and Chemical Company (ZPC), where Aramco acquired a 10% stake in 2023 to supply 480,000 b/d of crude oil; the Gulei II integrated complex in Fujian, a greenfield project with a 320,000 b/d refinery and a 1.5 million tons per year petrochemical cracker expected to be operational by 2025; and Huajin Aramco Petrochemical Company (HAPCO) in Northeast China, a US$12.2 billion project featuring a 300,000 b/d refinery and petrochemical plant capable of producing 1.65 million tons of ethylene and 2.0 million tons of paraxylene annually, which is set to begin operating by 2026.

Saudi companies are securing minority stakes in China's refining-petrochemical complexes, exemplified by Saudi Aramco's purchase of a 10% interest in Rongsheng Petrochemical for US$3.4 billion in 2023. This partnership paves the way for Rongsheng Petrochemical's participation in the Saudi Aramco Jubail Refinery Company (SASREF) expansion project in Saudi Arabia.

Partnerships between Saudi Aramco and Chinese companies to develop refineries in Saudi Arabia, notably the YASREF, a world-class full-conversion refinery that commenced operations in 2014. The strong bilateral relations extend beyond refinery and petrochemical projects to include investments in industrial parks and logistics zones along regions of the BRI, such as the PARK Energy Park, Hutchison Ports, and Jazan City for Primary and Downstream Industries (JCPDI). The JCPDI has attracted in excess of $26.7 billion in investment.

Demand for oil is driving investments from Saudi Arabia into China. At the beginning of 2024, SABIC, a subsidiary of Aramco, invested US$6.4 billion in a petrochemicals complex in Fujian, China. This investment makes SABIC a 49% partner in Fujian Fuhua Gulei Petrochemical and represents one of the largest foreign direct investments in the province.

Kuwait Petroleum Industries (PIC), a subsidiary of Kuwait Petroleum Corporation, acquired a minority stake of 25% stake in China's Wanhua Chemical Group in April 2025, marking its largest investment in China's petrochemical sector. This acquisition valued at $638 MM, is a significant move for PIC to expand its footprint in the Chinese petrochemical market (Hydrocarbon Processing 2025).

Chinese firms, such as Sinopec, Wison Engineering, and Tianchen, have played crucial roles in executing large-scale projects that are essential to the GCC's economic diversification and industrial development. These engineering, procurement, and construction (EPC) contracts include building world-class refineries, gas processing facilities, and petrochemical complexes, contributing to the growth of the energy sector in GCC countries.

Advancing the Development of Clean Production Technologies

Key players in China and the GCC energy value chains are investing in technologies that reduce carbon emissions. These investments include projects for carbon capture and utilization, the development of green hydrogen, and renewables such as solar panels and wind turbines, all aimed at decreasing reliance on fossil fuels. These initiatives are part of a broader regional strategy to align with global sustainability goals and meet the growing demand for cleaner energy solutions.

In the GCC, Saudi Arabia has been at the forefront of carbon emissions management. SABIC enhanced its efforts on this front with the pioneering carbon dioxide (CO_2) capture facility at its affiliate Jubail United Petrochemical Company, which involved a $170 million investment in 2015. This plant has the capacity to capture 500,000 tons of CO_2 that would otherwise be emitted during ethylene glycol production. The captured CO_2 is converted into valuable feedstock for various industrial processes. Saudi Arabia has also taken the regional lead in developing infrastructure for carbon capture, utilization, and storage (CCUS), with Aramco's current project capturing 800,000 tons of CO_2 per year.

Global demand for low-carbon hydrogen is expected to reach 20–30 million tons per annum by 2030, up from around 1 million tons per annum in 2022. The IEA predicts that hydrogen could meet 18% of global energy demand by 2050, with an estimated market size of US$150 billion to US$200 billion annually. The UAE and Saudi Arabia are developing ambitious green hydrogen strategies, while Oman has announced its own low-carbon path. Saudi Arabia has launched its National Hydrogen Strategy, targeting the production of clean hydrogen, ammonia, and blue hydrogen (with carbon capture) for domestic and export markets (Shokri 2023).

Hydrogen is widely regarded as a critical component of the decarbonization agenda. In 2000, Saudi Arabia made the first cross-continental shipment of clean hydrogen to Japan, followed by over eight commercial shipments of clean ammonia to Europe and Asia. The country is also building the world's largest carbon-free green hydrogen production plant in Neom, with a total investment value of US$8.4 billion (NEOM 2023).

GCC chemical companies have established four major international research and development (R&D) centers in China, representing 50% of their R&D centers in Asia, thus further solidifying the GCC–China partnership (GPCA 2021). These initiatives will provide mutual economic benefits and create opportunities in next-generation technologies for CO_2 reduction amid the global push for climate change mitigation and sustainable development.

In recent years, scientific and technological innovations within the refining and chemical industries have led to significant breakthroughs. By collaborating with Chinese digital companies, domestic refining and chemical enterprises have successfully utilized cutting-edge digital technologies to enhance productivity and efficiency while reducing the overall environmental impact.

The development of technologies enabling the clean energy transition is accelerating. The carbon neutrality goals and the need to address the energy trilemma are expected to fast-track the development of related industries within the oil refining and chemicals sectors, such as hydrogen and biofuels. The refining industry will expedite transformation and upgrade processes, enhance flexibility in producing clean refined oil and chemical products, and specialize in the production of high-end chemical materials.

China and GCC countries should institutionalize their energy technology cooperation through joint R&D initiatives, structured technology transfer mechanisms, and human capital development programs. The partnership should establish dedicated working groups to align research priorities in sustainable refining and petrochemical technologies, while developing standardized intellectual property protection protocols to facilitate knowledge sharing. Bilateral researcher exchange programs and joint training initiatives would help build the necessary technical capabilities. This proposed framework offers a practical pathway to enhance both parties' energy transition capabilities through coordinated technology development.

Collaboration in Crude-to-Chemicals (COTC) Projects

The traditional energy trade framework between China and the GCC countries, built on crude oil exports and refined product imports, is undergoing a fundamental transformation. Considering global energy transitions and environmental regulations, both parties face converging challenges that demand innovative solutions. This presents a comprehensive vision for evolving the bilateral energy relationship into a technologically advanced and mutually reinforcing industrial ecosystem that addresses decarbonization pressures while creating new value chains. At the core of this transformation is the opportunity to redefine hydrocarbon resources not merely as fuels but as chemical feedstocks. The GCC's strategic investments in COTC technologies, capable of achieving 30–50% conversion efficiencies, complement the growing demand for high-value petrochemical products and its commitment to enhancing industrial competitiveness while adhering to sustainability goals.

This situation offers a significant opportunity for Sino-GCC collaboration in COTC projects, which integrate refining and petrochemical production to maximize efficiency. COTC not only enables backward integration and greater self-sufficiency within the industry but also contributes to the evolving landscape, blurring the traditional boundaries between refiners and petrochemical producers.

The prospects for COTC facilities extend beyond economic considerations. Apart from their economic impact, COTC projects promise to contribute to environmental sustainability by exploring innovative ways to harness the potential of crude oil in a more resource-efficient and environmentally friendly manner.

Most of the planned or operational COTC plants are located in China. Examples include Hengli Petrochemical and Zhejiang Petroleum and Chemical, which are at the forefront of adopting COTC technologies, achieving petrochemical feedstock conversion rates in excess of 40%, and having a combined capacity to produce 2.9 million tons of ethylene and 7 million tons of PX. The Jiangsu Shenghong facility in Lianyungang, China, is another example of a large-scale COTC project, boasting a capacity of 16 million tons per year. This refinery targets substantial petrochemical output, including 4 million tons per year of PX, about 6 million tons per year of other chemicals, and 5.5 million tons per year of liquid fuels, with an ambitious 64% conversion to chemicals rate based on crude. A key enabler of China's success in this area is the development of domestic technologies for COTC.

Saudi Aramco is advancing its integrated strategy to convert more crude oil in China. This is evidenced by its focus on commercializing COTC technologies, such as its thermal crude-to-chemicals (TC2C) process, which aims to convert 70–80% of crude oil directly into chemicals. Saudi Aramco's innovative approach seeks to enhance chemical production efficiency per barrel of oil, reduce costs, and minimize the associated carbon footprint. This presents an area for potential collaboration between China and Saudi Arabia in the joint development of COTC projects.

Future Outlook

Over the past three decades, the Sino-GCC bilateral relationship has transitioned from one of marginal importance for both sides to a comprehensive strategic partnership, largely built on a trade relationship founded on energy and chemicals. Geopolitical tensions are muddying the outlook for global economic growth, while supply chain disruptions and a more polarized world will impact global trade patterns, and the GCC and China are ready to navigate these challenges. While the obstacles are formidable, the oil refining and petrochemical industries have consistently demonstrated their adaptability to changes in supply and demand.

Future energy demand is expected to arise primarily in the developing world due to increasing populations, a growing middle class, and urbanization. According to OPEC (2024), oil demand is projected to exceed 120 MMb/d by 2050, driven by faster growth in India, Africa, and the Middle East. Similarly, world refining capacity is expected to increase by 19.2 MMb/d, reaching 94 MMb/d by 2050. Over the long term, the use of oil in China will increasingly shift toward industrial and chemical applications. By 2060, petrochemical feedstocks are projected to account for 60% of the country's oil consumption, up from 50% currently, while transportation fuel use is expected to decline to less than 20% (Zheng 2024).

Petrochemicals will be the cornerstone of global oil demand growth, outpacing sectors such as trucking, aviation, and shipping. By 2030, petrochemicals are projected to account for over a third of the growth in oil demand, with this contribution increasing to nearly half by 2050. This significant increase in demand highlights the sector's growing influence on global energy trends. The industry currently consumes an increasing share of the world's oil and gas—approximately 14% (13 MMb/d) of oil and 8% (300 billion cubic meters [m^3]) of gas—and is expected to grow at a CAGR of 4.2% by 2032 (Fortune Business Insights 2024). The growing need for electrification and energy storage systems is anticipated to significantly accelerate the expansion of the petrochemicals market.

The United Nations (UN) global plastics treaty presents a strategic opportunity for China–GCC collaboration to jointly establish sustainable petrochemical standards that leverage their combined production scale and technological expertise. By collaboratively developing certified low-carbon polymer protocols, integrated supply chain tracking systems, and aligned carbon accounting frameworks, both partners can influence emerging global standards while maintaining competitiveness in their integrated refining–chemical operations. This proactive cooperation enables both parties to meet environmental requirements while complying with their respective regulations, effectively transforming compliance into a strategic advantage in the transition toward circular petrochemical economies.

Ultimately, the China–GCC strategic partnership—evolving from buyer-seller dynamics to the co-ownership of integrated value chains—offers a viable pathway for both parties to navigate energy transitions while maintaining economic competitiveness. For GCC nations, it provides a means to monetize their hydrocarbon resources without combustion. For China, it secures critical feedstock supplies while enhancing its domestic industries. The partnership's true synergy emerges from combining the GCC's strengths in low-carbon energy solutions with China's technological and manufacturing capabilities, creating mutual benefits, securing China's energy needs, and allowing GCC partners to participate in the growth of China's promising petrochemical markets. Together, this complementary collaboration model will redefine global energy governance frameworks that have historically been dominated by Western paradigms, establishing a new equilibrium of shared interests in the evolving energy landscape.

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5 Progress in China–GCC Industrial Capacity Cooperation

Philipp Galkin and Jing Song

BRI and Industrial Capacity Cooperation

Although international cooperation in industrial development was not initially designated as one of the five key pillars of China's Belt and Road Initiative (BRI), it has emerged as one of the major focus areas for Chinese policymakers. It effectively underpins the BRI's five pillars and facilitates the country's overall "going out"[1] and "opening up"[2] strategies.

The 13th Five-Year Plan (FYP)—the first one since the inception of the BRI—identified just three areas for advancing this initiative: cooperation mechanisms, economic corridors, and cultural exchanges. The priorities for "international cooperation on production capacity and equipment manufacturing" were listed in the "Strategy for Opening Up" section of the 13th FYP. The primary goal was globalization and increased exports of Chinese equipment, technology, standards, and services (NDRC 2016). The subsequent 14th FYP identified promoting the high-quality development of the BRI as one of its key tasks.

The highlights of the FYP for industrial capacity cooperation were based on the relevant policy documents promulgated by the State Council. The "Guiding Opinions of the State Council on Promoting International Cooperation in Production Capacity and Equipment Manufacturing" announces a threefold target: contributing to (domestic) economic growth, enhancing China's international competitive advantages, and developing mutually beneficial cooperation. The document also lists key industries prioritized for international cooperation, including iron and steel, non-ferrous metals, building materials, railways, electric power, chemicals, textiles, automobiles, communications, construction machinery, aerospace, shipbuilding, and ocean engineering (State Council 2015). Based on this scope and strategy, provincial governments followed suit and tailored the national plan according to their needs. Chinese government ministries integrated the targets of promoting industrial capacity cooperation into their work plans and provided technical and financial support to key industries and provincial initiatives. Relevant policy documents include "Several Opinions of the State Council on Speeding up the Cultivation of New Advantages in Foreign Trade Competition," "Implementation of the Action Plan for Deepening the Reform Standardization (2015–2016)," and "Three-Year Plan of Action for Promoting International Capacity Cooperation (2015–2018)" (Xu 2021).

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These documents refer to the BRI in several instances, explicitly intending to enhance coordination with the BRI's infrastructure development and facilitate the BRI's overall progress. The infrastructure, policy, and financial frameworks of the BRI are also presumed to support industrial capacity cooperation. However, because international industrial capacity cooperation by Chinese companies often produces significant domestic benefits—and involves countries both within and outside the BRI—this form of cooperation has, in practice, extended beyond the original scope of the BRI framework.

The semi-autonomous and dualistic nature of China's industrial capacity cooperation also manifests itself in many of its international agreements. The BRI memorandum between China and Italy lists industrial cooperation (without any significant details) under the "Unimpeded Trade and Investment" section. The Framework Agreement on Strengthening Production Capacity and Investment Cooperation with the United Arab Emirates (UAE) does not reference the BRI. The Statements on Comprehensive Strategic Partnerships with Kazakhstan and Indonesia assess the progress and set targets for industrial development and BRI cooperation. In some cases, China and its BRI partner countries do not declare any considerable goals or engage in industrial capacity collaboration projects, for example, Timor-Leste, while other countries, although not formally included in BRI, participate in significant joint projects with China and sign relevant cooperation agreements. For example, Brazil has signed more than 35 documents with China on bilateral industrial capacity development, infrastructure, aviation, science, technology, and other areas (Xu 2020) with joint industrial projects spanning electrical appliance and solar photo voltaic (PV) manufacturing to the aerospace industry.

Measuring Progress

The progress in industrial capacity cooperation can be tracked across three dimensions:

- From China's perspective: the general goals (both officially stated and implied), industry-specific targets and indicators, and performances of individual companies.
- From the recipient countries' perspective: a variety of indicators on the macroeconomic and industry levels and their alignment with strategic development plans.
- Micro level and case studies: progress and outcomes of specific cooperation projects.

The policy documents promulgated by Chinese authorities during the 13th FYP period emphasize the need to establish soft infrastructure and conclude bilateral and multilateral agreements to underpin industrial capacity cooperation. On the international front, the goal of "establishing a production capacity cooperation mechanism with key countries by 2020" (State Council 2015) can be considered successfully accomplished. Before 2020, China had signed agreements on industrial cooperation with more than 40 countries and launched relevant collaboration programs with regional organizations, including the Association of Southeast Asian Nations (ASEAN), the African Union, and the Community of Latin American and Caribbean States (CELAC) (Belt and Road Portal 2019). Clauses related to facilitating industrial capacity cooperation can also be found in other bilateral agreements, including BRI memoranda of understanding (MOUs), strategic partnership agreements, and other cooperation and action plans. Notably, a number of countries that are not formally BRI members are engaged in promoting joint industrial capacity development with China—either via industrial cooperation agreements (e.g., Brazil and Mexico) or third-party market cooperation mechanisms (e.g., France and Japan).

Significant progress has also been made in institutionalizing financial support for industrial cooperation projects. Dedicated joint capacity cooperation funds were established with Kazakhstan, Brazil, Japan, and countries in Europe and Africa, among other partners. In most funds, the Chinese side is represented by The China Investment Corporation or the Silk Road Fund of China. Joint industrial projects can also acquire financing via a variety of infrastructure investment and development funds with Chinese participation. Indirect financing, which usually comes in the form of loans or credit guarantees, is facilitated by development banks (such as the Asian Infrastructure Investment Bank and New Development Bank) established after the launch of the BRI.

International cooperation initiatives in adjacent areas or those of a broader nature also facilitate industrial capacity development. These include the establishment of joint structures and frameworks in the areas of customs administration, accounting and audit standards, and science and innovation. During the recent decade, China has arranged bilateral swap lines with more than 20 countries, signed 17 agreements to avoid double taxation, entered into nine new free trade agreements, and established the Regional Comprehensive Economic Partnership with 14 Asia-Pacific nations.

Domestic policy targets for industrial capacity cooperation comprise two major areas: (1) developing coordination among stakeholders—enterprises, financial institutions, local governments, and industry associations; and (2) improving support mechanisms such as taxation, insurance, financing, and risk assessment (NDRC 2016).

The State Council and the National Development and Reform Commission (NDRC) led the efforts to formulate an industrial capacity cooperation strategy within the broader BRI and domestic economic planning context. The implementation of their vision was delegated to other ministries and provincial governments. By the end of 2015, 32 provinces had submitted their BRI plans (Ye 2019). Despite their generic nature, the industrial policies and priorities varied depending on the provinces' economic and foreign trade structures. The central agencies tied these initiatives together, proposing and enforcing specific, actionable measures.

The State Administration of Taxation (SAT) issued a set of preferential measures benefiting the enterprises engaged in international industrial cooperation. The measures included business tax exemptions in certain special economic zones and industrial parks; value-added tax (VAT) exemptions for overseas mineral resource exploration, leasing services, and services provided to overseas units; and export tax rebates for foreign contracted projects and leasing to overseas lessees. The SAT also asked local tax authorities to provide consultations and up-to-date information for companies pursuing international opportunities.

The State Administration of Foreign Exchange pledged to support BRI projects with foreign exchange reserves. The Ministry of Finance (MOF) proposed new insurance schemes. Together with the Ministry of Commerce (MOFCOM), the MOF proposed a set of nationwide financial and organizational support measures for small and medium enterprises (SMEs) engaged in overseas investment and foreign contracted projects. The China Insurance Regulatory Commission, the China Development Bank, and the China Export and Credit Insurance Corporation also issued insurance support policies for the construction of major projects and mineral resource development.

The NDRC, MOFCOM, and Ministry of Foreign Affairs (MFA) joined efforts in developing information support systems for relevant industries and enterprises—the National Overseas Investment Project Record Management Network System and the Country-Specific Investment and Management Obstacles Reporting System—and issuing specific guidelines on foreign investment by country and industry (DRCNET 2023).

Foreseeing potential risk management issues for foreign investment projects, Chinese authorities focused on developing risk protection mechanisms and overseas security risk early warning and information reporting systems. This issue was later prioritized at the highest level, with the NDRC and MOF publishing a note, "Improving the Market Disciplinary Mechanism and Strictly Preventing Foreign Debt Risks and Local Debt Risks" in 2018 (NDRC and MOF 2018).

The domestic policy framework for industrial capacity cooperation was established during the first few years following the official launch of the BRI. After 2016, it was only supplemented by policies focusing on the establishment and operation of special economic zones (SEZ) and industrial parks—both at home and abroad. This may indicate that Chinese policymakers consider this framework to be sufficient and properly functioning. It should also be noted that most policies supporting industrial cooperation have a more general focus on facilitating the BRI or "going out" activities. It is not easy to quantify the impact of these policy initiatives on the performance of China's overseas industrial projects. However, certain indicators mark their progress. According to the Doing Business rankings, China has moved up in the categories of "paying taxes" and "trading across borders" from 122 globally to 105 and from 68 to 56, respectively, from 2013 to 2020 (World Bank 2020).

Domestic support policies and international agreements facilitated China's outward direct investment (ODI) in industrial capacity cooperation projects with BRI-participating countries. According to the American Enterprise Institute (AEI 2023), since the launch of the BRI in 2013, China has invested over $68 billion in greenfield projects of this type (see Figure 5.1). Most of these flows—76%—have

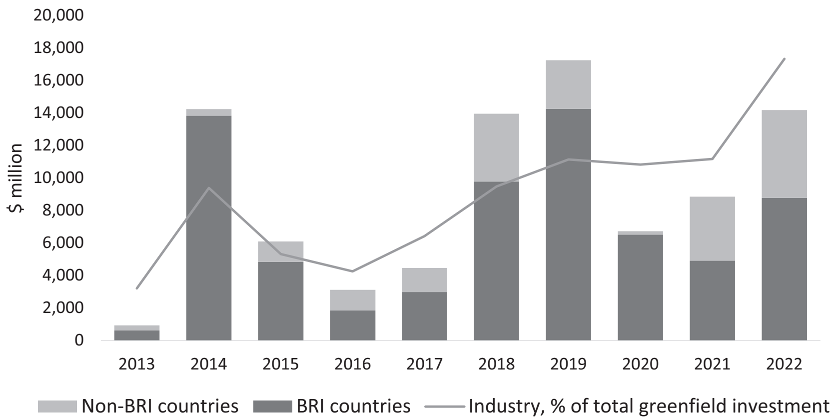

Figure 5.1 Dynamics of China's greenfield investment flows into foreign industrial projects* ($ million).

Source: AEI (2023).

been directed to BRI recipients. Another noticeable trend is the steadily increasing share of industrial projects in total Chinese greenfield ODI, which reached 70% in 2022.

However, it should be noted that greenfield ODI, which most directly contributes to industrial capacity expansion, amounted to only about 30% of total Chinese ODI in the industrial sector globally. Accounting for major mergers and acquisitions (M&A) and minority investments, 49% of China's ODI targeted the industrial sectors in BRI countries over the same observation period (AEI 2023). This shows the importance of the joint industrial capacity development projects in these countries initiated under the BRI framework.

Chinese companies also contribute to international industrial capacity development as contractors, building project facilities, and supplying necessary equipment. By the end of 2022, the total value of Chinese construction contracts for foreign industrial projects in BRI countries exceeded $56 billion (AEI 2023).

Most overseas industrial project contracts involving Chinese companies as contractors have been signed with BRI countries. As shown in Figure 5.2, the total contract values have exhibited a downward trend since 2017. In contrast, Chinese direct investment in overseas industrial capacity, as illustrated in Figure 5.1, has followed an upward trend.

Another indicator of China's contribution to international industrial capacity development is its export of machinery and construction materials. These exports also facilitate China's goals of promoting its industrial brands and construction, industrial, and technical standards.

BRI countries accounted for 48% of China's machinery exports,[3] totaling $133.8 billion in 2022. However, exports to BRI countries grew by 95.5% between 2013 and 2022, compared to a 60% increase to non-BRI countries. This shows both

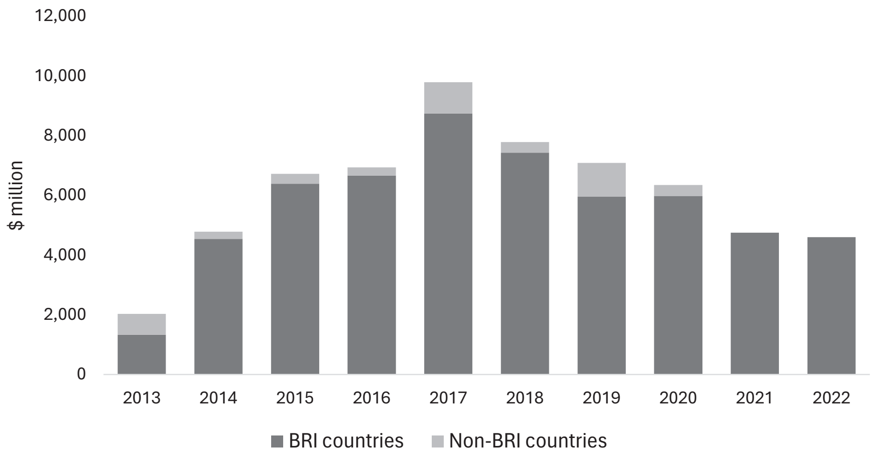

Figure 5.2 Total contract values for Chinese companies constructing foreign industrial projects* ($ million).

Source: AEI (2023).

the positive contribution of the BRI framework and, in some cases, the insufficient development of some BRI countries' domestic industrial infrastructure. In summary, Chinese machinery exports have shown steady and significant growth over the observation period and have outpaced the growth of total Chinese exports—reaching almost 8% of their total value (World Bank 2023).

The trends observed in China's construction material[4] exports differ from those of its machinery exports. In 2022, BRI countries accounted for 59% of Chinese construction material exports—or $9.2 billion. Exports to BRI countries also grew at 59% from 2013 to 2022, compared to 49% to non-BRI countries—indicating a positive impact of the BRI framework (World Bank 2023). However, in terms of both absolute export values and their share of total Chinese exports, construction materials significantly lagged behind machinery. Consequently, it can be concluded that China's cooperation in industrial capacity has been driven primarily by its investments and equipment exports, with construction assistance playing a more limited role—particularly in recent years.

One of the BRI's policy goals is to optimize China's domestic industrial framework by transferring excess capacity to BRI economies. It can be debated as to whether the initiative has been a major driver in this process, as the impacts of domestic industrial policies and market dynamics should not be underestimated. However, domestic capacity utilization rates can serve as a benchmark for the success of this BRI policy goal.

Despite significant fluctuations during the COVID-19 pandemic, China's overall industrial capacity utilization remained largely unchanged from 2016 at around 74%. However, when this indicator is disaggregated into sectors, it shows a significant variance across industries, with some demonstrating progress in domestic capacity optimization. General equipment manufacturers increased their capacity utilization by 14.5% and ferrous and non-ferrous metal smelters by 8.2% and 6.1%, respectively. In contrast, the utilization rates for textile, chemical, and electric machinery industries have remained flat, and manufacturers of automobiles and computers have seen their utilization rates decline by −8.7% and −5.5%, respectively (CEIC 2023).

The objectives of China's industrial capacity cooperation strategy are to "form a number of overseas production capacity cooperation demonstration bases," "form a group of backbone enterprises with international competitiveness and market development capabilities," and "make significant progress in a number of key production capacity cooperation projects" (State Council 2015).

The progress in the first area can be measured by the performance of Chinese Overseas Economic and Trade Cooperation Zones (COCZ) and their industrial development. By the end of 2021, according to the MOFCOM's registry, the 113 COCZ were located in 46 countries. They attracted a cumulative investment of $50.7 billion, paid $6.6 billion to the host countries in taxes, and created 392,000 local jobs (MOFCOM 2023). Due to varying degrees of Chinese participation, the total number of relevant SEZ that emerged during the BRI period is challenging to estimate. Some zones were established on a bilateral basis with the direct involvement of Chinese authorities, while others attracted Chinese companies along with participants from other countries. Moreover, many such zones do not appear in official Chinese registries, as many private industrial enterprises utilize existing global SEZ in pursuit of their "going out" strategy without any centralized coordination.

By 2023, more than 200 overseas industrial parks with Chinese participation had been initiated and developed, 82 of which are attributed to the BRI (DRCNET 2023). China's overseas industrial parks play a critical role in boosting the development of China's overseas markets and the construction of global value chains. Many of these parks are still in their development phase, and a few of them have already become financially sustainable. Successful examples include the China–Indonesia Comprehensive Industrial Park located in the Indonesian Sulawesi province, which has evolved into a global nickel, iron, and stainless-steel industrial base, and the Thai-Chinese Rayong Industrial Zone, which has become the biggest industrial cluster center and manufacturing export base in Thailand, with 170 Chinese-backed factory projects.

China has also been developing its domestic free trade zones since 2013, bringing the total number to 21 in 2023. The industry-related focus areas of these zones reflect the country's current domestic industrial development priorities: advanced manufacturing, robotics, aerospace and aviation, and auto manufacturing (with a focus on new energy vehicles and relevant infrastructure), among others.

The most successful industrial capacity cooperation projects can often be found within the COCZ. The United Iron and Steel Project, with an annual output of 3.5 million tons, resides in the Malaysia–China Kuantan Industrial Park (MCBC 2023). A joint venture with Tsingshan Steel in Indonesia's Morowali Industrial Park can produce up to 3 million tons per year of steel (Ginting and Moore 2021).

However, stand-alone projects can also be successful, as suggested by the example of the Smederevo plant in Serbia revived by the HBIS Group.

Each of the industries prioritized by China for international capacity cooperation produced at least a couple of successful "key cooperation projects," including the follows:

- Non-ferrous metals: The Bozshakol copper concentrator project in Kazakhstan, named "Best National Industrial Project" by Kazakhstan, with 37 million tons per annum of sulfide and oxide ore processing capacity (China Daily 2022).
- Building materials: Myanmar Conch (Kyaukse Industrial Zone) became the country's leading manufacturer and exporter of cement, with a production capacity of 5,000 tons per day (ZKG 2023).
- Transport: A Changan Auto plant in Karachi produces 30,000 vehicles per year (Pakistan Observer 2023).
- Chemicals industry: A chemicals complex built by the Sinomach subsidiary in Uzbekistan, with an annual capacity of 475,000 tons of polyvinyl chloride, methanol, and caustic soda, won China's Overseas Quality Project Award in 2020 (Sinomach 2022).
- Textiles industry: A Jinsheng Group factory in Uzbekistan with an annual output of 22,000 tons of cotton yarn per year. It exports 95% of its products (ERI 2023).

Many Chinese industrial companies enhance their international competitiveness by engaging in capacity development projects under the BRI. HBIS Group and Zijin Mining are good examples of Chinese industrial leaders that started to pursue global strategies and have been successful in doing so during the years of BRI development. HBIS Group initially deployed its international strategy in 2014. By 2023, it had production bases in South Africa, Australia, Serbia, North Macedonia, and the United States (U.S.), supplemented by shares in some 70 overseas companies. By 2025, overseas business is projected to account for 25% of the group's revenues (HBIS 2023). Major foreign acquisitions of China's mining giant Zijin Mining Group also started after the BRI's launch. By the end of 2022, the group's mining assets included copper mines in Serbia and the Democratic Republic of Congo (DRC), a gold mine in Colombia, and a lithium project in Argentina (Zijin 2022).

The industry-specific goals for capacity development cooperation under the BRI do not significantly differ from one another in scope. They appear to align with China's domestic industry structure, its aim of utilizing its competitive advantages, and expanding its presence in markets with high demand or resource potential. Certain high-tech industries such as aerospace, shipbuilding, and auto manufacturing are also required to develop their research and development (R&D) capabilities via international cooperation. Given the absence of specific quantitative performance indicators in the public domain, it can be argued that the expectations set by Chinese policymakers for the period in review have generally been met.

Identifying Challenges

Despite undeniable progress along many dimensions, industrial capacity development under the BRI framework continues to be hampered by challenges. This can be illustrated by the list of "troubled" deals put together by the AEI. Their total value from the BRI's inception to the end of 2022 is estimated to have been \$54.1 billion, of which \$22.7 billion was made in BRI countries (AEI 2023). Although the share of BRI-participating countries in industrial development projects and the total value of these projects have declined over the last decade, the unrealized investments and the number of such projects remain significant.[5] Moreover, many projects that progress beyond the initial stage (not reflected in this chart) face delays and other challenges that impede the realization of their potential.

The nature of international industrial projects—long-term investments with significant upfront costs in a foreign environment—amplifies the risks associated with them. Unlike many infrastructure projects, whose future revenues and costs are more predictable as they fall under direct government regulations, industrial projects tend to have greater exposure to global competition and market and macroeconomic risks. Furthermore, many industrial expansion projects are undertaken by SMEs, which generally have less international expertise than major Chinese corporations operating in the fields of energy and infrastructure. Thus, the challenges faced by the BRI participants in industrial capacity expansion are both those attributed to BRI projects in general, alongside more industry-specific ones.

Chinese policymakers tend not to emphasize the BRI's challenges in their speeches or policy documents. In addition, in recent years, China has released hardly any major policy documents covering industrial capacity cooperation or the BRI strategy in general. Given this, one way of pinpointing problematic areas for the BRI is to look for relevant "key issues" and "focus areas" in speeches and press releases of key Chinese spokespeople.

In his address to the BRI symposium in Beijing, China's President Xi Jinping urged increased efforts in promoting industrial capacity cooperation. He also emphasized the need to address the associated risks by developing and improving "early-warning and risk assessment platforms" and the "management of overseas projects and risk control" (Xinhua 2021). The quality of risk assessment and control procedures presents an overarching challenge to successful international industrial development. This domain covers all existing and potential challenges discussed in this section, ranging from macroeconomic and geopolitical challenges to those related to project location and partner entities. Many problems have emerged during project development and operation phases due to miscalculations made in the planning phase of their probability and potential impacts.

Other areas for improvement highlighted by President Xi include Chinese enterprises adapting to local laws and customs, combatting cross-border graft, and focusing on improving the livelihood of people in BRI countries. If implemented successfully, these initiatives could reduce the tensions between local communities and Chinese investors. In several instances (a gold mine in Kyrgyzstan, a nickel smelter in Myanmar, and a cement plant in Indonesia), these tensions—spurred by working conditions or accidents—have even turned violent. In other cases, protests have emerged over the potential environmental impacts of industrial projects (copper mines in Serbia and Myanmar), the alleged loss of jobs to Chinese workers (mineral development projects in Nigeria and Zambia), and general concerns over the impacts of Chinese development on local communities (Kazakhstan and Pakistan) (Balkan Insight 2024; Anadolu Ajansı 2021; CPC 2021). In addition to disrupting existing projects and impeding further joint industrial development, such instances generate negative sentiment, which—propelled by the media and think tanks of China's geopolitical rivals[6]—affects the overall perception of industrial cooperation under the BRI.

Analysis from the opposing geopolitical camp's perspective can help identify issues pertinent to China-led industrial development cooperation. The Council on Foreign Relations report on the implications of the BRI for the U.S. identifies potential weaknesses attributed to BRI projects that could be exploited to "mitigate the economic risks of BRI" (CFR 2021, 5). Overlapping with the issues emphasized by President Xi, these include standards of lending, corruption, and environmental and economic sustainability (CFR 2021).

It would be unfair to attribute the above-mentioned issues exclusively to the Chinese side. Certain BRI countries have low sovereign credit ratings, high levels of corruption, and other problems with their soft and hard infrastructure, necessary for industrial development. These issues increase the financial and operational risks of existing and potential projects. However, industry specifics often dictate the necessity of capacity expansion in such locations. For example, the unique mineral deposits of Peru and Congo presumably outweigh the potential risks of these non-business-friendly jurisdictions. Unsurprisingly, joint mining projects in these countries faced multiple problems (Bloomberg 2022; The China Project 2023).

Another issue related to joint projects in recipient countries is their design and technical standards, which are sometimes adopted from the U.S., European Union (EU), or other jurisdictions, and often differ from Chinese standards. These differences can present in various parts of the value chain and project implementation phases, including design, engineering, manufacturing, and services. While in some cases, such as energy efficiency, adopting Chinese standards may be beneficial for the local industries, in other instances, that is, manufacturing railway cars, such established standards present a challenge for Chinese companies.

The global dynamics of respective industries can also affect existing and future BRI industrial projects. Fierce international competition in transport manufacturing or nuclear power station construction makes it challenging to win local contracts and find markets for existing and future output. Other global markets may go through a cyclical downturn and suffer from overcapacity. The HBIS steel plant in Serbia, for example, had to idle its blast furnace due to weak demand (Steel Radar 2022). In such unfavorable market conditions, some BRI industrial projects may be disadvantaged compared to international competitors.

Finally, the risks associated with the location and financial structure of BRI projects, particularly if not adequately assessed, can make them especially vulnerable to potential global macroeconomic and geopolitical shocks, such as the war in Ukraine and the ongoing tensions in the Middle East.

Moving Forward in New Realities

In recent years, global macroeconomic and geopolitical developments have made it more challenging for international industrial capacity cooperation projects to launch and succeed. The COVID-19 pandemic disrupted international economic relationships, including those in the BRI, as the movement of capital, products, and people slowed, and countries became increasingly focused on domestic issues. Many foreign industrial development projects were put on hold or canceled. Extreme policy responses—such as lockdowns and the exponential expansion of the money supply—observed in many economies led to inflation and supply chain disruptions globally.

These problems and the subsequent policy responses are a symptom of the general vulnerability of the global economic system. It has already been struggling with macroeconomic headwinds: inflation outpacing slowing economic growth, a higher cost of capital due to the recent global monetary policy tightening cycle, currency swings, subdued investment, mounting debt vulnerabilities, funding shortages, etc., which remain primarily unaddressed (UN 2023). Unsurprisingly, many analysts see a recession on the horizon (Bankrate 2023).

Economic downward trends are aggravated by rising de-globalization and protectionism. In the industrial domain, these trends manifest in increased barriers to entry for foreign products in the form of tariffs and non-tariff measures, technological protectionism, restrictions on foreign investment in "sensitive" industries and infrastructure, and an increasing focus on investing in domestic supply chains in lieu of outward investments.

On the geopolitical front, many experts proclaim the impending end of "pax-americana" or the Western (or G7/Global North)-led order, as the U.S. and their allies increasingly focus on mounting domestic issues and shifts in the global power balance become increasingly evident (Foreign Affairs 2022). The conflict in Ukraine and subsequent division in policy responses observed across the globe can be seen as a harbinger of shifting from the "rule-based order" to the unchartered territory of "realpolitik" and fragmentation.

In this changing environment of increasing nationalism and tougher competition, China is seen by many developed economies in the Global North as a major rival. Prominent public figures publicly opposed China on geopolitical, economic, and military issues (New Geopolitics 2023; Politico 2023a). This attitude has already affected industrial cooperation with China. Chinese companies started to have problems with listings on Western exchanges and bond issuance and were prohibited from investing in specific industries and projects in Western economies. Recently, these developments have been accelerating, as the U.S. has further restricted investments in China (The Wall Street Journal 2023), Canada banned Chinese mining investment and froze ties with AIIB (Investment Monitor 2022; Reuters 2023), and Italy has left BRI.

Moreover, the U.S., EU, and G7 recently announced "alternatives to BRI." The U.S.-led Build Back Better World seeks to address the $40 trillion worth of infrastructure needed by developing countries by 2035 (The White House 2021). The EU's Global Gateway aims to mobilize up to 300 billion euros from the EU budget, member states, and the private sector by 2027 (Foreign Policy 2023b). Partnership for Global Infrastructure and Investment by G7 intends to mobilize $600 billion in loans and grants for "sustainable, quality infrastructure projects in developing and emerging economies" (Brookings 2022).

In these new realities, BRI and industrial capacity cooperation have become increasingly important from the economic development perspective and from strategic and geopolitical viewpoints. Global and regional powerhouses will race to expand their influence on the "geopolitical swing states"—that is, the countries that are not direct allies of the U.S. or China and have unique competitive advantages, such as possessing critical aspects of global supply chains (resources in particular), uniquely suited for nearshoring, offshoring, or friendshoring, and those possessing significant capital that can be applied for foreign investment.

These global shifts also provide China—along with other competitors—with an opportunity to enhance its role in global industrial capacity development as supply chains reshuffle. Countries seek to strengthen and rearchitect their domestic R&D, manufacturing, and distribution networks based on a renewed focus on increased security and resilience. At the same time, some developing nations still have to build their industrial bases from scratch.

In certain areas, China has a competitive edge over the development initiatives of its Group of Seven (G-7) counterparts. Despite industrial capacity cooperation under BRI experiencing several issues, it has already started to gain momentum. With the relevant infrastructure—such as COCZ—in place in many partner countries, and with Chinese industrial companies accumulating expertise in overseas development, China-led industrial capacity cooperation is poised to be more rapid and efficient. Chinese development finance institutions also tend to be less dogmatic than their Western-led counterparts, significantly reducing competition for Chinese enterprises and aiding the flow of finance to many countries. Currently, over 20 countries are under U.S. sanctions (U.S. Department of Treasury 2023), many of which are supported by U.S. allies. These sanctions outright prohibit or significantly reduce the ability of Western entities to trade with and invest in the targeted jurisdictions. Finally, the current trends in China's money supply and monetary policy differ from those in the U.S. and the EU. While the U.S. and the EU have been tightening their monetary policy by steadily raising their key rates and reducing their money supply, as measured by the M2 and M3 indicators, the Chinese monetary base continues to expand, with the Bank of China's key rate steadily decreasing (Trading Economics 2023).

China's approach to industrial development and cooperation under these new realities has already been reflected in its policy documents and international initiatives. The 14th FYP (NDRC 2021) emphasizes the growing importance of self-reliance via developing domestic scientific and technological capabilities and the central role of the domestic industrial market. In foreign cooperation, emerging markets and neighboring countries are prioritized. These strategies coincide with retaliatory policies when implemented on the "tactical" level—via restrictions on exports of some rare earth materials and dual-purpose technologies (MOFCOM

2023), anti-dumping probes, an investigation into EU dairy subsidies, and an overall tighter control of certain imports from Japan and the EU (Ministry of Agriculture and Rural Affairs 2023).

The efforts to promote the globalization of Chinese standards, products, and technologies are part of this new paradigm and have been reemphasized in the 14th FYP. The internationalization of the renminbi (RMB)—also highlighted in the FYP and further emphasized by MOFCOM and the People's Bank of China (2023)—plays a crucial role in strengthening China's ties with partner economies. The FYP also advocates strengthening the link between the BRI and local development agendas.

Despite its sharper regional focus, national security concerns, and growing economic confrontation with the West, China does not seem to be attempting to dismantle existing global economic frameworks. On the contrary, its recent Global Development Initiative (GDI) and Global Security Initiative (GSI) emphasize alignment with global principles and agendas.

The GSI mentions industrial cooperation only in the context of supply and industrial supply chain security (MOFA 2023), and the GDI lists industrialization as one of its key focus areas (MOFA 2021). The regional focus of GDI—ASEAN, Africa, and Latin America—also confirms China's shift to a focus on emerging markets, China's neighbors, and South–South cooperation. This initiative suggests that the BRI is developing links to regional development agendas and cooperating with the United Nations (UN), the Group of Twenty (G20), and other global institutions.

Given the sparse references to the BRI in China's recent policy documents, these initiatives can be seen as an effort to rebrand China's approach to international development, cooperation, and industrialization, bringing such efforts under the umbrella of the current global system in an attempt to shield them from critique and counteractions. In addition to the usual contemporary development buzzwords (e.g., "sustainable," "inclusive," "green," "climate governance"), the GDI lists the goals of the UN's 2030 Agenda for Sustainable Development, commonly referred to as Agenda 2030, as its core mission—entrenching itself within the existing globalist mainstream paradigm.

Based on recent actions and policy documents, in the following years, China's industrial capacity development cooperation strategy will likely have the following attributes:

- It will be performed within the established global economic and power system.
- Within this system, it should contribute to increasing China's global influence.
- A sharper geographic focus: nearshoring, friendshoring, and countries with critical resources.
- An increased attention to risk management, compliance, and integration with local economic and cultural systems.
- An increased role for the private sector.

How successful this balancing act turns out to be, only time will tell.

China–GCC Industrial Cooperation

Expanding domestic industrial capacity is a shared key pillar across the GCC countries' strategic development plans. With target years ranging from 2030 (Saudi Arabia, Qatar) to 2040 (Oman), GCC nations seek to significantly expand the share of their manufacturing sectors in their respective gross domestic product (GDP) and multiply non-energy exports. Thus, Saudi Arabia plans to more than double its manufacturing GDP compared to its 2020 baseline and more than triple its non-oil exports. The UAE also intends to double the current contribution of its manufacturing sector to its GDP by 2031, while Oman expects 20.2 billion Omani rial (OMR) of manufacturing value added in 2040—more than quadrupling the current (2022) 4.6 billion OMR of manufacturing value added (Strategic Gears 2023).

These development plans also focus on industries prioritized for further expansion or development from scratch. The common priority sectors across the GCC region tend to be those where countries have a competitive advantage due to their resource endowments and lower cost of energy, namely petrochemicals, plastics, and building materials. Another common development agenda is diversifying into the food and medical industries. Heavy industry is represented by machinery and equipment in the development plans of the UAE and Saudi Arabia, as well as by the aluminum industry in Qatar's development plan. The differences in the desired future industrial structure across the region seem to be driven by the availability of resources (Saudi Arabia is pursuing opportunities in the mining industry, for example) or by the specific ambitions of individual countries: Saudi Arabia is also seeking to develop its military industry, the UAE its electronics industry, and Qatar additive manufacturing (MOIAT 2023; MIM 2022; MOF 2019; Strategic Gears 2023).

Besides the priority sectors, GCC governments are also stimulating industrial development and localization on a broader basis. A prominent policy tool applied in the GCC region for this purpose is local content requirements. Under this policy, governments and companies majority-owned by governments have to give preferable treatment to locally produced goods and SME suppliers or follow set quotas in their procurement processes to prioritize them.

Such ambitious development plans require significant capital investment, which would be difficult to achieve without foreign cooperation. In recent years, GCC countries have shown different methods of attracting foreign direct investment (FDI). FDI inflows to Kuwait, Saudi Arabia, and the UAE roughly doubled during the last five years, while inflows to Bahrain, Qatar, and Oman were relatively flat (UNCTAD 2023).

One would expect China—a major regional trade partner—to channel a substantial share of its outward investment to GCC countries, especially given recent progress in bilateral relations. While this trend is observed in the energy sector (including joint projects in renewables), and more recently in infrastructure, Chinese investment flows to other industrial sectors remained modest. According to the AEI (2023), from 2013 to 2022, total Chinese investment in the GCC's industrial sector (excluding energy) amounted to $3.46 billion. To put this number into perspective, it represents less than 1% of China's total outward investment in foreign industries over the period and only 22% of China's investment in the GCC's energy sector. For comparison, FDI inflows to the UAE alone in a single year, 2022, totaled $22.7 billion (UNCTAD 2023).

Until recently, China's contribution to developing regional industrial capacity has been transactional rather than strategic. Construction contracts awarded to Chinese companies to build industrial facilities in the GCC since the inception of the BRI have amounted to $5.9 billion, exceeding investment inflows from China into regional industries by 70% (AEI 2023). Chinese exports of machinery and construction materials to the region (shown in Figure 5.3) also significantly exceed investment flows into the GCC's industrial sector.

Despite the recent increase in the absolute values of China's exports, the GCC's share of total Chinese exports remained flat for machinery, and it has been in a downward trend for construction materials as China continues expanding its presence in other BRI countries.

There are several plausible explanations for why China–GCC cooperation in the industrial sector has remained relatively quiescent compared, for example, to the cooperation seen in the energy sector and China's significant industrial presence in other BRI regions. At the current stage of development, GCC's industrial complex, with a few exceptions, is not at the forefront of technological innovation. Thus, Chinese companies seeking access to industrial technologies may invest elsewhere. The GCC industrial sector's current development phase also limits the regional business-to-business (B2B) market for industrial products, and the business-to-consumer (B2C) market is capped by the GCC's population of under 60 million people. On the other hand, GCC countries possess significantly more financial and investment capabilities than many other BRI participants. This implies that Chinese investors and financiers are not the only game in town and must compete with other foreign entities seeking to establish their presence in the region and with regional institutions.

The GCC's energy and infrastructure sectors seem to be more lucrative for Chinese investment due to the member countries' significant petroleum resource endowments and strategic geographic locations. This has diverted attention and financial resources from the industrial sector. This is illustrated by the initial "1+2+3" cooperation model proposed during the China-Arab States Cooperation Forum in 2014. This model puts energy at the core of bilateral relations, supported by "two wings"—infrastructure, and trade and investment, and three breakthrough cooperation areas: nuclear, space, and new energy.

The "1+2+3" framework helped lay a necessary foundation for bilateral industrial capacity cooperation. Unlike joint energy and infrastructure projects, which—due to their scale and strategic importance—are often initiated and put forward at the highest government level, industrial cooperation generally tends to be driven by the private sector. In this regard, developing relevant hard and soft infrastructure

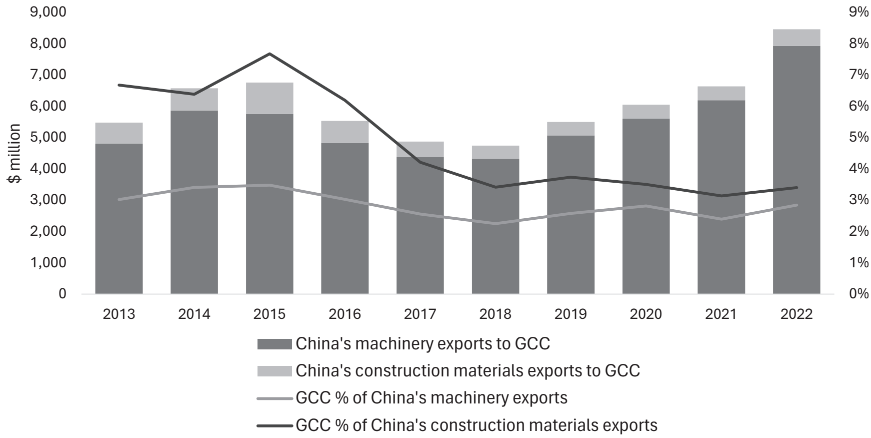

Figure 5.3 Chinese exports of machinery and construction materials to the GCC ($ million).
Source: World Bank (2023).

and becoming familiar with the GCC's business environment are essential prerequisites for scaling up industrial cooperation.

Substantial progress has already been made along this path. Three major regional hubs comprising ports and industrial parks were developed with Chinese participation: the Khalifa Industrial Zone in Abu Dhabi, the China–Oman Industrial Park in Duqm, and Saudi Arabia's Jazan City for Primary and Downstream Industries. Saudi Arabia partnered with the China Geological Survey to conduct one of the most extensive geological surveys in the world, exploring mineral deposits and new reservoirs, and paving the way for the development of Saudi Arabia's domestic mining sector and relevant downstream industries (ZAWYA 2023a). RMB clearing houses were established in the UAE and Qatar, and several Chinese banks opened branches in GCC countries.

Establishing more comprehensive bilateral policy frameworks reinforces these developments. China's relationships with the UAE and Saudi Arabia were upgraded to "comprehensive strategic partnerships" in 2018 and 2022, respectively. Bahrain, Kuwait, Oman, and Qatar also signed strategic partnership agreements with China between 2014 and 2018. Saudi Arabia and the UAE signed agreements with China on production capacity and investment cooperation, among many other sector-specific cooperation documents. The parties also strive for an early conclusion of the China–GCC Free Trade Agreement, which would further boost bilateral industrial cooperation.

The coordination of China–GCC economic and industrial policies has also been strengthened by the establishment of joint institutions: the China–Arab States Cooperation Forum, China–GCC Strategic Dialogue, the China–GCC Joint

Economic and Trade Committee, the Sino-Arab Economic and Trade Committee, and the China–GCC Trade Cooperation Forum. Similar bilateral structures were also created with individual GCC countries, including the China–Oman Joint Committee on Economics and Trade, the China–Qatar Business Council, and the China–Kuwait Friendship Association.

These groundwork measures are already starting to have an impact. During the recent session of the China–Arab States Cooperation Forum, China and Saudi Arabia signed industrial cooperation agreements in excess of $10 billion in total value for the production of electric vehicles, trains, chemicals, and steel. Notably, industrial deals comprised most of the total $10+ billion in deals signed at the forum (ZAWYA 2023b), nearing the total inward FDI received by Saudi Arabia in 2022. This highlights the significant potential for regional industrial capacity development, which could be unlocked with China's participation.

With the policy measures and infrastructure largely in place, China–GCC industrial cooperation is starting to gain traction. Based on the current state of affairs and the trajectory of joint China–GCC industrial development, progress in the following areas could enhance the pace of this development and its outcomes:

- Utilizing the location, logistical capacities and resources of the GCC countries in developing global industrial supply chains that target markets beyond China and the GCC.
- Localizing the production of components for joint energy, petrochemicals, and logistics projects.
- Enabling Chinese SMEs to capitalize on the potential of the GCC's various SEZ, economic cities, and other incentives, such as local content requirements.
- Aligning industrial standards in conventional industries and developing joint approaches to standardization in emerging sectors such as biotechnology, new-generation information technologies and transportation technologies, among others.

Notes

1 The "going out" or "going global" strategy was first announced by Jiang Zemin in 2000 with the aim to encourage domestic enterprises to invest overseas.
2 The "opening up" strategy refers to the broad economic reforms that began after Mao Zedong's death in 1976.
3 These data comprise items under HS Code 84, except for items pertaining to agriculture, the power sector, and appliances.
4 These data comprise items under the HS Code 68.
5 The percentage of problematic investments attributed to industrial cooperation approximately matches its share of total BRI investments, indicating that this domain is not the most problematic one.
6 To cite only a few examples: ANI (2021), Foreign Policy (2023a), and Reuters (2021).

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6 Infrastructure Cooperation Between China and the GCC

Xia Sun and Nora N. Nezamuddin

Introduction

The GCC countries have seen substantial infrastructure advancements, which have contributed to their continued economic growth over the years. Their continued population growth, economic transformation, manufacturing growth, and industrial growth require large-scale infrastructure and construction booms in new cities. From solar power plants and acetylene plants to refineries and pipelines, investments in the GCC need to match the large-scale infrastructure projects. Before discussing the future needs of the GCC countries, an understanding of the current status of critical infrastructure such as transport, energy, and communication systems is necessary. Typically, "infrastructure" is defined as "interrelated physical components that provide goods and services that are essential to enable, maintain, or improve living conditions in society" (Fulmer 2009). This chapter limits its focus to transport connectivity, energy pipelines, and the communications network and does not consider soft infrastructure such as education, culture, law enforcement, and other services. The authors examine the role China plays in the GCC's ongoing infrastructure expansion and regional connectivity efforts.

This chapter first highlights and provides a comparative analysis of current infrastructure development in the GCC countries, including transportation, energy, and communication. It then discusses China's role in current and future infrastructure development in the GCC. The third section highlights challenges to the success of infrastructure cooperation between China and the GCC. Finally, it provides policy recommendations for both Chinese and GCC parties and concluding remarks.

Overview of Key Infrastructure Developments in the GCC

Transportation System

The transportation systems in the GCC countries are generally developed and include transnational highways, railways, airports, seaports, and public transit. However, each GCC country has a varying degree of transport network connectivity. Currently, the main form of land-based connectivity between countries is personal cars for passenger movement and trucks for cargo movement. Figure 6.1

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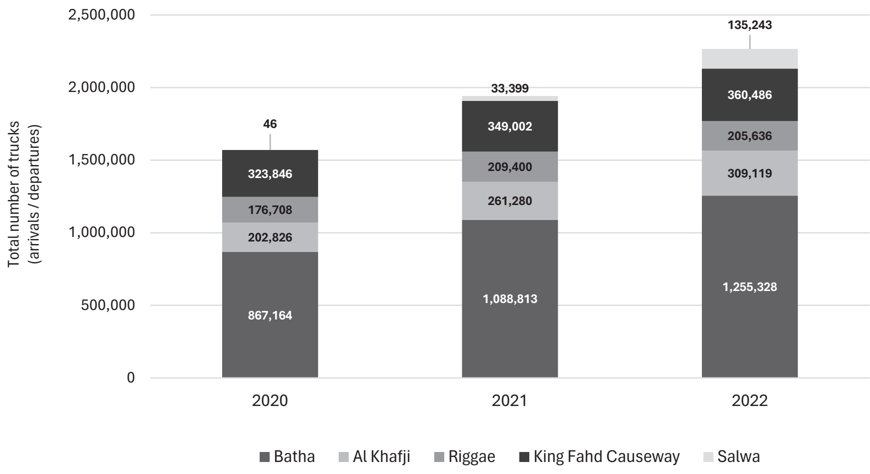

Figure 6.1 Truck movement through GCC land ports.

Source: GaStat (2023).

depicts the total throughput of trucks at the five key land ports (customs borders) that connect the GCC countries, sourced from the Saudi General Statistics Authority's (GaStat's) Statistical Yearbook 2023 (GaStat 2023). The five land ports include Riggae, Al Khafji, the King Fahd Causeway, Salwa, and Batha (Figure 6.1). Both Riggae and Al Khafji are located on the Kingdom of Saudi Arabia (KSA)–Kuwait border. The King Fahd Causeway is a bridge connecting Saudi Arabia to Bahrain, facilitating both passenger and freight movement. Salwa is a customs border between the KSA and Qatar. Finally, Batha is the customs border connecting the KSA and the United Arab Emirates (UAE). Batha also serves as the access point between the KSA and Oman since there is no direct land port between the two countries. In 2022, the Batha land port accounted for around 55% of the GCC's total truck throughput, followed by 16% via the King Fahd Causeway, and 14% via the Al Khafji land port. The normalization of relations between the KSA and Qatar in January 2021 increased the number of trucks transiting via Salwa from 46 in 2020 to 135,243 in 2022.

Infrastructure projects such as transnational railways are being constructed to increase the overall land-based connectivity among GCC countries. One example is the high-speed electric passenger railway project agreed between Saudi Arabia and Qatar in December 2025 which seeks to connect King Khalid International Airport in Riyadh with Hamad International Airport in Doha via key cities such as Dammam and Al-Ahsa (Saudi Press Agency 2025). Another example is the GCC Rail Network, which has been discussed intermittently since 2017, with an interruption of discussions during the COVID-19 pandemic. In 2021, the GCC Secretariat announced the continuation of the project, with the GCC

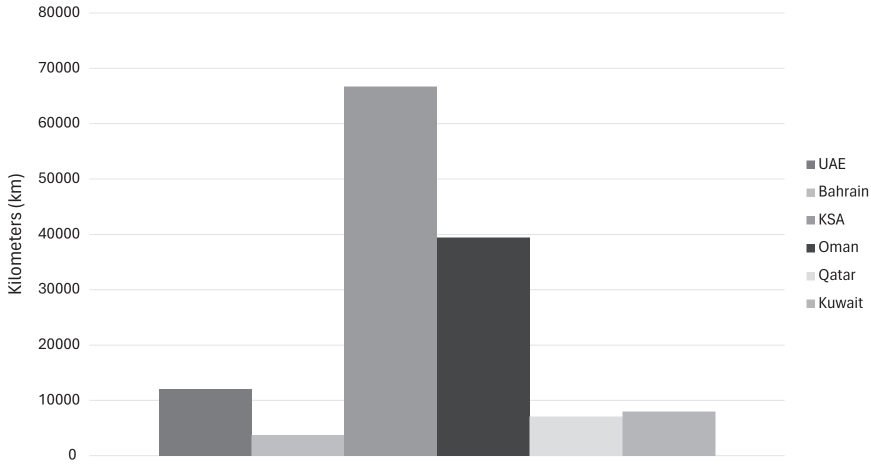

Figure 6.2 Constructed roads in the GCC.

Source: GaStat (2023).

Rail Authority (GRA) established in 2022 (Iqbal 2023a). Discussions have been made between the GRA and the respective representative countries. For example, in July 2023, Bahrain's Ministry of Transportation and Telecommunication met with the GRA to discuss rail connectivity between the two countries. The network is projected to extend an estimated 21 kilometers (km) into Saudi Arabia and an estimated 24 km into Bahrain (Iqbal 2023a). Saudi Arabia has approved a rail line linking Riyadh and Kuwait City with high-speed trains (ZAWYA 2023a). The portion of the GCC Rail Network connecting the UAE and Oman has also progressed. The Oman–Etihad Rail Company was established in 2022 to implement the estimated 303 km network linking the two countries (Iqbal 2023a). Finally, a rail connection between Saudi Arabia and Qatar is being considered as part of the GCC Rail Network.

Intercontinental transport networks have been proposed that use the GCC countries as a key link, further enabling the export and transshipment of the GCC's hydrocarbons to Asian and European markets. In September 2023, the Group of 20 (G-20) Summit announced the signing of a memorandum of understanding between Saudi Arabia, the United States, the European Union, India, the UAE, France, Germany, and Italy to develop the India–Middle East–Europe Economic Corridor (IMEC) (Bhatt and Roychoudhury 2023). The IMEC aims to enable mutual development and economic growth in Europe, the Arabian Gulf, and India. It will consist of two separate corridors, connecting India to the Gulf in the east and the Gulf to Europe in the north. To achieve the larger goal of international interconnection, a number of GCC countries have been working toward increasing their domestic transport network connectivity and enhancing the modality within their countries (Bhatt and Roychoudhury 2023).

Saudi Arabia

Saudi Arabia has history of establishing strong road connectivity, with an estimated 66,695 km of constructed roads (Figure 6.2). The KSA ranks first for road connectivity in the World Economic Forum's (WEF's) "2019 Global Competitiveness Report" (GCR). However, Saudi Arabia ranks 26th for the quality of its road infrastructure. Additionally, the KSA's transport infrastructure is ranked 34th out of the 141 countries in the WEF's report and 4th out of the six GCC countries (Schwab 2023).

Saudi Arabia is the only GCC country with an interregional rail network. It has an estimated 5,000 km of railways connecting different parts of the country. Notable rail networks include the North Train which connects Riyadh Province with the Northern Borders Province, the East Train connecting Riyadh Province to the Eastern Province, and finally the Haramain High Speed Rail connecting the Holy sites in Makkah and Madinah provinces. However, given Saudi Arabia's large size, its railway network is considered insufficient, with the country ranking 126th in railroad density. The country ranks 26th for the efficiency of its train services (Schwab 2023).

Saudi Arabia has 28 airports, 14 of which serve international and domestic flights, and the other 14 serve only domestic flights. The KSA's airport connectivity is ranked 24th globally, or 2nd in the GCC countries, behind the UAE. However, Saudi Arabia ranks 34th globally for the efficiency of its air transport services, behind the UAE, Qatar, and Oman (Schwab 2023).

The KSA currently has 10 seaports spread across the Red Sea coast to the west and the Arabian Sea coast to the east. The King Abdullah Port in the King Abdullah Economic City (KAEC) is the only privately owned and operated port in the country. Saudi Arabia is ranked 21st globally for its shipping liner connectivity but ranks 40th for the efficiency of its seaport services, behind all GCC countries except for Kuwait (Schwab 2023). Given Saudi Arabia's current transport situation, the National Transport and Logistics Strategy set by the Ministry of Transport and Logistics Services outlines key targets to improve the overall transport network, aiming to establish the country as a transport and logistics hub.

UAE

The UAE's transport infrastructure ranks 8th out of 144 countries in the WEF's GCR, the top ranking GCC country. It ranks 23rd for road connectivity but 7th for the overall quality of its roads, ahead of all other GCC countries (Etihad Rail 2024). The UAE has an estimated 12,000 km of constructed roads (Figure 6.1). The UAE does not hold a rank for rail transport because most of its interregional railway was established between 2020 and 2023 by Etihad Rail, the national railway company, after the publication of the WEF's report. Today, the UAE has about 900 km of railways, connecting all seven emirates and forming part of the larger GCC Rail Network (Etihad Rail 2024). The UAE also ranks the highest among the GCC countries in aviation, ranking 19th out of 144 countries for airport connectivity and 7th for the efficiency of its airports' services (Etihad Rail 2024). This is because the UAE's Dubai International Airport (DXB) and Zayed International Airport (AUH) are among the busiest airports globally, with the DXB ranking 1st in international passenger traffic since 2019 (Airports Council International 2024). In terms of its maritime sector, the UAE boasts 12 commercial seaports that play a significant role in the country's economy. In 2021, Jebel Ali port in Dubai was ranked as the 11th container port globally by the World Shipping Council in terms of volume (World Shipping Council 2019). The UAE ranks 12th for the efficiency of its seaport services and 13th for its shipping liner connectivity.

Qatar

Qatar ranks 19th in the WEF's GCR for its transport infrastructure, the third-highest ranking in the GCC after the UAE and Oman. Qatar's road connectivity ranks 18th while the quality of its road infrastructure ranks 16th, with around 7,000 km of roads constructed (Figure 6.1) (Schwab 2023). Similar to the UAE, Qatar's railway infrastructure was completed after the publication of the WEF's GCR in 2019; therefore, the country's railway system is not ranked. However, as part of its preparation to accommodate the large volume of spectators during the 2022 FIFA World Cup, and as part of Qatar National Vision 2030, the country built a 76 km metro system, linking different parts of the capital city Doha (Metro Doha 2024). Qatar has one of the busiest airports in the world. An estimated 45 million international passengers travel through Doha International Airport annually, making it the 9th busiest airport in 2023 (Airports Council International 2024). Qatar ranks 32nd for airport connectivity and 14th for the efficiency of its air transport services. Finally, in terms of its maritime sector, Qatar boasts six seaports, ranking 42nd for shipping liner connectivity and 15th in seaport services efficiency.

Oman

Oman is the second-highest-ranked GCC country in the WEF GCR's Transport and Infrastructure Index, ranking 18th, behind only the UAE. Oman has the second longest road network in the region, after Saudi Arabia, with an estimated 39,444 km of roads and ranking 15th in the GCR (Figure 6.1) (Schwab 2023). Oman is ranked 10th out of 144 countries for the quality of its road infrastructure, reflecting the prioritization of infrastructure by the Omani government. The country does not currently have an existing railway network. However, as part of its agreement with other GCC countries to develop the GCC Rail Network, Oman has established its own national rail company, Oman Rail. It has signed a $3 billion agreement with the UAE's Etihad Rail to develop a 303 km line linking the UAE with the port of Sohar (Oman Rail 2024). Oman has five airports; its airport connectivity is ranked 47th, while the efficiency of its airport services is ranked 29th. Oman has six seaports, with the port of Salalah and the port of Sohar playing important roles for the country. Oman ranks 24th for shipping liner connectivity and 22nd for the efficiency of its seaport services (Schwab 2023).

Bahrain

Bahrain ranks 35th overall for transport and infrastructure in the WEF's GCR, second lowest after Kuwait. Bahrain is not ranked on its road connectivity, although the country boasts an estimated 3,714 km of constructed roads (Figure 6.1). However, the quality of its road infrastructure is ranked 24th (Schwab 2023). Bahrain does not have a railway transportation system, but it is currently working on pre-qualification packages for the construction of a planned 109 km metro system to address the growing need for improved mobility in the country (Bahrain Ministry of Transportation and Communication 2024). Bahrain boasts one major international airport, Bahrain International Airport (BIA), which was established in 1927, making it the first airport in the Arabian Gulf. The connectivity of its airport is ranked 45th in the WEF's GCR, while the efficiency of its air transport systems ranks 115th, which is considerably lower than other GCC countries (Schwab 2023). The total passenger movement in the second quarter of 2024, reported by Civil Aviation Affairs, was 731,434, while total cargo and mail movement in the same period was 33,004 (Bahrain Ministry of Transportation and Communication 2024). Bahrain has 14 seaports with varying degrees of commercial and non-commercial activity. The Khalifa bin Salman Seaport is an important commercial port for Bahrain, serving as the country's key transshipment hub. Bahrain ranked 50th for its shipping liner connectivity and 28th for the efficiency of its seaport services.

Kuwait

Kuwait is the lowest overall ranking GCC country in the WEF's GCR, placing 79th out of 144 countries. Its road connectivity is its strongest metric, ranking 17th, with around 7,994 km of constructed roads. However, Kuwait ranks 84th for the quality of its road infrastructure, behind all other GCC countries (Schwab 2023). Like Bahrain and Oman, Kuwait does not have an existing railway network. However, the country is working with Saudi Arabia to develop a rail link between the two countries, which would also integrate into the larger GCC Rail Network and is expected to be 650 km long (Gulf Business 2024). The project is expected to be completed by 2028 and will have three phases of implementation.

Kuwait has one commercial airport, Kuwait International Airport (KWI), and several private airports. KWI is ranked 45th in the WEF's GCR for its connectivity, and 115th for the efficiency of its air transport services. Kuwait has three seaports, with Shuwaikh Seaport serving as the country's key commercial port. Kuwait ranks 79th for its shipping liner connectivity, behind all other GCC countries. Its seaport services, ranked 93rd, also place below all other GCC countries.

Energy Infrastructure

The Gulf region boasts a comprehensive energy system infrastructure, including oil and gas pipelines, tankers, and refineries. However, this infrastructure, while valuable, is vulnerable to natural or manmade hazards; a major concern for the region's main oil-exporting countries (Soltvedt and Kinnear 2022). For example, Saudi Aramco's infrastructure, including its refineries and power stations in northern Jeddah, has been repeatedly hit by missiles. Oil and gas sectors have been identified as the most vulnerable energy sources in both Abu-Dhabi and Dubai (Al Kaili, Pathirage, and Amaratunga 2014). In 2020, the GCC countries accounted for about 42% (GCC-Stat 2023) of total global oil exports, indicating that hydrocarbons still play a key role in the economic growth and stability of most GCC countries.

Of the six GCC countries, Qatar and Oman are net natural gas exporters. However, other GCC countries, that have not traditionally had strong natural gas sectors, such as Kuwait and Saudi Arabia, have made attempts to build natural gas pipelines. Existing natural gas pipelines in most of the Gulf region are still unable to meet natural gas transportation needs. In 2019, Saudi Arabia announced an integrated gas grid with its Gulf neighbors, but so far there has been no progress on the project. If a Gulf natural gas network is realized, it will not only meet local natural gas demand, it will also integrate the region's natural gas resources, enabling their export through terminals in the Arabian Gulf, Gulf of Oman and Red Sea (Alsayegh 2023). The GCC Interconnection Authority (GCCIA), established in 2001, is responsible for connecting, operating and maintaining the power grids of the six GCC countries, and it is the regulatory agency for the region's electricity trading market (Al-Mohaisen 2005). The interconnected grid has been fully operational since 2010, providing the region with a foundation for a clean energy transition.

Communication Systems

Communication systems and digital infrastructure are key to achieving energy targets such as sustainability and efficiency. However, communication systems are vulnerable to attacks and, as such, require increased built-in security and resilience. Gulf countries have made significant progress in digital innovation over the past decade, accelerated by the COVID-19 pandemic, adopting digital technologies at scale for consumer, business, and government applications (Geronimo 2022). Information and communication technology systems (ICT) are widely used in GCC countries' smart grids, smart agriculture, government services, tourism, e-commerce, telemedicine, and smart cities, among other applications.

As Gulf States begin to diversify away from being solely hydrocarbon-based economies to knowledge-based economies, information and communications technology will be an important sector driving economic diversification. The size of the GCC's ICT market was estimated to be $129.07 billion in 2024 and is expected to reach $203.09 billion by 2029, growing at a compound annual growth rate (CAGR) of 9.49% during the forecast period (2024–2029) (Mordor Intelligence 2024). To this end, the Gulf countries' ICT sectors are formulating new strategic goals and development plans to meet their targets. For example, the UAE Artificial Intelligence Strategy 2031 aims to increase productivity in the healthcare, transport, technology, renewable energy, education, environment, and transportation sectors as part of the government's goals to mark the UAE's 100th anniversary. Cloud computing provider Amazon Web Services (AWS) has hired account managers, solutions architects, professional services consultants, support staff, and other functions to support customers after launching its first Middle East data center in Bahrain (Mordor Intelligence 2024). Currently, the main ICT industry competitors in the

GCC include Google, IBM, Microsoft, HP, SAP, Oracle, and Amazon, among others. China's Huawei and Alibaba Cloud have also now entered the Gulf ICT market.

China's Role and Participation in Key Infrastructure Construction in the GCC

In January 2016, the Chinese government issued the "China Policy Document on Arab Countries," expressing its desire to cooperate with Arab countries in several areas of interest. In the field of infrastructure construction, the document states that "Chinese enterprises and financial institutions are encouraged and supported to expand their participation in cooperation with Arab countries in the fields of infrastructure construction such as railways, highways, ports, aviation, electricity, communications, [among others]" (Government of China 2016). Since then, the participation of China in infrastructure construction in the GCC has accelerated. China has signed Belt and Road Initiative (BRI) cooperation documents with all 22 Arab countries and the Arab League, with the Gulf countries the first to sign national strategic alignments with China. Since Chinese state-owned banks can finance projects related to the BRI, this gives China financial and cost advantages when bidding.

The GCC has more than $2 trillion dollars in infrastructure-related projects underway, of which Chinese companies have invested over $6.5 billion dollars (Howlett 2019). In 2023, Saudi Arabia scored 131 in the Belt and Road Infrastructure Development Index, placing 3rd among the 85 BRI partner countries, and improving two places from 2022. The UAE scored 124, ranking 6th, up five places from 2022. As a bloc, the GCC also ranked high in the infrastructure index (Table 6.1) (Howlett 2019).

Chinese companies are actively bidding and have already won a number of new infrastructure projects in the GCC, including railway construction in the KSA and the UAE. The restart of the GCC Rail Network project, and the launch of the GCC Railway Authority to oversee the implementation of the project and ensure the adoption of common technical specifications and unified standards, provides opportunities for Chinese railway companies. These companies have extensive experience in building high speed rail on complex terrain and can ensure seamless rail connections in deserts, mountains and coastal areas (Iqbal 2023b).

From a digital infrastructure perspective, GCC countries will accommodate a growing number of fifth-generation (5G) telecommunications network users, with a projected market size of $16.4 billion annually for ICT products by 2025 (Zinser 2020). The Digital Currency—Multilateral Central Bank Digital Currency Bridge (m-CBDC), currently in its development phase, could facilitate cross-border transactions and payments. China has become a global leader in certain areas of the digital economy, with Chinese tech giants as well as major telecoms and infrastructure providers participating in the digital transformation of the GCC. These companies provide a wide range of technologies from end-user devices to servers, mobile infrastructure, and cloud platforms (Calabrese 2022). Digital economic cooperation has become an important part of the relationship between China and the GCC countries, and China has considerable investment potential in the Gulf's digital infrastructure and ICT markets.

Table 6.1 Infrastructure investment environment and investment prospects in the GCC countries (as of the end of 2022)

Countries	*Strategic relationship*	*National vision*	*Scale of trade with china ($ billion)*	*China's investment scale stock ($ billion)*	*Infrastructure development index ranking*	*Investment prospects*
Saudi Arabia	Comprehensive strategic partnership	Vision 2030	Largest trading partner country (116.0)	3.0	3	Inter-city highway and railway construction; photovoltaic and power grid construction
UAE	Comprehensive strategic partnership	UAE 2031	Second-largest trading partner country (99.3)	11.9	6	Solar, hydrogen and liquefied natural gas (LNG)-related infrastructure
Qatar	Strategic partnership	2030 National Vision	Largest trading partner country (26.6)	0.9	38	LNG export infrastructure
Kuwait	Strategic partnership	2035 National Vision	Largest trading partner country (31.5)	1.0	56	Renewable energy sources such as ports and electricity
Oman	Strategic partnership	Vision 2040	Largest trading partner country (40.5)	0.3	64	New wind energy power station
Bahrain	General diplomatic relations	2030 Economic Development Vision	Third-largest trading partner country (2.0)	0.1	83	Transport and digital infrastructure
GCC countries	China shipping strategic partnership	GCC Long-Term Comprehensive Development Strategy (2000–2025)	Largest trading partner (315.8)	17.2	2/8 (Western Asia and North Africa)	Tourism, railways, power grids

Sources: Compiled from the websites of the Ministry of Foreign Affairs and the Ministry of Commerce of China, China's "One Belt and One Road" website, "'Belt and Road' Joint Construction National Infrastructure Development Index Report," and other data.

Saudi Arabia

In December 2022, the Chinese and Saudi Arabian governments signed a comprehensive strategic partnership, aligning the BRI with Vision 2030, and deepening the consensus on promoting cooperation between the two countries in infrastructure and other construction projects. Saudi Arabia plans to invest $45 billion in a national railway network, making it possible for China to invest in and contract transportation infrastructure projects in Saudi Arabia (Ronghan 2022). At the China-Saudi Arabia Business Forum on August 16, 2023, Chinese companies and banks signed 12 infrastructure development and financing agreements with Saudi Arabia, worth more than 500 million Saudi riyals (SAR) ($1.33 billion) (ZAWYA 2023b).

Chinese companies are currently involved in several land-based transportation infrastructure projects in the KSA. The first was the signing of an agreement in February 2023 between Hafil, a Saudi transportation service provider, and Hong Kong-based Kwoon Chung Bus Holding (KCBH) to operate the interregional bus service, Darb Al-Watan (TGA 2024). The bus service covers the central, eastern, and northeastern regions of Saudi Arabia, with 99 stops along 26 routes and 75 destinations (TGA 2024). The second infrastructure project with Chinese involvement is the infamous Saudi Landbridge railway project, which is intended to link the country's western and eastern ports via the capital, Riyadh. Although the Landbridge project has been intermittent since its inception in the mid-2000s, the project was reignited in 2023 under an agreement between the Saudi Transport General Authority (TGA) and the China Railway Construction Corporation (CRCC). In October 2023, China Construction Seventh Engineering Bureau won a bid to work on the Saudi NEOM tunnel project. The project, currently the largest transportation and public infrastructure project in the KSA, is located in Tabuk Province and includes the construction of a 3,452-meter-long high-speed passenger railway tunnel and four connecting passages. The project is the first large-scale infrastructure project undertaken by China Construction Seventh Engineering Group Corporation in the Saudi market (CICCC 2023).

Saudi telecom company Mobily has signed a memorandum of understanding with China's Huawei to cooperate on cloud services and enhance their digital and Internet of Things (IoT) business-to-business (B2B) products. The KSA has signed agreements with relevant Chinese companies and institutions to cooperate on constructing smart cities and developing artificial intelligence (AI) technology. Technology giants including Alibaba and Huawei will also work on the world's largest photovoltaic energy storage project in the Red Sea region of Saudi Arabia. Additionally, Huawei is working with the Ministry of Hajj and Umrah to develop digital infrastructure to streamline the pilgrimage to Mecca, including control rooms at reception centers in Mecca and Medina. The Jollychic platform, an e-commerce application in the Gulf, has expanded its services in Saudi Arabia by creating a digital payment wallet. It plans to expand its ecosystem to include on-demand food delivery, online travel and transportation booking. Alibaba has been significantly expanding its operations in Saudi Arabia, with the Saudi Data and Artificial

Intelligence Authority signing an agreement to receive intelligence-driven smart city solutions for Saudi cities. Saudi Arabia's National Center for Artificial Intelligence will work with Huawei to train local AI engineers to ensure a skills pipeline that supports a diverse and data-driven economy.

UAE

In May 2010, China and the United Arab Emirates signed a $3.4 billion agreement as part of the BRI to promote cooperation on railway construction, engineering, and technical exchanges, among others (China Daily 2010). China is the UAE's second-largest trading partner, with the latter an important gateway and transportation hub for Chinese goods exported to the Middle East. According to the United Nations Conference on Trade and Development's latest report on the global economy, foreign investment projects in the UAE surged by 28% in 2023, second only to the United States. This highlights the UAE's enduring investment appeal, reflecting its competitive advantage and ability to attract talent (TradeArabia 2024).

The main UAE projects awarded to Chinese contractors include the Bab Oilfield project, constructed by the China Petroleum Engineering and Construction Corporation (CPECC), Dubai Branch, in 2017. In November 2018, the Abu Dhabi National Oil Company (ADNOC) signed a liquefied oil and gas sales agreement with China's Wanhua Petrochemical Group to build the world's largest underground liquefied oil and gas reserve. The Dubai Electricity and Water Authority signed an investment agreement with China's Silk Road Fund to build the world's largest solar power plant. Dubai World Ports (DP) World and Zhejiang China Commercial City Group signed an investment agreement to build a 3 square km trade market in the Jebel Ali Free Trade Zone.

In 2017, China Ocean Shipping Group Company (COSCO) made its first investment in the Middle East, participating in the expansion of Khalifa Port. The project used AI technology and successfully launched the first unmanned card collection station at a Middle East terminal.

Qatar

In 2022, the bilateral trade volume between China and Qatar was $26.55 billion, a year-on-year increase of 54.7%. At the end of 2022, the direct investment stock of Chinese enterprises in Qatar was $940 million. The HBK Contracting Company and the China Railways Construction Corporation undertook the construction of the Lusail Stadium, the main stadium of the 2022 FIFA World Cup in Qatar.

Developing a liquefied natural gas (LNG) export business is an important national strategy for Qatar. The Qatari-China LNG trade dates back to 2009 when China received its first shipment of gas from Qatar (Qarjouli 2022). In 2022, Sinopec and the Qatar Energy Company (QEC) signed a 27-year LNG purchase and sale agreement in which the QEC will supply 4 million tons of LNG to Sinopec annually (Downs, Mills, and Nie 2023).

In 2023, the QEC stated that Sinopec will invest in the eastern expansion of Qatar's North Field LNG project, which will hold the equivalent of 8 million tons of annual production capacity (Sinopec will take a 5% stake in the equivalent of one North Field East LNG train) (El Dahan and Mills 2023). Qatar's northern oil and gas fields are part of the world's largest gas field, which Qatar shares with Iran. The Iranian section of the field is known as the South Pars field. The QEC signed six northern oil and gas field expansion deals in 2023. So far, Chinese companies have limited direct investments in Qatar, but there is room for investment and cooperation in future LNG projects.

Kuwait

In 2023, the leaders of Kuwait and China jointly witnessed the signing of the "Joint Statement on the Five-Year Plan for Bilateral Cooperation Between the People's Republic of China and the State of Kuwait (2024–2028)" as well as a number of bilateral cooperation agreements for renewable energy, infrastructure construction, environmental governance, and other fields (MoFAPRC 2022). China's BRI infrastructure plan and Kuwait's 2035 Economic Diversification Plan share a common goal of forming a vibrant global trade area. Kuwait's 2040 Economic Zone requires large-scale infrastructure construction, with major project bids totaling $30 billion. Infrastructure cooperation between China and Kuwait can support energy cooperation, e-commerce, and the construction of smart cities. In addition, the Kuwait Investment Authority (KIA) opened a second office in Shanghai, expanding its financial investment in China and becoming the first foreign investor in China's high-speed rail network.

Kuwait's nationwide commercial 5G network, built in cooperation with Huawei, is the first such network in the Middle East and will provide a strong impetus for Kuwait's economic transformation. During the opening of the Hangzhou Asian Games in 2023, Kuwait Crown Prince Sheikh Mishal Ahmed Al-Jaber Al-Sabah visited China and signed a memorandum of understanding aimed at enhancing bilateral cooperation on environmental infrastructure for sewage treatment plants, electric energy systems and renewable energy development, the Mubarak Kabir port project and the construction of economic zones (ZAWYA 2023c). More than 40 Chinese companies are actively contributing to Kuwait's national development projects (ZAWYA 2023d).

Oman

Oil and natural gas are Oman's traditional pillar industries. Oman has implemented economic liberalization policies in recent years to attract foreign investment and increase investment in infrastructure construction (Salami 2023). In 2011, the Duqm Special Economic Zone (SEZ) was established in Oman, covering an area of 2,000 square km and a coastline of 80 km. It is currently the largest SEZ in the Middle East and North Africa (MENA) region. In 2017, the China–Oman (Duqm) Industrial Park constructed by Ningxia held an infrastructure foundation laying ceremony (Tuo 2017). The park is located in the Duqm SEZ, covering an area of 11.72 square km. The project was planned, constructed, funded, and operated by China-Afghanistan Wanfang Investment Management Company. As of 2024, many companies from the petrochemical, renewable energy, and pharmaceutical industries have settled in the Duqm SEZ.

Bahrain

Bahrain plans to upgrade some of its existing infrastructure in order to improve its service capabilities and quality. This includes the expansion of the BIA, with an increase in annual passenger capacity from 9 million to 14 million, developing a new oil pipeline from Saudi Arabia to Bahrain, adding a new LNG receiving terminal, constructing a metro rail line to enhance connectivity, constructing a pipeline connecting Bahrain, Saudi Arabia, and Qatar, and maintaining and reconstructing some of its highways.

Several Chinese firms have qualified to bid for the development of the first phase of the metro network in Bahrain. These include the China Railway Construction Cooperation, CRRC Hong Kong, the China Railway Group, and the China Harbor Engineering Company (Levesque 2023). China's Huawei is headquartered in Bahrain, and the China Harbor Engineering Company and the Jangho Group Company all have offices in Bahrain, Chinese companies are expected to participate in Bahrain's future airport, railway, and other infrastructure projects.

Challenges Facing China–GCC Infrastructure Cooperation

Chinese financial institutions first entered the Gulf region when the Bank of China opened a branch in the Dubai Financial Center. Chinese banks won major contracts in the Gulf by bidding for large-scale infrastructure construction projects, especially road construction. However, Chinese investments also compete against GCC country investments in places such as Africa and South Asia. For example, DP World, an Emirati port operator, is in direct competition with its Chinese counterpart for a contract tender to operate the port of Djibouti. The signing of a memorandum of understanding between the two parties can serve as a co-investment commitment for joint investment (Mohamedbinzayed.ae 2024). Another source of competition for China to keep in mind is the signing of the IMEC agreement, which could potentially undermine the cooperation agreements established under the BRI.

Korean companies have also become competitors for Chinese investment in the KSA and UAE, especially on some large-scale water treatment facilities and power plant projects, with Korean companies such as the Korea Electric Power Company (K EPCO) winning construction contracts. In 2023, the Saudi Fund for Development (SFD) and the Asian Infrastructure Investment Bank (AIIB) signed an agreement for the KSA to contribute $10 million to support the bank's new financing plan for the Least Developed Countries (LDCs) (ZAWYA 2023e). Cooperation between Gulf financial institutions and international financial institutions such as the AIIB can help the latter bridge the funding gap and support LDC infrastructure construction and other production sectors.

Local conflicts continue in countries surrounding those of the GCC, posing security risks to local investment. The new round of conflicts in the region has caused disruptions to key Red Sea routes, which has affected the path of seaborne trade along the East-West Corridor. If the conflict in the region spreads further, this could pose a risk to GCC infrastructure and, in turn, a risk to Chinese investments in the region. These types of security challenges highlight the need for continued resilience in infrastructure development.

Conclusions and Policy Recommendations

Suggestions for Cooperation between Both Parties

In view of the security risks faced by strategic maritime passages, China and the GCC countries should cooperate with India and Central Asian countries to build a land passage through Eurasia. This would require massive investment in infrastructure construction, such as cross-border roads, railways, ports, pipelines and shipping. Both China and India are highly dependent on energy imports from Gulf countries. Cooperating with India to build intersecting land passages and pipelines could help enable energy resource integration between the Caspian Sea and Gulf regions. There are several existing forums that can be utilized to create such strategic partnerships, such as the BRICS (Brazil, Russia, India, China, and South Africa) bloc, which has been expanded to include the KSA, Iran, and the UAE, among other countries, and the Shanghai Cooperation Organization (SCO) (where Iran and India are members). It is important to recognize that existing bilateral and multilateral I agreements may have overlaps. It is also important to reduce redundancies by merging or combining agreements in order to push partnerships forward.

The free trade agreement between China and the GCC will not only increase the volume of trade between the two parties, but its spillover effects will also promote economic cooperation and economic integration within the GCC. Currently, free trade negotiations between the United Kingdom and the GCC are ongoing, and a breakthrough is expected soon (Al Arabiya 2023). Negotiations on a free trade area between the GCC and India have also resumed. China is the GCC's largest trading partner, but it has yet to reach a free trade area agreement with the bloc. Both sides should analyze the main reasons for the obstruction of free trade zone negotiations, speed up these negotiations, and sign an agreement as soon as possible.

In terms of increasing and maintaining infrastructure security, the United Nations' peacekeeping initiatives include facility security, naval security operations in the Red Sea, and maintaining the security of other sea lanes. To protect the security of key infrastructure in the Gulf region and safeguard China's local trade and investment interests, China–Gulf cooperation must be expanded to the security field. The military forces of China and the GCC countries could participate in peacekeeping and escort missions under the United Nations framework to protect the common interests of both parties. This would be beneficial for both parties, given the volatile situation in the Middle East, with more countries becoming engulfed in an escalating situation.

Recommendations for China

The main criticisms faced by the Belt and Road Initiative include concerns about debt sustainability, transparency, environmental and social impacts, geopolitical motivations, labor and human rights, consultation processes, and its implications for global trade and governance. Addressing these criticisms is critical for China to ensure the BRI's long-term success and sustainability. Measures such as increasing transparency, conducting comprehensive risk assessments, promoting sustainable practices, prioritizing local ownership and interests, and promoting meaningful consultations with local communities and governments can help address these issues and promote the BRI's next phase. To this end, construction quality standards, environmental management system standards and decarbonization standards for local construction projects in the GCC should be developed and followed during the construction phase of infrastructure projects (ZAWYA 2023f). China could also consider joining the IMEC agreement to bolster partnerships between itself, GCC and European Union countries.

China proposed the Green Belt and Road project, which became the Belt and Road Initiative Green Development Coalition (BRIGC), with the purpose of strengthening the environmental supervision of infrastructure development. However, all infrastructure projects, whether coal power, clean energy, or other infrastructure projects, will have a certain degree of environmental impact. Developing unified and consistent construction standards and environmental protection standards is the key to promoting successful project implementation. Otherwise, China's infrastructure construction in the Gulf region will still be restricted by the rules of its investment and contracting partners.

At present, most of the infrastructure construction and investment projects acquired by China are obtained through subcontracting. Quality standards, environmental protection management and decarbonization standards are all formulated by the contracting party and the general contractor. Once violations are found during the construction process, costs rise, resulting in project delays. To this end, Chinese companies should negotiate these standards as the main content of the bid document when bidding to prevent projects from being blocked due to non-compliance with standards or violations during the implementation process. Additionally, Chinese companies should be involved in the planning phase of construction by providing digital management services and during the maintenance phase by providing safety and security services.

Recommendations for GCC countries

Furthering economic integration between the GCC countries can help increase the security of the bloc. One example of economic integration is the GCC grid interconnection project, the GCC Interconnection Authority. The project improves the efficiency of the respective power sectors, reduces the need for investment in the power industry and adds new non-fossil fuel generation capacity. Another example is the highly anticipated GCC Rail Network linking all GCC countries. Accelerating the development of this network will increase mobility between the six GCC countries and enhance the economic growth and movement of goods and people between the countries. These joint infrastructure investments will also bring economic growth to the individual GCC countries.

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7 China–GCC Cooperation Through the Lens of the Circular Carbon Economy

Mari Luomi, Xi Liang, and Fatih Yılmaz

Introduction

Countries worldwide have expressed their ambitions to reach net-zero emissions in support of the goals of the Paris Agreement on climate change. Given the wide diversity of countries' national circumstances, socioeconomic development statuses, national endowments and policy priorities, making sense of where different countries stand and how well positioned they are to make progress relative to one another is challenging. While there is no perfect way of comparing countries to each other, and all comparative approaches have their winners and losers, the circular carbon economy (CCE) provides a practical framework that takes into account diverse country contexts while allowing for holistic assessments of how countries are addressing their emissions through different technologies and approaches. It also pinpoints areas where further efforts or support are needed to enable countries to reach net-zero emissions. In this chapter, we use the examples of China, Saudi Arabia, and the United Arab Emirates (UAE), along with the economic bloc the two latter belong to, the Gulf Cooperation Council (GCC), to demonstrate how the CCE Index, a country comparison composite indicator, enables precisely this.

The need to reach global net-zero emissions to limit the negative impacts of climate change is uncontested (IPCC 2023). Countries have agreed under the Paris Agreement to do so in the second half of this century (UNFCCC 2015). The exact timing of reaching net zero collectively depends on the temperature goal targeted. To stand a reasonable chance of keeping global warming below 1.5 degrees Celsius (°C) above pre-industrial levels, the Intergovernmental Panel on Climate Change (IPCC) estimates that the world needs to reach net-zero carbon dioxide (CO_2) emissions in 2050–2060. To stay below the 2°C threshold, net-zero CO_2 needs to be reached globally by around 2070 (IPCC 2023). Countries worldwide have adopted different net-zero target years based on their considerations of capacity and equity, and the Paris Agreement also recognizes that emissions will peak later in developing countries than in developed countries (IPCC 2023). At the time of writing, in July 2024, close to 100 countries had a net-zero or carbon neutrality target in place in the form of a declaration, policy or law (ECIU 2024). China has set a target to reach carbon neutrality by 2060, and five of the six GCC countries have announced net-zero or carbon neutrality targets for 2050 or 2060 (IPCC 2023).

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However, far fewer countries have specified a strategy or put in place policies that demonstrate how they seek to achieve these targets. China has put in place a long-term strategy. Its Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy, submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2021, refers, among other things, to achieving a peak in CO_2 emissions by 2030 (UNFCCC 2024). Of the five GCC countries, so far only Oman and the UAE have communicated long-term strategies to the UNFCCC, laying out different sectoral pathways the countries could take to reach net-zero CO_2 or greenhouse gas (GHG) emissions by 2050 (UNFCCC 2024). Moreover, countries' mid-term emission targets for 2030 or 2035, which are enshrined in their nationally determined contributions (NDCs), are generally not in line with their net-zero ambitions or the goals of the Paris Agreement (UNFCCC 2023). Over time, it is expected that, under the Paris Agreement, countries will continue to raise the ambition of their NDC pledges, with developed countries leading, so that the collective level matches what is needed to achieve the goals of the Paris Agreement.

Beyond the concrete strategies, plans, and policies in place, implementing the set pledges will be the most difficult task. Global CO_2 emissions from energy reached a record high of 37.4 gigatons in 2023 (IEA 2024a). According to the IPCC, there are implementation challenges in all approaches to cutting emissions, including technology risks, scaling up and costs (IPCC 2023). Adopting low-emission technologies is more challenging in developing countries, given their overall weaker enabling environments, making it more difficult to access the technologies and financing required (IPCC 2023).

This chapter seeks to contribute to the understanding and analysis of where China and the GCC stand on their respective roads to net-zero emissions, or carbon circularity, by using the CCE Index for both framing and quantitative comparisons. The chapter starts by describing the CCE concept and explaining how it can be used for country comparisons. It then examines China and the GCC, with Saudi Arabia and the United Arab Emirates (UAE) as case studies, in two areas: first, how they are currently faring on adopting and applying various CCE technologies and approaches to reduce greenhouse gas emissions and increase carbon circularity in their economies; and second, how well their enabling environments—policies and regulation, technology, knowledge and innovation, finance and investment, business environments, and system resilience—are supporting their net-zero transitions.

The analysis conducted in this chapter shows that the performance and transition potential of the three countries—China, Saudi Arabia and the UAE—are underpinned by highly varied factors. Based on the CCE Performance scores, China has significant potential to contribute both to the deployment of clean energy and the expansion of electrification in the Gulf. Technologies in hard-to-abate sectors also present important collaboration opportunities that could further build on existing hydrocarbon trade relationships. In terms of CCE Enablers, China leads the two Gulf countries by a wide margin in two of the five dimensions: technology, knowledge and innovation; and finance and investment. Under finance and investment specifically, China has taken a significant lead compared to the UAE and particularly Saudi Arabia in the area of CCE investments, whereas the UAE has been more successful in raising sustainable debt relative to its gross domestic product (GDP). In the system resilience dimension, the UAE and Saudi Arabia perform better than China.

There are two major challenges shared by China and the GCC countries: high reliance on hydrocarbons in a context of fast economic development and a need for higher levels of CCE financing and stronger enabling environments for transition investments. In this context, and building on the findings from the 2023 CCE Index, this chapter recommends that China and the GCC countries strengthen their collaboration in four areas: constructing clean energy infrastructure; fostering technological talent; facilitating sustainable finance flows; and promoting hydrocarbon industry transformations.

Using the CCE Lens to Analyze Progress and Potential to Reach Net-Zero Emissions

The current status of countries' GHG emissions, their emission reduction targets, and even their financing needs and gaps are well documented (Yilmaz et al. 2023). However, finding a way to meaningfully compare where countries stand today in relation to their long-term emission targets and to each other remains complicated, if not contested. Under the UNFCCC, countries traditionally fall under two groups: Annex I and non-Annex I (or developed and developing), and their related historical responsibilities and different capabilities to take climate action are recognized.[1] Many countries, particularly developing ones, are reluctant to be compared with one another due to their widely differing national circumstances and development trajectories. Their unique contexts make direct comparisons challenging, especially when relying on a single metric, such as GHG emissions. Countries also have different national endowments and development trajectories and, therefore, different strengths and weaknesses in relation to net-zero transitions. As a result, each country will have a different pathway to net zero (Yilmaz et al. 2023). Another area of disagreement when it comes to comparisons is which emission reduction technologies and approaches should be used or prioritized. For example, many oil-producing countries feel excluded from transition narratives that emphasize the need to exclusively focus on renewable energy and energy efficiency.

Notwithstanding this, cross-country comparisons can be useful for various purposes, including identifying leaders and pioneers, and laggards, or those in danger of being left behind. They can also help pinpoint countries' individual strengths and weaknesses, which can help highlight where international cooperation is needed to bridge gaps. An approach that supports the widely accepted view that countries should implement all possible technologies as rapidly as feasible, and in the most cost-effective manner to mitigate their emissions, is helpful in this context. This is where the CCE concept becomes useful.

The CCE Concept

Originating in the mid-2010s (e.g., McDonough 2016), the concept of CCE has been extensively used since 2020 by scholars and stakeholders in Saudi Arabia and beyond to frame and conceptualize net-zero transitions in a language and approach that is intended to be inclusive, holistic and practical. Luomi et al. (2021, 10) have defined the CCE as an "approach to managing CO_2 (and other GHG) emissions, including ultimately achieving net-zero emissions, that considers all available mitigation options and helps identify gaps in implementation, policy and enabling environments." These scholars have used a definition of CCE that builds on the circular economy's three dimensions—reducing, reusing and recycling—and adds negative carbon emissions as a fourth "R," namely "remove" (Williams 2019).[2] The major distinction between the circular economy and CCE is that, while the circular economy focuses on flows of resources, materials, and products, the CCE focuses on flows of energy and emissions (Luomi et al. 2021).

The CCE concept covers all main mitigation technologies and approaches, from energy efficiency, renewables, and nuclear energy, to point source carbon capture and (CCS), to natural sinks and direct air capture. In essence, it is a call for policymakers and experts to holistically explore and utilize all possible technology options on the road to net-zero, and for each country to do so in a way that is most cost-effective and best fits its national circumstances and potential to reach net-zero.

The CCE Index Framework and 2023 Results

The CCE Index was developed by researchers in Saudi Arabia in 2021 to translate the CCE concept into concrete, tangible terms, measure countries' progress in reaching and potential to reach net-zero emissions, and enable policy discussions and comparisons across countries through a unified language. The CCE Index introduces an indicator-based framework that contains 38 quantitative metrics from harmonized, reputable global data sources. Each country receives a score of 0–100 on each of the indicators, which are then aggregated to form dimension, sub-index, and index scores. Since 2022, the CCE Index has included 64 countries, covering approximately 90% of the world's GDP and CO_2 emissions (Luomi, Yilmaz, and Alshehri 2021, 2022). Figure 7.1 illustrates the indicator framework of the CCE Index. The full indicator details, including scores and underlying data, as well as the index methodology and related analysis are available via the CCE Index portal: https://cceindex.kapsarc.org/.

The CCE Index measures two important areas. First, the Performance score shows how a country is currently faring on carbon circularity by gauging the breadth and depth of its engagement with various CCE technologies and mitigation approaches, known as CCE activities. The eight main CCE activities the index covers are as follows: energy efficiency, renewable energy, electrification, nuclear energy, fuel switching, natural sinks, carbon capture utilization and storage

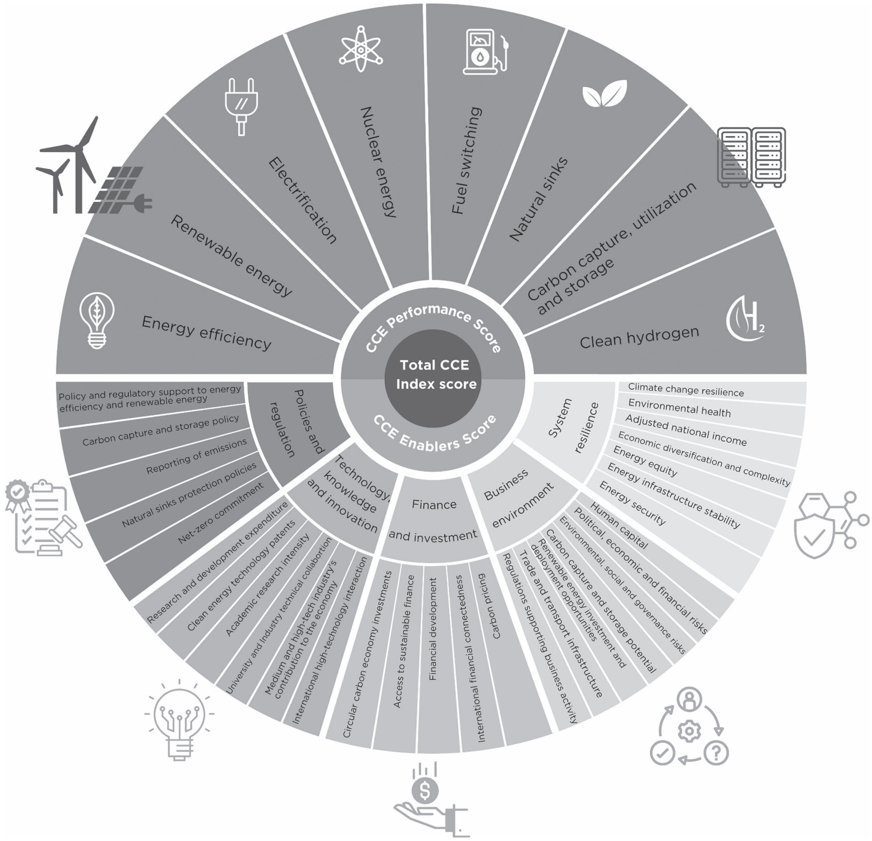

Figure 7.1 The CCE Index framework.

Source: CCE Index web portal (Alaa Alarfaj) 2023.

Note: Indicators within CCE Performance receive equal weighting, as do indicators in each of the five CCE Enabler dimensions. The dimension scores are then aggregated to form the CCE Enablers score, also applying equal weighting. The total CCE Index score is formed from the average of the Performance and Enablers sub-indices.

(CCUS), and clean hydrogen. In most cases, the maximum score (100) is derived from the average of the top performing countries' values on each indicator and, conversely, the bottom score (0) is the average of the lowest performing countries' values. An average of a country's scores on the eight CCE activities forms its CCE Performance score. Countries that perform well on three or four CCE activities generally achieve the highest scores on CCE Performance. For example, in the 2023 edition of the CCE Index, the three best ranking countries in this area, Norway, the United Kingdom, and Canada, all ranked in the top 10 on three or more indicators. Norway, for example, scored 100 in renewable energy, electrification, CCUS, and clean hydrogen.

The second score calculated in the CCE Index is the CCE Enablers score, which indicates how well a country is positioned to make progress toward carbon circularity or net zero. This is measured through five dimensions: (1) policies and regulation; (2) technology, knowledge, and innovation; (3) finance and investment; (4) business environment; and (5) system resilience. In each dimension, countries receive a score from 0 to 100 on five to seven different indicators that gauge a country's enabling environment and structural conditions. For example, under the policies and regulation dimension, indicators measure policy and regulatory support for energy efficiency and renewable energy, carbon capture and storage, natural sinks protection, emissions reporting, and net-zero commitments by national and sub-national governments. The finance and investment dimension contains indicators on CCE investments, sustainable debt issuances, financial development, foreign direct investment net flows, and carbon pricing. The Enablers score consists of the averages of the dimension scores, which in turn consist of the averages of the individual indicator scores. Consistently high scores on all dimensions generally indicate strong Enablers performance. For example, in the 2023 CCE Index, the five top-performing countries—Switzerland, Germany, the Netherlands, the United Kingdom, and Norway—ranked in the top 15 out of 64 in all Enabler dimensions. Together, the CCE Performance and CCE Enablers scores form the total CCE Index score, which is the average of these two sub-index scores (Performance and Enablers) and provides an aggregate score of how well a country is doing on the CCE by and large.

In terms of their performance on the total CCE Index, in 2023, China and the six GCC countries ranked between 16th and 49th on both sides of the median. Of the GCC countries, the UAE was 16th and Saudi Arabia is 20th, closely followed by Qatar in 21st place (for context, China was ranked 17th). The two leading and largest GCC economies, the UAE and Saudi Arabia, will be the focus of further analysis in sections 3 and 4.

As for most countries on the CCE Index, China's and all GCC countries' CCE Enablers scores were higher than their CCE Performance scores, albeit by varying margins. One way to interpret this is that countries' potential to move toward CCEs is higher than their current performance. The following sections decompose the CCE Index further into its two sub-indices (Performance and Enablers) to examine how China and the two leading GCC countries, Saudi Arabia and the UAE, are faring on the road to net-zero emissions and CCEs.

CCE Performance

This section examines the breadth and depth of China, Saudi Arabia, and the UAE's current engagement with the various CCE technologies and approaches. It does so by comparing the three countries with each other and with various other peer country groups, based on the 2023 results of the CCE Index.

As illustrated in Figure 7.2, the CCE Performance sub-index covers eight climate change mitigation approaches that contribute to reducing, recycling, reusing, and removing emissions. The 2023 CCE Performance results for China, Saudi

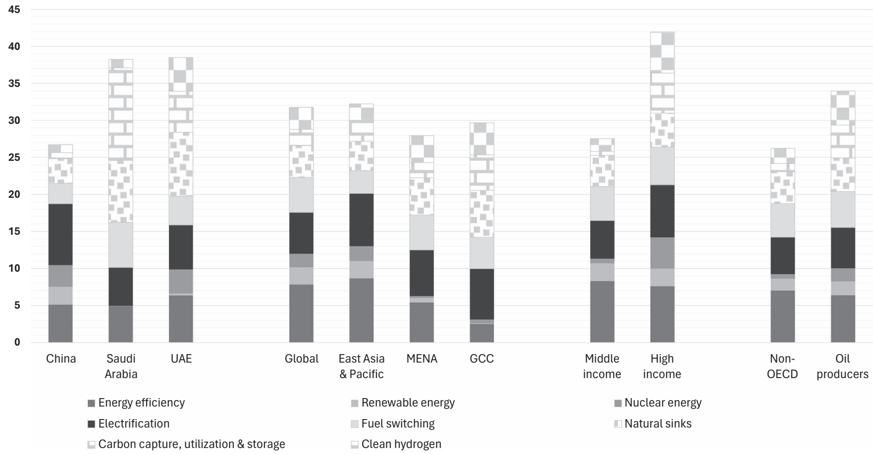

Figure 7.2 2023 CCE performance scores for China, Saudi Arabia, the UAE, and selected groups.

Source: Luomi, Yilmaz, and Alshehri (2024).

Arabia, and the UAE are shown in Figure 7.2, which also contains the global average and results for country reference groups based on development and income status and region. In this area, the two GCC countries' performances are stronger than China's: In 2023, both Saudi Arabia and the UAE scored 38, China scored 27, while the global average stood at 32. Compared to group averages, the UAE and Saudi Arabia scored higher on CCE Performance than all their peer groups—namely, the GCC, Middle East and North Africa (MENA), non-Organisation for Economic Co-operation and Development (OECD) countries, and oil producers. With the exception of the high-income countries' group, China's score was above the non-OECD average and on par with the middle-income countries' average score. Given that all the indicators are scaled to economy size, China's scores naturally hide the strides it has made in terms of absolute levels of clean technology deployment.[3]

In terms of individual drivers of country scores, Saudi Arabia displays strong performance in CCUS, natural sinks and fuel switching, relative to the global average. In CCUS (for which it scored 100), Saudi Arabia's project pipeline is among the world's largest in terms of sequestration capacity when scaled to GDP size. Factored into the score is the country's plan to develop a major CCS hub in the industrial city of Jubail with a total capacity of 44 million tons of CO_2 per year ($MtCO_2$) by 2035 (SPA 2023). Out of this, 18 $MtCO_2$ were in early development as of 2022 (BNEF 2023a). In natural sinks, measured both based on a country's proportional natural sink size (forest area) and how well these are preserved, Saudi Arabia achieved a relatively high score (67) despite it having a small forest area. This is because of its high score in ecosystem conservation. As part of the Saudi Green Initiative launched in 2021, the country announced an ambitious plan to plant 10 billion trees across the country, with 600 million to be planted by 2030 (SGI 2024).

Fuel switching measures both the total shares and changes in the shares of coal and oil in the electricity mix from 2021 to 2026. Saudi Arabia's score on this indicator was 49, which reflects the fact that, while oil still plays a major role in the country's power sector, it has been rapidly replaced by natural gas over the last decade. Compared to the global average, Saudi Arabia's scores are low in renewable and nuclear energy, and energy efficiency. These low scores can be explained by path dependencies: renewables have only recently been introduced in the Kingdom due to its abundant fossil fuel wealth; nuclear has also not been considered as an option until recently, given the country's robust domestic energy security. The competitive advantage derived from the country's hydrocarbon wealth has given rise to energy-intensive industries and an energy-intensive economy. However, the government has set an ambitious target of generating half of Saudi Arabia's electricity from renewable energy by 2030 (Kingdom of Saudi Arabia 2021), and renewable energy installations have started scaling up. Various policy instruments that target improvements in energy efficiency have also been put in place.

The UAE, in turn, received high scores in CCUS (44), clean hydrogen (36), natural sinks (69) and nuclear energy (25) compared to the global averages for these indicators. Similar to Saudi Arabia, it has a sizeable CCUS project pipeline, including a total capacity of 3.3 $MtCO_2$ of projects that are both operational and in various stages of development, which factors into its CCE Performance score (BNEF 2023a). The UAE also has a sizeable clean hydrogen pipeline relative to its GDP, consisting of a total planned production capacity of approximately 340,000 tons per year (BNEF 2023b). The UAE's score in natural sinks is relatively high for the same reason as Saudi Arabia's. Even though the Gulf's harsh climate limits the expansion potential in this area, the UAE has plans to plant 100 million mangroves by 2030 in addition to its existing 124 million, which would create an additional carbon sink of approximately 1 $MtCO_2$ (UAE 2023a).

The UAE scored above the global average in nuclear energy. With the 2023 CCE Index registering the share of nuclear energy in the country's total energy mix in the year 2021 (3.2%) and the UAE's Barakah nuclear plant expected to become fully operational in 2025 (The National 2023), its score on this metric will show a further uptick in future CCE Index editions. Similarly, the UAE is also scaling up its renewable energy capacity in line with its NDC target of 14.2 GW by 2030 (UAE 2023a). The share of renewables in the country's total energy mix in 2021 was less than 1% (0.75%).

China, in turn, has made significant strides in electrification, surpassing the global average score and continuing to improve in 2023 compared to 2022. On this metric, the Asia-Pacific region scored 57, higher than the global average of 47. China led the way with an electrification score of 66, with electricity accounting for 26.8% of its total final energy consumption in 2021 (Enerdata 2023). Over the last 40 years, China's electricity consumption has surged, growing from 276 terawatt-hours (TWh) in 1980 to 9,220 TWh in 2023 (Statista 2024). This sharp increase was driven primarily by the services and industrial sectors, including the manufacture of photovoltaic (PV) modules, electric vehicles, and material processing, which outpaced construction-related industries such as glass and cement (IEA 2024b). On the supply side, China has rapidly expanded its renewable energy sources, which are expected to curb and eventually replace coal-fired electricity. In 2023, China accounted for 38% of the world's total renewable electricity generation, and projections indicate this share will increase to 60% by 2028 (IEA 2023). Its growing electricity consumption and decarbonized energy supply pave a swift path for China to meet its climate commitments.

The construction sector has seen the highest annual growth in electrification, primarily due to strong efforts to promote new electric heating technologies. China manufactured approximately 60% of the world's heat pumps in 2022 (CHPA 2022). Moreover, the ongoing electrification of the residential and transport sectors will continue to drive China's rising electricity demand. As the world's largest exporter of automobiles and the country with the most registered electric vehicles, China's electric vehicle ownership reached 20.41 million in 2023, with 7.43 million new registrations for the year (Central People's Government of the People's Republic of China 2024). In April 2024, China's penetration rate of new energy vehicles surpassed 50%, achieving its national target set for 2035 ahead of schedule. Moreover, the Ministry of Housing and Urban-Rural Development implemented the General Code for Building Energy Efficiency and Renewable Energy Utilization in April 2022, requiring all new, expanded, or renovated buildings to be designed for energy efficiency. By 2060, China's overall electrification rate is projected to be around 65%, with industry, buildings, and transport sectors reaching 60%, 70%, and 55% respectively (EF China 2021).

In the area of clean energy technologies, China (23) scored well above the global average (19) on the back of its 56 operable reactors, which in 2021 accounted for 2.9% of the country's primary energy consumption and approximately 5% of its electricity mix (Enerdata 2023; WNA 2024). In renewable energy, China (19) scored on par with the global average, but it has a substantial absolute capacity. While Europe, the United States (U.S.), and Brazil have also achieved all-time highs in renewable capacity additions, China's acceleration has been extraordinary. According to the IEA (2023), China commissioned as much solar PV capacity in 2023 as the rest of the world did in 2022, and its wind power capacity also grew by 66% year on year. In fuel switching, China (22) still scored below the global average (38). Fossil fuels now constitute less than half of China's total installed generation capacity, a significant reduction from a decade ago when they accounted for two-thirds of its power capacity. By the end of 2026, China could boast as much as 1,000 gigawatts of solar PV power alone, contributing significantly to the global renewable capacity needed to meet the 2030 targets of the Paris Agreement (Hilton 2024).

China also scored the lowest in clean hydrogen (9) and CCUS (7), falling behind the global averages (24 and 18, respectively) and the East Asia and Pacific averages (18 and 22, respectively). Notably, China has significantly increased its performance on both indicators compared to previous years (in 2021, its score on clean hydrogen was 1 and on CCUS 3), echoing the continuous efforts made by the country in this area. China has made significant advances in green hydrogen in particular, albeit with a slow start. As the world's largest hydrogen producer, China developed around 33 Mt in 2020, with less than 0.1% of this coming from renewable energy sources (IEA 2023a). However, China has implemented a strategic focus and scaling up plan, which has helped it gain substantial achievements: In March 2022, the Chinese government published a comprehensive plan for green hydrogen energy, with ambitious goals. By 2035, it aims to have invested $1.6 trillion in the hydrogen sector, including in research, production, and utilization (World Economic Forum 2023). By 2022, over 300 renewable energy hydrogen production projects had been planned and constructed, with a total production capacity of over 200,000 tons per year for 72 ongoing and completed projects (China EV 100 2024).

CCUS, recognized as a strategic technology for achieving carbon neutrality, particularly in hard-to-abate sectors, has gained substantial traction in China, in terms of both policy initiatives and technological advancements. CCUS technologies were included in China's 14th Five-Year Plan in 2021 and mentioned in many carbon-related policies such as its Action Plan for Carbon Peaking Before 2030. By 2022, the country had issued over 70 CCUS-related policies (Global CCS Institute 2023). China has also made significant progress in demonstrating large-scale, full-chain industrialization using various technology combinations. Projections indicate that China's demand for CCUS-enabled emission reductions could reach nearly 100 Mt per year (ranging from 58 to 147 Mt per year) by 2030 and approximately 2.35 billion tons per year (ranging from 2.11 to 2.53 billion tons per year) by 2060 (The Administrative Center for China's Agenda 21, Global CCS Institute, and Tsinghua University 2023).

When comparing the economies of the two GCC countries and China, the differences in scale between them, not apparent from the CCE Index results which scale all metrics to economy size for a fairer comparison, also deserve attention. However, in some instances, such as technology leadership, scale matters. China's clean hydrogen ambitions, for example, are nine times those of the UAE. However, China's CCUS pipeline is similar in absolute terms to Saudi Arabia's.

The major complementarities in CCE Performance between Saudi Arabia, the UAE, and China appear to be renewable energy, CCUS, and clean hydrogen. In the area of renewable energy, China is a world leader in capacity additions. It could also support clean hydrogen deployment in the GCC, where Saudi Arabia and the UAE have highly ambitious plans to scale up their capacity starting from low levels. Alongside increasing production capacity of these technologies, distribution of clean energy and energy storage will also need to be scaled up to support electrification across various sectors.

All three countries demonstrate a strong interest in scaling up CCUS. Geological CO_2 storage capacity in both GCC countries and China is estimated to be significant. Some studies have estimated Saudi Arabia's potential in sedimentary formations to be 446 gigatons of CO_2 (GtCO2), while China's onshore basins are projected to have a comparable storage capacity of 448 GtCO2 (Ye et al. 2023; Zhong et al. 2023). While the CCE Index scores the two GCC countries higher than China in CCUS, global projects are only starting to come online, and all countries, including China, Saudi Arabia, and the UAE, will need significantly higher capture and storage capacities for CCUS to start moving the needle on emission reductions—and eventually removals. A similar picture is observable in the area of clean hydrogen, where all three are countries actively engaged. As discussed earlier, China has made larger developments in clean hydrogen production capacity in terms of absolute size, but the GCC countries have indicated high ambitions relative to their economy sizes. International cooperation can significantly help the scale-up of technologies to levels required to meet the goals of the Paris Agreement. These are discussed in more detail in Section 5.

CCE Enablers

This section takes a similarly comparative approach to the section above in exploring how well various enabling and system factors are supporting net-zero and CCE transitions in China, Saudi Arabia, and the UAE. As shown in Figure 7.1, the CCE Enablers sub-index covers 30 indicators that are thematically grouped into five areas: policies and regulation; technology, knowledge and innovation; finance and investment; business environment; and system resilience. The first four dimensions gauge factors crucial for supporting a country's journey toward net-zero emissions. The fifth enabling dimension, system resilience, holds a two-way relationship with the CCE transition. On the one hand, factors such as energy grid stability, economic diversification and resilience to physical climate risks facilitate countries' transitions. On the other hand, net-zero transitions should not adversely affect a country's energy security, energy equity, or economy, among other aspects (Luomi, Yilmaz, and Alshehri 2024).

Figure 7.3 shows the 2023 CCE Enablers results for China, Saudi Arabia, and the UAE, along with the global average and results for country groups based on their development, income status, and region. In this part of the index, China (score 58) outperformed Saudi Arabia (44) and the UAE (56). China's and the UAE's total CCE Enablers scores were higher than all of their reference groups (East Asia and Pacific, middle-income countries, non-OECD countries, and oil producers), as well as the global average. Saudi Arabia's CCE Enablers were roughly on par with the global (45) and GCC (46) averages but below the oil producers and high-income group averages.

Compared to the global averages in the five enabling areas, Saudi Arabia's strengths are its business environment (65 compared to a global average of 57), and energy and overall system resilience (72 compared to 59). It scored below the global averages in technology, knowledge and innovation (23 compared to 28), and finance and investment (17 compared to 34). The UAE scored above the global average in all five areas, but its widest positive margins were in the areas of system resilience (74 compared to 59), business environment (71 compared to 57), and finance and investment (47 compared to 34).

China's scores were above the global average in all areas except system resilience, where it scored 56 compared to a global score of 59. Its slightly lower-than-average score in system resilience is primarily due to its low adjusted national income

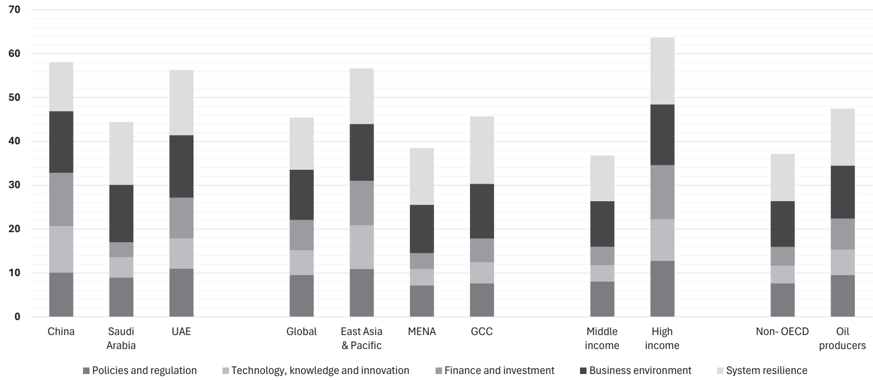

Figure 7.3 2023 CCE enablers scores for China, Saudi Arabia, the UAE, and selected groups.

Source: Luomi, Yilmaz, and Alshehri (2024).

score, which stands at only 12 points. Its performance in two dimensions is significantly higher than the global average: technology, knowledge, and innovation (53 compared to a global score of 28) and finance and investment (61 compared to a global score of 34). Similar to the UAE and Saudi Arabia, China's business environment indicators are also more robust than the global average (70 compared to a global score of 57).

It is worth making a few brief observations of each of the five dimensions of the CCE Enablers sub-index. As already noted above, all indicators are proportional to country size to enable more meaningful comparisons. In policy and regulation, China's and the UAE's policy and regulatory support for renewables and energy efficiency (score 72) is somewhat more robust than that of Saudi Arabia (60), whereas in CCS policy, China (47) outperforms the two GCC countries (both 17) by a wide margin. In technology, knowledge and innovation, China scores higher on research and development spending (65) than the UAE (40) and Saudi Arabia (12). In high-technology trade, China excels (96) compared to the UAE (36) and Saudi Arabia (9).

There are also major differences in the finance and investment dimension, with China scoring a full 100 in CCE investment, followed by the UAE (54) and Saudi Arabia (6). In foreign direct investment flows, the UAE is a global leader (100), with Saudi Arabia (27) and China (24) far behind. Thanks to its national emissions trading scheme (ETS), China scores full points (100) in carbon pricing, while the UAE and Saudi Arabia still did not have any regulated carbon pricing mechanisms in operation in 2023. In business environments, the three countries each have different strengths, with China ranking in the top 10 globally for renewable energy investment attractiveness and the development of CCS resources. Saudi Arabia and the UAE also rank in the top 10 for CCS resource development, as well as political, economic and financial risks. The UAE also ranks among the global leaders in ease of doing business and trade logistics.

Finally, in the area of system resilience, necessary for successful CCE transitions, Saudi Arabia's energy security (score 88), which measures the share of fuel imports in its total imported goods and services, is significantly higher than those of China (49) and the UAE (36). All three countries have achieved high levels of power grid stability. However, there remains a gap between the UAE's and Saudi Arabia's energy equity score (at 100 and 97, respectively) and China's (72). Despite the dusty desert conditions of the Gulf, the UAE and Saudi Arabia still score higher than China in both indoor and outdoor air quality (73, 68 and 46, respectively) and climate risk, measured by economic and human losses due to extreme weather events (100, 62 and 36, respectively).

Given the crucial role of finance and technology in implementing net-zero and CCE transitions, these two CCE Index Enablers dimensions merit further unpacking.

Finance and Investment

The finance and investment dimension of the CCE Enablers sub-index contains five indicators. Three are CCE transition-specific metrics, namely CCE investments (i.e., total investments in renewable energy, CCS, hydrogen, energy storage, electrified transport, electrified heat, nuclear and sustainable materials as a share of GDP); access to sustainable finance (green, social, and sustainability-linked bonds and loans issued per country of domicile, as a share of GDP); and carbon pricing (an ETS, carbon tax or crediting mechanism implemented, scheduled or under consideration at a national or subnational level). In addition, the last dimension incorporates two more generic financial enabler indicators: the Financial Development Index score from the International Monetary Fund, and international financial connectedness (foreign direct investment net in and outflows as a share of GDP). While general financial development and financial connectedness are primary conditions for attracting any kind of global capital, countries' access to sustainable finance and other means of funding are also of high importance for enabling the deployment of net-zero transition investments. Figure 7.4 displays the finance and investment dimension scores for China, Saudi Arabia, and the UAE, and the average scores of their relevant reference groups, along with the global average. The proportional contributions of each of the five indicators to the total scores are also shown in the figure. Overall, China scores extremely well (61), on par with the high-income group average (62) and well above those of all its other peer groups, as well as the two Gulf countries. There is also an important difference in the finance and investment dimension scores of the UAE (47) and Saudi Arabia (17), with the UAE performing above all its reference groups except the high-income countries. Saudi Arabia, in turn, scores similarly to the MENA region on average (18), but well below the global average (34).

In the transition-specific indicators, China scores 100 on CCE investments but only 16 (the global average being 28) in access to sustainable finance (i.e., sustainable debt). In carbon pricing, it again scores a full 100. China's score in CCE investments increased from 90 in 2022 to 100 in 2023, establishing itself as a leading example to other countries. In 2023, global investment in energy transformation

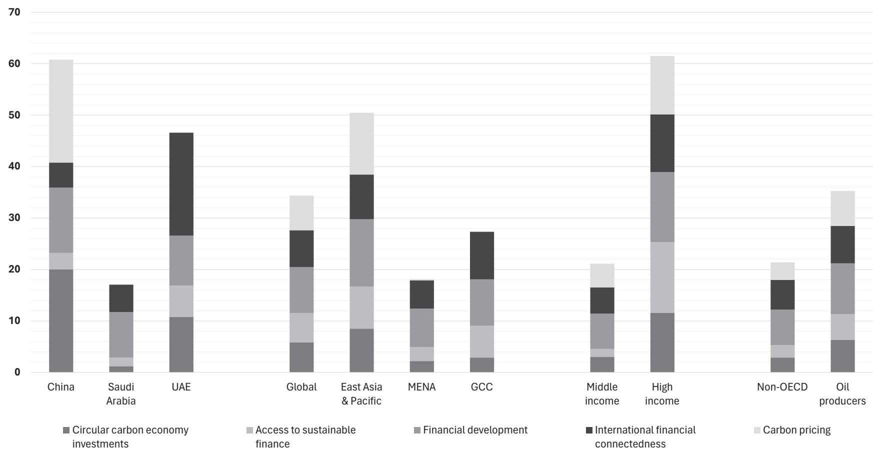

Figure 7.4 2023 Finance and investment scores for China, Saudi Arabia, the UAE, and selected groups.

Source: Luomi, Yilmaz, and Alshehri (2024).

reached a historic peak of $1.77 trillion, increasing by 17% compared to the previous year. China led these investments with an expenditure of $676 billion in 2023, representing 38% of total global investment in energy transformation during that period (Bloomberg NEF 2024). This pattern of investment by China indicates a strong focus on wind and solar energy within the CCE, while other sectors such as lithium batteries, energy storage, and hydrogen energy experienced notable declines in 2023[4] (CINNO Research 2024).

Similarly, China achieved a full score in carbon pricing because of its ETS and national crediting mechanism. During the past year, its carbon market made substantial and unprecedented progress. Since trading commenced in July 2021, China's carbon market has experienced rapid development, establishing a comprehensive institutional framework. In October 2023, the Ministry of Ecology and Environment issued the Management Measures for Voluntary Greenhouse Gas Emission Reduction Trading Regulation (Trial) and the methodology for Chinese Certified Emission Reduction (CCER) projects, enabling the resumption of CCER trading after a six-year hiatus. Additionally, in January 2024, China's Provisional Regulations on the Management of Carbon Emission Trading were announced, representing the highest level, broadest scope, and most comprehensive legislation in China's carbon market to date. Currently, China's carbon market encompasses only the electricity industry but covers approximately 5.1 $GtCO_2$ (per year), making it the world's largest carbon market by coverage. Plans are in place to expand its coverage to other sectors during the 14th Five-Year Plan period, including cement, civil aviation, and electrolytic aluminum industries. The 15th Five-Year Plan aims to incorporate further industries such as steel, paper, glass, petrochemicals, and chemicals.

China's score in the sustainable finance indicator is 16, significantly lower than the global average of 28. This relatively low score can be attributed to the incomplete and uneven development of its sustainable finance sector, despite its high investments in climate change mitigation. China's primary transition finance tools include transition bonds, sustainability-linked bonds, sustainability-linked loans, sustainability re-linked bonds, and special refinancing loans for clean and efficient coal utilization. Transition investment projects in China are primarily undertaken by large state-owned enterprises (SOEs) and financed by domestic banks, notably following the launch of the "carbon-reduction supporting tool" by the People's Bank of China (PBC 2021). In addition, China's transition financing relies predominantly on domestic capital rather than diversified international funding channels, resulting in its financial performance falling short of expectations. Traditional bank lending in China predominantly benefits large enterprises (particularly SOEs), often excluding small and medium-sized enterprises (SMEs) which account for 65% of the country's carbon emissions (World Economic Forum 2022). Since the launch of China's national carbon emissions trading market in 2021, there has been an acceleration in the growth of ESG-related thematic funds and banking wealth management products. However, ESG funds in China are still in their early stages, with most being broad ESG funds that selectively focus on environmental, social, and corporate governance factors, with pure ESG funds comprising a smaller share (ohESG 2023).

In absolute terms, China's green loan balance reached $4.14 trillion by the end of the third quarter of 2023, representing a year-over-year growth of 36.8%, making it a global leader in green finance (PBC 2023). Its domestic green bond market had a balance of $0.29 trillion, ranking second globally. However, green credit constitutes approximately 92% of green finance, with green bonds accounting for around 6% and green equity financing making up about 2%. This structure indicates a heavy reliance on green loans, while the development of direct green financing remains inadequate. In 2022, since the introduction of carbon-reduction support tools, over $84.95 billion in carbon-reduction support loans have been issued by 21 Chinese banks, with over 90% of these funds directed toward the clean energy sector. Banks prefer to offer lower interest rates for clean energy projects due to their stable repayment sources and low credit risks, typically involving large SOEs with outstanding repayment capabilities. In response to these challenges, China implemented pilot projects on climate investment and financing in selected cities in 2021, aiming to explore innovative tools and business models to improve the accessibility of sustainable financing.

In these three CCE/net-zero transition-specific indicators, the UAE scores 54 in CCE investments, which is above the global average (29), and records a score of 30 in sustainable debt, on par with the global average (28). Saudi Arabia, on the contrary, scores lower than the global average in the two indicators. Both countries have yet to establish carbon pricing schemes and, hence, do not receive positive scores from this indicator.

Parallel to the global energy transition, GCC countries have also been undergoing major socioeconomic transformations fueled by ambitious sustainability visions, such as Saudi Vision 2030 (Kingdom of Saudi Arabia 2016) and We the UAE 2031 (UAE 2023b). Focusing on sustainability, these visions include various decarbonization projects, including renewable energy, energy efficiency, clean hydrogen, and carbon management technologies. For instance, as part of Vision 2030, Saudi Arabia aims to transform its power sector generation infrastructure from mainly diesel-based to half renewable energy and half natural gas. It is developing one of the world's largest CCUS hubs with a 44 Mt capture capacity, striving to become a global leader in clean hydrogen production and planting 10 billion trees as part of its Saudi Green Initiative (Kamboj et al. 2023). Overall, the projects outlined under Saudi Vision 2030 amounted to several trillion U.S. dollars, requiring substantial financing from both domestic and international sources to be realized. The Kingdom's Public Investment Fund (PIF) and other SOEs play a major role in these projects' initial financing and building phases. At the same time, as part of its Vision 2030 ambitions, the Kingdom aims to increase private-sector involvement in the economy, viewing this as an opportunity for further private-sector development and economic diversification, including the development of its financial sector.

There has been a significant increase in recent years in CCE investments in Saudi Arabia, while the UAE has followed a stable investment path over the last decade. Saudi Arabia's annual transition investment reached $10.8 billion in 2023, or about 1% of its nominal GDP in that year, up from slightly less than $1 billion in 2019 (BNEF 2024). In the last decade, the UAE has recorded an average annual investment of $3–4 billion, which corresponds to about half a percent of its GDP. Both countries invested a significant amount of these sums, about two-thirds, in renewable energy, mainly solar; and they have only recently started installing wind power. Renewable energy deployment is also critical for both countries' clean hydrogen ambitions.

The remaining one-third of the countries' investments went into clean hydrogen and CCUS, critical clean technologies for their transition plans. Both the UAE and Saudi Arabia have ongoing green and blue hydrogen projects in various development stages and with sizable capacities. They are estimated to reach a total of about 0.8 billion metric tons once commissioned, according to the BNEF database. Saudi CCUS projects have a capture capacity of 19.4 million tons. Similarly, the UAE has several ongoing CCUS projects with a total capture capacity of 4.6 million tons. Additionally, the UAE has been steadily investing in nuclear energy in the last decade, with its investments totaling $20.5 billion as of 2023. Nuclear power generation is also under consideration as part of Saudi Arabia's decarbonization ambitions. Overall, both GCC nations have already invested significantly in the transformation of their energy sectors, with increasingly ambitions plans for the coming years.

The projects described above are generally being undertaken by SOEs and are being financed by a mix of wealthy sovereign wealth funds and other private sources. For instance, the renewable energy projects already being implemented in Saudi Arabia are mainly led by ACWA Power (a PIF subsidiary), with the clean hydrogen projects being led by Aramco and NEOM (a PIF subsidiary). Similarly, the giant UAE SOE Masdar has been the leading investor in the UAE's renewable energy and green hydrogen projects. These SOEs and their respective sovereign wealth funds have also mobilized significant private sustainable financing from both domestic and global debt markets in recent years. Parallel to the global expansionary trend in sustainable finance in the post-COVID era, bond and loan issuance in both countries have increased remarkably. For instance, Saudi Arabia's penetration of global sustainable debt was about $0.5 billion in 2019. This reached $17.5 billion (corresponding to 1.6% of its nominal GDP) in 2023 (BNEF 2024). Similarly, the UAE's access to global sustainability funds was slightly less than 1% of its GDP in 2019, reaching $17.4 billion in 2023, or 3.4% of its GDP. These debts were mostly issued in the form of green loans and bonds, with domestic private financial institutions also active buyers of this debt, alongside the SOEs. Considering the increased interest and efforts in both countries to accelerate their access to private sustainable finance (e.g., the recent announcement of the Green Financing Framework by the Saudi Ministry of Finance [Belahmidi et al. 2024]), private sustainable finance flows are expected to continue growing in the region.

As mentioned above, neither the UAE nor Saudi Arabia had regulated carbon pricing mechanisms in place in 2023, which gave them a score of 0 on this indicator. However, in 2024, Saudi Arabia is planning to make operational its Greenhouse Gas Crediting and Offsetting Mechanism (GCOM), which it originally announced in 2022 at the United Nations (UN) Climate Change Conference in Sharm El-Sheikh. The UAE's second NDC refers to a "carbon registry and trade system covering all sectors" under development (UAE 2023a). There have also been some voluntary carbon market (VCM) developments in both countries, with the Saudi sovereign wealth fund, PIF, spearheading a VCM trading platform, and the UAE-based financial center Abu Dhabi Global Market launching a carbon trading exchange in collaboration with AirCarbon Exchange (ACX) of Singapore.

In terms of the generic finance enablers, China (63) scores well above the global average (45) in financial development but performs slightly below the global average (34) in international financial connectedness (24). China's high score in the Financial Development Index is underpinned by its strong performance in the areas of financial market efficiency and access, as well as financial institutions' efficiency (IMF 2023). China's utilization of international finance to support its carbon-neutral transition, in turn, is constrained by limited market access and the need for reform. China maintains strict capital controls to manage cross-border capital flows. These controls limit the integration of China's financial system with global markets. China's stock and bond markets are largely inaccessible to foreign investors and, despite recent reforms, foreign ownership limits persist.[5] Recently, China has been actively promoting bilateral agreements and regional initiatives, often focusing on specific regions or countries rather than a comprehensive global integration.

In addition to the UAE's high score in CCE Investments, its relatively high score in the finance and investment dimension is underpinned by a full (100) score in international financial connectedness. The country's non-oil powerhouse, Dubai, is well known as a global financial hub: its net foreign direct investments represent

10% of the country's GDP. Saudi Arabia, in turn, scored below the global average (36) in financial connectedness (Saudi Arabia's score being 27), with net foreign direct investments representing less than 3% of its GDP. Notably, however, the country's score increased by nearly 10 points from 2021, driven by a significant increase in foreign direct investment. An improving investment environment and efforts to improve the competitiveness and strength of the private sector were estimated to have boosted foreign direct investment inflows from 30 billion Saudi Arabian riyals (SAR) ($8 billion) in 2020 (the year of the COVID-19 pandemic) to SAR 123 billion ($32.8 billion) in 2022 (Saudi Ministry of Investment 2024). The Saudi government is aiming to increase its foreign direct investments 20-fold between 2021 and 2030. Efforts in this area have included enhancing the country's investment policy framework and developing four Special Economic Zones (Saudi Ministry of Investment 2021).

The two countries have developed financial systems, with their financial development scores (Saudi Arabia scoring 44 and the UAE 49) near the global average (45). Of the areas measured by the Financial Development Index, the UAE boasts a high score in financial market access, whereas the UAE and Saudi Arabia both perform relatively well in the depth of financial markets (IMF 2023). Saudi Arabia has seen significant improvement in its Financial Development Index scores: Between 2021 and 2023, the country's score increased by 11%, the UAE's fell by 1.5% and that of China remained relatively constant, increasing by 0.4%.

Technology, Knowledge, and Innovation

The CCE Enablers technology, knowledge and innovation dimension comprises six indicators. Three indicators measure knowledge creation: clean energy technology patents (relative to the population); the "intensity" of academic research (Nature Index, normalized to population size); and research and development (R&D) expenditure (as a share of GDP). Three indicators measure the extent of technology spillovers: university–industry technical collaboration (World Intellectual Property Organization survey score for university–industry research collaboration); medium- and high-tech industry's contribution to the economy (share of total manufacturing value added); and international high-technology interaction (share of trade in high-tech of total trade).

Figure 7.5 shows the technology, knowledge, and innovation dimension scores for China, Saudi Arabia, and the UAE, along with those of their reference groups. The proportional contributions to the total scores of each of the five indicators are also displayed. As in finance and investment, China again displays strong performance in this dimension overall, with a technology, knowledge and innovation score (53) significantly above the global average (28) and those of all its reference groups. Notably, the East Asia and the Pacific region, which in the 2023 CCE Index covers 10 countries, also scores very high (50) relative to the global average; it is also above the high-income country average (47). One primary factor contributing to East Asia and the Pacific region's high score is its strong domestic demand, combined with robust policy support and market advantages. As of 2022, more

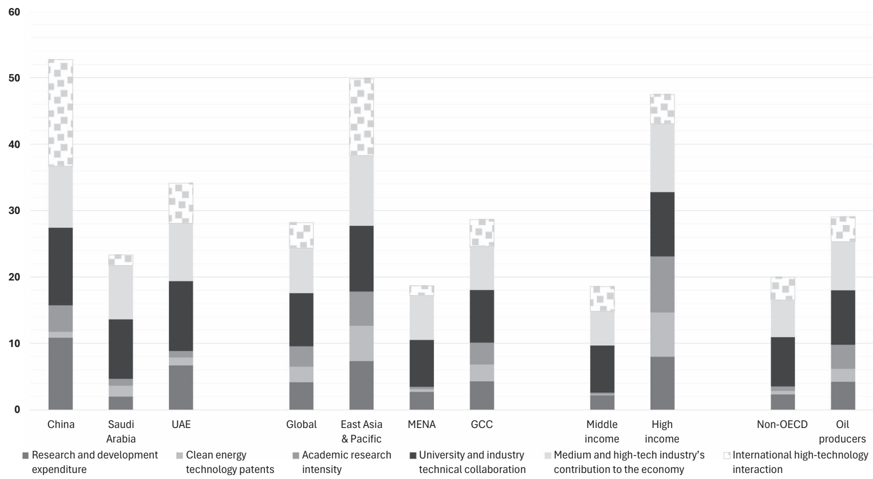

Figure 7.5 2023 Technology, knowledge, and innovation scores for China, Saudi Arabia, the UAE, and selected groups.

Source: Luomi, Yilmaz, and Alshehri (2024).

than 15 countries and 670 companies in the Asia Pacific region have established or are committed to emission reduction targets, fostering new investment prospects in green technology (McKinsey 2022). Additionally, Asian companies have a solid track record of executing large-scale infrastructure projects efficiently, with the region representing 53% of global infrastructure spending between 2004 and 2019 (McKinsey 2022).[6] The UAE (34) and Saudi Arabia (23) score on both sides of the global average (28), with the UAE outperforming all its reference groups except high-income countries and with Saudi Arabia scoring above the MENA average.

In terms of the knowledge creation indicators, China's R&D expenditure (2.4% and score 65) is significantly above the global average (25) and its regional average (44). In clean energy technology patents, however, which cover a range of technologies including solar, wind, geothermal energy, and fuel cells, China (5) scores below the global average (14). Finally, China scores 24 in academic research intensity, above the global average (18). Notably, the knowledge creation indicators have highly skewed distributions, with 70%–80% of the countries scoring less than 10, mainly due to the concentration of global knowledge creation activities in certain developed countries. It is worth noting, however, that the CCE Index relies on scaled factors, which tend to disfavor large countries like China. For instance, clean energy technology patents are measured by the number of World Intellectual Property Organization (WIPO) patent registrations per one million people. However, the WIPO patent registrations between 2018 and 2022—the period covered in the 2023 edition of the CCE Index—show that China filed 1,480 green patents, ranking fourth in the world, behind Japan (2,201), the United States (2,047), and Germany (1,893).

Saudi Arabia and the UAE generally score below the global average in the knowledge creation indicators. However, the UAE's spending on R&D (1.5% of its GDP and a score of 40) is well above the global average (25) and is near the high-income countries' average (48). However, the two countries' patent registrations and academic research intensity relative to their population sizes remain at similar levels. Knowledge creation is a multifactor, long-term and complex process that is highly concentrated in certain developed economies. Universities' traditional prioritization of providing education for local populations over academic research could also play a role in knowledge creation (Hvidt 2015). It is worth noting that both Saudi Arabia and the UAE have been increasingly investing in select academic institutions to strengthen their R&D capacities[7] as part of their knowledge-based economy strategies.

As for technology spillovers, China's scores are consistently significantly higher than the global average: 70 in university–industry collaboration (global average 48); 56 in medium and high-tech industry's contribution to the economy (global average 41); and 96 in international high-technology interaction (global average 23). China has consistently viewed collaboration between industry, academia, and research institutions as a crucial approach for transforming technology into practical productivity and stimulating innovation. In 2012, China embarked on a new phase of transforming and upgrading its model of industry–academia–research cooperation. The Central Committee of the Communist Party of China and the State Council issued "Opinions on Deepening the Reform of the Science and Technology System and Accelerating the Construction of the National Innovation System," which emphasized the central role of enterprises in technological innovation, calling for the establishment of systems and mechanisms for enterprise-led industry technology R&D. This accelerated the creation of a market-driven, enterprise-led technology innovation system, closely integrated with industry–academia–research collaboration (Wen 2023). In subsequent years, various initiatives such as national collaborative innovation centers, national independent innovation demonstration zones, national key laboratories, national laboratories, and local laboratories have rapidly expanded, providing a strong foundation for high-tech development.

Under its innovation-driven development strategy, China has consistently increased its innovation output and contribution to the economy. Between 2015 and 2022, the ownership of high-value patents and the proportion of enterprises with registered trademarks per 10,000 R&D personnel grew at annual rates of 12.5% and 11.9%, respectively. Additionally, technology market transaction contracts saw an annual growth of 9.9%. Contributions to the GDP of the "three new" economy—comprising new industries, new business formats, and new business models—along with the those from patent-intensive industries grew annually by 2.3% and 2.1%, respectively (NBS 2023). High-tech exports grew from $391 billion in 2008 to $924 million in 2022, with a peak of $936 billion in 2021 (Knoema 2023), maintaining China's lead as the top high-tech exporter (WIPO 2024). Private firms significantly contributed to low-carbon innovation, securing 178,000 green and low-carbon patents from 2016 to 2022, with a 12.5% annual growth rate, surpassing the global average. China's advancements in solar photovoltaics, wind power, hydrogen technologies, and energy storage, such as lithium-ion and compressed air storage, highlight the private sector's role in driving low-carbon innovation (EDF 2023).

Both the UAE and Saudi Arabia score above the global average in university–industry collaboration (63 and 54, respectively), and medium and high-tech industry's contribution (52 and 49, respectively). In international high-tech interaction, the UAE's (36) score is above the global average (23) and Saudi Arabia's (9) is below. While the first two indicators focus mainly on domestic technology spillovers, the latter focuses more on international technology spillovers via international trade. The UAE and Saudi appear to have strengths in domestic technology spillover, especially in certain sectors, including the oil and gas industry and petrochemicals. Furthering the penetration of international cutting-edge technologies to expedite decarbonization efforts further remains an untapped opportunity, especially for Saudi Arabia. One good example of this would be to further the development of solar panel manufacturing capacity in the Kingdom as part of the Vision 2030 goals. By and large, transferring critical decarbonization knowledge to where it is needed the most will require global cooperation across all dimensions, especially between developed and developing economies.

China–GCC Comparison—Identifying Areas for Collaboration

As the analysis above has shown, although China, Saudi Arabia, and the UAE score similarly in the total CCE Index, their performance and transition potential are underpinned by highly varied factors. Looking at the absolute differences in the Index scores of the three countries also allows for the identification of potential synergies and, consequently, collaboration. This section first identifies these differences and then concludes by proposing four areas where China and the two Gulf countries could explore expanding their collaboration in support of CCEs and net-zero transitions.

In terms of CCE Performance, China's scores in renewable energy and electrification are significantly higher than those of both Saudi Arabia and the UAE. That said, even China's renewable energy score is still relatively low globally when scaled to its GDP. In nuclear energy, China and the UAE are leading Saudi Arabia by a similarly wide margin. This, along with China's absolute leadership in the global renewables industry today, indicates that it has significant potential to contribute both to the deployment of clean energy and the expansion of electrification in the Gulf.

Scaled to its GDP, Saudi Arabia's CCUS pipeline is extremely ambitious compared to those of China and the UAE. The same is true for the UAE's clean hydrogen ambitions compared to the two other countries. In technologies for hard-to-abate sectors, there are important collaboration opportunities that could further build on the major hydrocarbon trade relationships that already exist between China and the GCC countries.[8]

In terms of CCE enablers, China leads the two Gulf countries by a wide margin in two of the five dimensions: technology, knowledge and innovation, and finance and investment. In system resilience, the UAE and Saudi Arabia perform better than China. In policy and business environments, the three score close to one another.

There are two areas with wide differences between the three countries. First, in finance and investment, China leads significantly in CCE investments. However, the UAE has been more successful in raising sustainable debt relative to its GDP and is the most globally connected in terms of financial flows. Second, China's carbon markets are fully operational, while those in the Gulf are only just starting to emerge. Under the technology, knowledge, and investment dimension, China leads the UAE and, again, particularly Saudi Arabia in R&D investments and high-technology trade scaled to GDP. It also scores higher than the two Gulf countries in academic research and university–industry collaboration.

The three countries face two major common challenges in accelerating their CCE and net-zero transitions. On the one hand, all have highly fossil fuel-reliant, dynamic economies. The GCC countries are highly dependent on their oil and gas industries for economic development. With global attention on climate change governance and a trend toward renewable energy and decarbonization, their trade partners' reliance on fossil fuels will gradually decline. As wealthy emerging economies, the GCC countries are facing increasing pressure to reduce their emissions, and their export economies are also under pressure to decarbonize. China is endowed with plentiful coal but limited oil and gas resources. The high carbon lock-in effect caused by its coal-dominated energy infrastructure has become the main obstacle for China in achieving its carbon peak goal.

The GCC and China are still facing challenges in many enabling areas essential for promoting the development of CCEs, including leveraging the required levels of financing, technological innovation, and cultivating relevant professional talent. All three countries still require higher levels of CCE financing and stronger enabling investment environments. To improve energy and resource utilization efficiency, reduce carbon emissions and technological costs, and promote the widespread application of core technologies, green and low-carbon development also requires technological innovation and R&D, breakthroughs in core technologies such as renewable energy, carbon capture and storage, and digital transformation. To support the research, innovation, and promotion of these technologies requires a large number of professionals, and there is an urgent need to strengthen the talent available.

China and the GCC have already engaged in extensive cooperation to jointly address the risks brought about by climate change, promote the green and low-carbon transformation of the economy, and promote sustainable development. Under the Belt and Road Initiative (BRI), both Saudi Arabia and the UAE have strengthened their collaboration with China in key areas, particularly in infrastructure development, trade, finance, policy coordination, and people-to-people exchange. These partnerships are guided by the concept of green development, aiming to balance economic growth with environmental protection and share the benefits of sustainable development across BRI countries.

In 2018, China and the UAE signed the Comprehensive Strategic Partnership. It covers several areas relevant to CCE transitions, including renewable and clean energy and green industries (WAM 2018). In 2022, during a high-level meeting in Riyadh, China, and Saudi Arabia signed the Comprehensive Strategic Partnership Agreement. It outlined cooperation in various areas, including energy efficiency, nuclear energy, and broader interconnectivity via the BRI (Radwan 2022). During the China–GCC summit in 2022, China proposed five major areas for cooperation between China and the GCC countries in the next three to five years: building a new framework for energy cooperation, advancing financial investment cooperation, expanding innovation in new areas of science and technology cooperation, including developing aerospace, and building vibrant cultural and linguistic partnerships. At the first China–Arab States Summit, China further proposed "eight joint actions" for practical cooperation between China and the Arab states. Among these, the joint actions on green development and innovation outlined a path for building a future-oriented green cooperation community. The UAE and Saudi Arabia are also participants in the Asian Infrastructure Investment Bank, established in 2016 on China's initiative. It has an authorized capital stock of $100 billion and a strong sustainability focus (AIIB 2024).

Enabled by the increasingly strong and diversified economic relationships between China and the Gulf energy powerhouses, there are four areas where collaboration could be further strengthened to support accelerated CCE transitions on both sides. These are discussed as follows:

1) **Constructing clean energy infrastructure:** The GCC countries have abundant solar and wind energy resources, while China has world-leading technology and a large-scale transmission network for wind and PV power generation. Both sides should strengthen their cooperation on energy infrastructure construction, renewable energy, and clean energy technologies, guide investment in new energy fields such as solar energy, wind energy, nuclear power, and hydrogen, strengthen innovation and the research and development of new energy equipment and low-carbon technologies such as energy storage, smart grids, and CCUS, and carry out energy infrastructure construction and operation projects, and localized production. Both parties should gradually shift from cooperation via conventional trade to a new model that emphasizes both investment and energy infrastructure construction. This model would help ensure the stable supply of key clean energy technologies and their required minerals and achieve sustainable production. It would also help create a broader market for investment in clean energy intelligence and power grid construction, further promoting the green and low-carbon transformation of both economies.
2) **Fostering technological talent:** The clean energy industry is mostly technology intensive and requires high levels of technical talent. However, GCC countries continue to struggle with a skills mismatch. More specifically, the cultivation of high-end technical talents has not kept up with the pace of green development and energy transformation. The GCC and China can strengthen their technology exchange and talent cultivation in clean energy, establish joint research centers and technology exchange platforms, cooperate on scientific research and

clean energy technology R&D through educational cooperation and training exchange, develop talent joint training mechanisms in key professional fields, and promote innovation and knowledge sharing. Cultivating a group of innovative technical talents in multiple professional fields, such as energy, environmental protection, and finance, would also benefit both parties.

3) **Facilitating sustainable finance flows:** Sustainable, or ESG finance, is an important support tool for promoting the development of the circular carbon economy, and China and the GCC should strengthen cooperation in the field of green finance. This could include cooperating on financial regulations, jointly formulating green finance standards and regulatory policies, facilitating the access of enterprises from both sides to the capital markets, establishing a mutually recognized green bond market and green credit system, and providing more flexible and preferential financing support for green projects. Both China and the GCC could also consider developing incentives for additional emission reductions through green financing, building on the current green financing efforts. This could entail establishing joint investment, financing and risk sharing mechanisms for green projects; innovating new models of green investment and financing; supporting the investment and construction of green and low-carbon projects through green bonds, green loans, green funds, and green insurance; and providing stable funding sources and favorable financing conditions for green and low-carbon projects.
4) **Promoting hydrocarbon industry digitalization:** Finally, in the process of promoting energy transformation, the digitalization of the traditional energy industry has become a key area of transformation. At present, digital technology is widely used not only in the petroleum industry but also in clean energy fields such as natural gas, renewable energy, and hydrogen. The energy industry is advancing in digitization, networking, and intelligent technologies. China and the GCC could strengthen cooperation in areas such as digital technology, big data, cloud computing, and communication networks, and jointly build a series of innovation and entrepreneurship incubators. They could also carry out digital economy projects around cross-border e-commerce cooperation, communication network construction, and digital energy transformation. Through value creation, data integration, and platform empowerment, they should jointly promote the application of digital technology in the development of circular carbon economies.

Notes

1 While this differentiation has evolved from being a binary to a dynamic one (see, e.g., Voigt and Ferreira 2016), it plays out in many ways under the Paris Agreement. The Paris Agreement provides developing countries certain flexibilities in how they pursue its implementation in light of their different national circumstances. It also sets further obligations for developed countries in light of the "common but differentiated responsibilities and respective capabilities" principle.

2 However, authors and actors have made different choices when classifying types of CO_2 flows (Luomi et al. 2021).

3 Given the size of its economy, China would rank extremely high in a global comparison of various CCE-relevant metrics in absolute terms, such as renewable energy capacity. However, to allow for meaningful comparisons across countries, all indicators are scaled to GDP or population size, as relevant.

4 The main investments were directed toward wind and solar energy, totaling approximately \$532 billion and comprising around 46.8% of the total investments, representing a 10.3% increase from the previous year. Investments in lithium batteries amounted to about \$224 billion, accounting for around 19.9% of total investments but reflecting a 26.6% decrease year-on-year. Investments in energy storage reached approximately \$224 billion, representing 20.1% of total investments but seeing a year-on-year decrease of 40.1%. Investments in hydrogen energy were around \$119.2 billion, accounting for about 10.6% of total investments and showing a 25.1% decrease year-on-year.

5 The Qualified Foreign Institutional Investor (QFII) program allows foreign institutional investors to access China's capital markets, but the quotas are limited.

6 China's government-issued R&D grants have enabled Chinese manufacturers to invest significantly in in-house R&D. This support has driven innovations such as the world's first 16 megawatt (MW) offshore wind turbine being connected to the grid at the Fujian Offshore Wind Farm in 2023, which produces an average of more than 66 million kilowatt hours (kWh) of green electricity per year. Furthermore, government initiatives, such as establishing key state laboratories and fostering collaborations with key suppliers and local universities, have played a crucial role in enhancing the overall progress and competitiveness of enterprises.

7 Examples include the King Abdullah University of Science and Technology in Saudi Arabia and Khalifa University of Science and Technology in the UAE, both of which boast sizable research funds and international collaboration across various disciplines.

8 Saudi Arabia made the most progress in fuel switching, followed by the UAE and China. The UAE leads in energy efficiency, followed by China and Saudi Arabia. Both the UAE and Saudi Arabia have higher scores in natural sinks than China, albeit their proportional carbon sink capacities are significantly smaller than China's.

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8 China–GCC Cooperation

Trends in Sustainable Financing and Transition Investment

Peiyuan Guo and Claudia Belahmidi

Introduction

Finance is a fundamental component of any modern economy. Markets can allocate resources efficiently and support economic growth through various types of financial instruments.

In the field of energy transition, the financial sector plays a crucial role in supporting both green projects and carbon-intensive industries. Projects such as renewable energy and high-speed rail systems require substantial investments, commonly referred to as green investments or green finance, which are designed to deliver measurable environmental benefits. At the same time, carbon-intensive sectors like oil and gas, steel, and iron also require capital to implement their transition plans. These investments, known as transition finance or transition investments, help reduce carbon emissions—either in total volume or intensity—within the targeted companies or projects.

Green finance has been evolving over the past few decades, with commercial banks and venture capital firms (VCs) serving as early adopters. In the 1990s, commercial banks identified the potential for environmental risks to translate into significant financial risks, prompting them to integrate environmental and social risk management into their lending practices. Concurrently, VCs were among the first to recognize the economic potential of environmentally sustainable solutions, leading to investments in green technologies and environmentally conscious enterprises.

In recent years, green finance has become increasingly systemic, propelled by the rapid expansion of environmental, social, and governance (ESG) investment. While ESG investment is aligned with the United Nations (UN) Sustainable Development Goals (SDGs) addressing economic, environmental, and social issues, green finance remains primarily focused on environmental priorities. Alongside these priorities, related concepts such as sustainable finance and climate finance have also emerged. The United Nations Development Programme developed a comparative framework to clarify the similarities and distinctions among these frameworks (Xu and Wang 2020).

Compared to green finance, transition finance is a relatively recent development. According to the Group of Twenty (G-20), it encompasses financial services

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that facilitate economy-wide transitions toward lower emissions and climate resilience, in alignment with the SDGs and the Paris Agreement (G-20 SFWG 2022a). Key instruments used by these entities include sustainability-linked bonds, sustainability-linked loans, and carbon efficiency indices.

Transition finance has a larger potential market size than green finance, as it encompasses industries with substantial assets (Lee and Du 2023). However, the elevated carbon emissions in these sectors have raised investor concerns regarding greenwashing. To address such issues, in 2022, the G-20 Sustainable Finance Working Group (SFWG) introduced high-level principles for transition finance, providing a clear framework for implementation (Lee and Du 2023).

For China and the Gulf Cooperation Council (GCC) countries, both green finance (or sustainable finance) and transition finance are important. This chapter provides an overview of the developments in green and transition finance and outlines a roadmap for partnership between China and the GCC. Specifically, it addresses the following key questions:

- What is the current state of green finance and transition finance in China and the GCC, particularly in debt and equity markets, and what is their future potential in addressing climate change?
- How have transition finance instruments developed, and what is their future outlook?
- What role do regulators play in shaping policies, standards, taxonomies, and reporting frameworks for green and transition finance?
- What are the current developments on and prospects for China–GCC cooperation in these areas, including existing partnerships and potential strategies for collaboration?

Development of Green Finance

Debt Markets

Green Bonds

Green Bonds are marketable securities whose proceeds are exclusively used to support green industries, projects, or economic activities that comply with specified criteria. These bonds are issued in accordance with legal processes and are used to repay principal and interest as agreed (China Green Bond Standard Committee 2022).

In 2023, China's green bond market advanced significantly in policy guidance, standardization, and regulatory frameworks. By year-end, the cumulative issuance of labeled green bonds reached $616.2 billion (or 4.46 trillion Chinese yuan [CNY]), with $372 billion (CNY 2.7 trillion) meeting the Climate Bonds Initiative's definition of green bonds. In 2023 alone, China issued $131.3 billion (CNY 0.94 trillion), of which $83.5 billion (CNY 0.6 trillion) complied with these standards (Climate Bonds Initiative 2024).

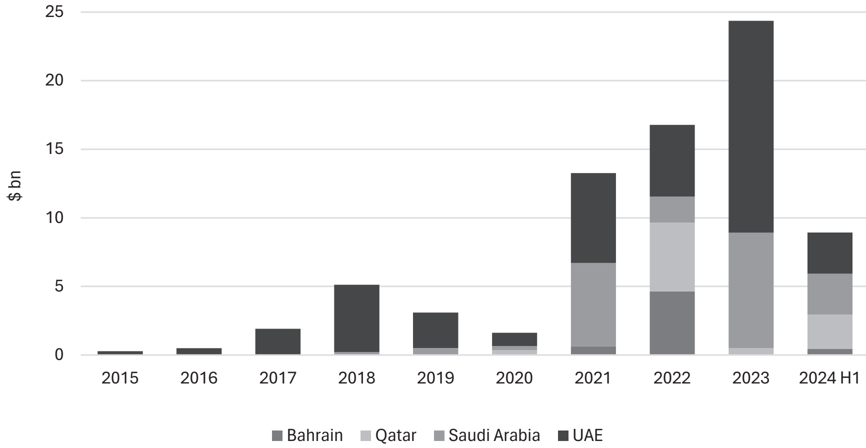

Figure 8.1 GCC sustainable debt issuance by country (2015–2024 year to date [YTD]).
Source: Bloomberg (2024).

Despite a slight decline in its issuance, in 2023, China remained the world's largest green bond market for the second consecutive year, making significant progress in aligning its green debt standards with international frameworks. Domestically, green bonds issued by provincial state-owned enterprises grew by over 24% in 2023, while non-state-owned enterprises saw a 4% decline in issuance due to their lower credit ratings. Beijing led with $374 billion issued, up over 10% year on year, while Shanghai's issuance of green bonds surged 170% (Climate Bonds Initiative 2024). Other regions also experienced solid growth in green bond issuance.

The growth of sustainable finance in GCC countries has been significant, with a marked increase in sustainable bond issuance from approximately $1.6 billion in 2021 to $24 billion in 2023 (see Figure 8.1). This trajectory is particularly remarkable as global investments in green instruments and projects dipped during the same year (Bloomberg 2024).

The entities issuing green bonds included banks (the Dubai Islamic Bank, the Abu Dhabi Commercial Bank, Al Rajhi), corporations (the Saudi Electricity Company, DP World, Masdar, RAQA, Aldar), sovereign wealth funds (Mubadala and the Public Investment Fund [PIF]), and the first sovereign sustainable bond within the GCC (Sharjah). While the United Arab Emirates (UAE) had more green issuers, Saudi Arabia is narrowing the gap. This growth in GCC green bond issuance follows favorable economic conditions and rising demand for sustainable investments in the member countries, with younger generations increasingly prioritizing ESG issues.

Given that over the past five years, 85% of the sustainable debt market in GCC countries has been composed of sustainable loans, it is not surprising that financial institutions have led the bloc's sustainable debt issuance. Corporate GCC issuers have been active since 2021, with balanced issuance comprising loans and bonds.

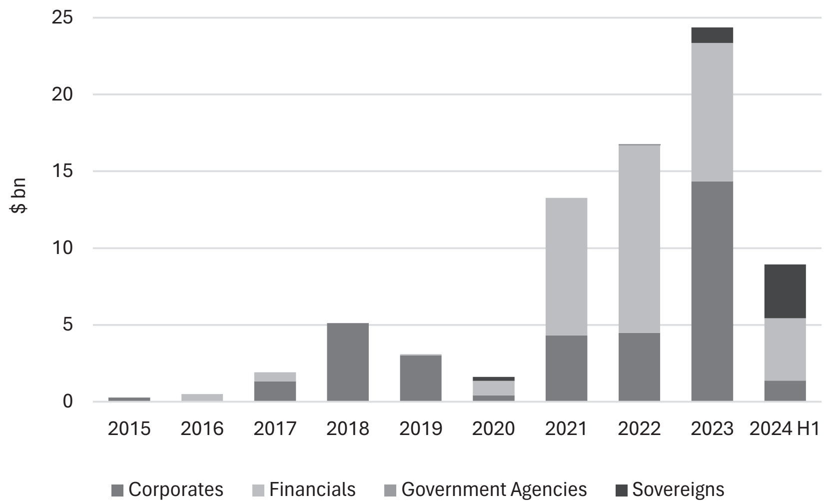

Figure 8.2 GCC sustainable debt issuance by type (2015–2024 YTD).

Source: Bloomberg (2024).

Leading industries in this space are energy, industrials, and utilities. As shown in Figure 8.2, total green bond issuance in the region surged from under $5 billion in 2020 to nearly $25 billion in 2023, primarily driven by increased participation across corporates and financials. Issuance is expected to expand in the medium to long term, as GCC sovereigns develop their green bond programs.

Green debt issuance leads the GCC's sustainable debt market, with Qatar and Saudi Arabia focusing on green bonds while the UAE addresses a wider range of sustainability-themed projects. Use-of-proceeds bonds and sustainability-linked bonds are also growing, helping finance corporate transitions without proceeding restrictions. These bonds are tied to specific issuer-defined ESG goals, linking goal achievements to investor coupon payments.

Green Loans

Green credit is the largest category in China's green finance market. As per the Green Credit Guidelines issued by the former China Banking Regulatory Commission (CBRC) in 2012, Chinese banks are encouraged to provide green loans (green credits) to support the development of a green economy, low-carbon economy, and circular economy (CBRC 2012). According to China's central bank, the total outstanding green credit equaled CNY 28.58 trillion in Q3 2023—a substantial year-on-year increase of 36.8%—outperforming China's overall credit growth by 26.6 percentage points (Xu 2023).

Domestically more provinces and cities set green credit targets in 2023. For example, Shanghai has targeted over CNY 1.5 trillion in green financing by 2025, while Guangdong has a target for green credit issuance of 10% of all loans by 2030. Chongqing plans to exceed CNY 600 billion in green credit issuance by the end of 2025 (Guo and Wu 2024). These policies promote the future growth of green credit. Chinese banks are also adopting various sustainable investment practices, supported by government green development initiatives. Specifically, as of June 30, 2024, 26 banks have signed the Principles for Responsible Banking, and 29 banks have signed the China Banking Sector Green Credit Joint Commitment.

Green loans play a pivotal role in financing sustainable development across the GCC, aligning with the region's economic diversification strategies and long-term sustainability goals (World Bank 2022). Banks in the region are becoming increasingly active in green finance. In 2022, Emirates NBD issued a $500 million green bond to support renewable energy and energy efficiency projects (Emirates NBD 2022). Qatar National Bank (QNB) offers sustainability-linked loans tied to solar energy and water conservation initiatives, with interest rates contingent on meeting ESG targets (QNB 2022). In Saudi Arabia, the National Commercial Bank (NCB) provides financing for solar and energy-efficient projects under the framework of the Saudi Green Initiative (NCB 2023). Similarly, UAE-based banks such as Abu Dhabi Commercial Bank (ADCB) finance major clean energy ventures, including the Mohammed bin Rashid Al Maktoum Solar Park developed by the Dubai Electricity and Water Authority (ADCB 2023). This landmark project aims to generate 5,000 megawatts of solar power by 2030, significantly advancing the UAE's renewable energy ambitions (UAE Government 2024).

Green finance has emerged as a key pillar of sustainable development strategies across the GCC, with both Saudi Arabia and Qatar integrating it into their long-term national visions. Saudi Arabia's Vision 2030 underscores the importance of green finance as a catalyst for economic diversification and environmental sustainability. The Saudi Green Initiative, launched in 2021, provides a framework to expand green financial instruments—such as green loans—to support investments in renewable energy and environmental conservation (Saudi Green Initiative 2021). In alignment with this strategy, leading domestic companies like the National Industrialization Company (Tasnee) have begun leveraging green finance to support their transition to more sustainable production processes (Tasnee 2023).

Similarly, Qatar's National Vision 2030 places strong emphasis on sustainable development, with institutions such as the Qatar Green Building Council advocating for the use of green loans to finance energy-efficient infrastructure.

Despite this momentum, key challenges persist across the GCC. One major barrier is the lack of standardized green finance regulations, which leads to inconsistencies in project evaluation and classification (Moore 2022). Furthermore, the broader shift from oil-dependent economic models to green finance systems requires significant policy reforms and infrastructure investments, which remain ongoing.

Equity Market

The Asset Management Association of China (AMAC) defines green investment in capital markets as investments aimed at enhancing corporate environmental performance, developing green industries, or reducing environmental risks. AMAC encourages asset managers to systematically integrate ESG factors into portfolio management (AMAC 2018).

As of September 30, 2023, Chinese ESG mutual funds accounted for 7.45% of all equity and hybrid funds, up 11% from 2022. Additionally, 28 fund managers have committed to the Principles for Responsible Investment (PRI), reflecting a significant shift toward ESG integration. A total of 97 funds has issued 738 ESG mutual fund products (see Figure 8.3.). Nearly 60% of the 157 mutual funds in China offer ESG options, in addition to 279 equity funds, 24 bond funds, 397 hybrid funds, 29 funds of funds (FOFs), and nine international (qualified domestic institutional investor [QDII]) funds (SynTao Green Finance and China SIF 2023).

By Q3 2023, China's ESG funds had reached CNY 438.31 billion in value (SynTao Green Finance and China SIF 2023), dominated by energy conservation and environmental protection funds.

ESG-related indices experienced particularly fast growth after China announced climate targets in 2020. As of September 2023, index companies in China, represented by the China Securities Index Company, had released 202 equity indices that incorporate ESG factors. Among them, 70 are ESG Select indices and 92 have energy conservation and environmental protection themes (SynTao Green Finance and China SIF 2023, 33).

AMAC counts 1,022 private funds with green industry themes, worth over CNY 482.6 billion. About 90% of these are private equity funds. Additionally, 60 private equity funds have signed the PRI (SynTao Green Finance and China SIF 2023, 57).

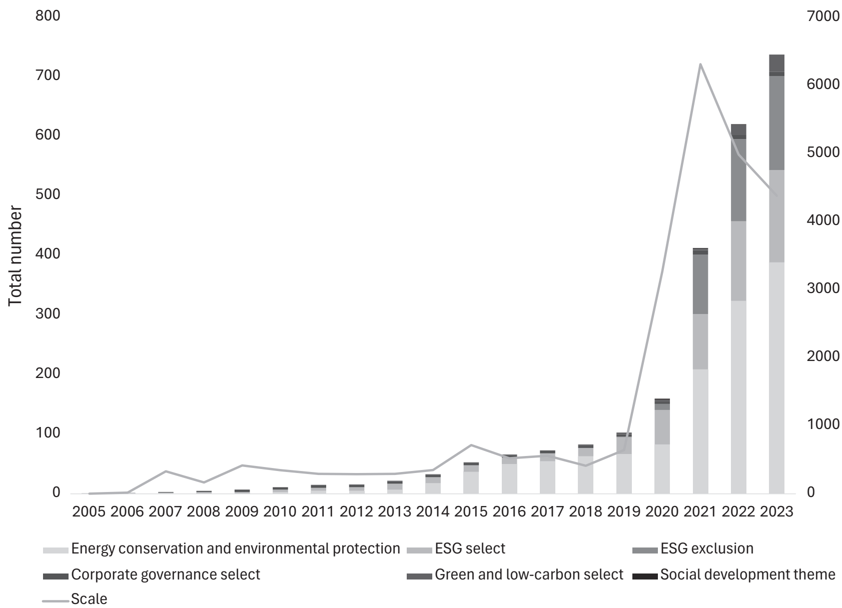

Figure 8.3 ESG fund growth in China.

Source: Wind, China SIF.

In the GCC, sustainable equities have faced volatility. The market reached $25.1 billion in 2023 (LSEG 2024) but lagged behind its 2021/2022 levels due to geopolitical tensions refocusing investor priorities.

GCC revenue remains heavily dependent on hydrocarbons, but the member countries' economic diversification and greening agendas promise growth in other sectors, including finance and green companies. Leading sustainability-oriented and green companies are mainly based in the UAE and Saudi Arabia, and prioritize waste management, water desalination, and the expansion of renewable energy capacity.

Most companies in this sector are privately owned, part of consortia, or backed by sovereign funds, which limit access for retail investors and ESG-themed exchange traded funds (ETFs). Saudi Arabia is exploring initial public offerings (IPOs) to attract private investment, but government entities like PIF may not allow external capital to invest in critical projects like Neom. GCC countries have approached IPOs cautiously, as exemplified by the UAE's Averda, which has repeatedly considered going public without success.

In the UAE and Saudi Arabia, investors in green equities favor sustainability-driven industries. Renewable energy firms like Acwa Power and Masdar lead in solar and wind projects, while companies like Bee'ah are at the forefront of waste management initiatives. Other priorities include sustainable infrastructure (Tabreed's cooling solutions) and innovative agriculture (Badia Farms' food security). The UAE features firms with diverse ownership structures, whereas Saudi Arabia prioritizes large-scale projects through the PIF.

Market Potential for Green Finance

The global sustainable finance market was valued at $519.88 billion in 2022, with its compound annual growth (CAGR) from 2023 to 2030 expected to be 22.6% (Grand View Research 2023). Sustainable finance assets under management (AUM) reached $37.8 trillion in 2022, reflecting significant capital inflows into sustainable investments (Global Market Insights 2024).

Estimates of the annual investment needed to achieve the UN SDGs vary widely. A McKinsey study estimates there is a need for $9 trillion in annual green investment globally, with the European Union (EU) requiring €350 billion of additional investment annually until 2030 to achieve its net-zero targets (McKinsey & Company 2021). Despite commitments from institutions with $130 trillion in AUM (Latham & Watkins 2023), adverse economic conditions caused the market to contract in 2022. Future growth is expected through regulatory support and increased investor awareness.

In 2023, green bonds constituted over 36% of the sustainable finance market, where the market was dominated by equity funds focused on sustainable practices. ETFs and index funds tracking sustainable indices have gained popularity due to their transparency and cost-effectiveness (Grand View Research 2023). Institutional investors, such as pension funds, represented over 78% of the market in 2022, recognizing the need to integrate ESG factors to support environmentally sustainable returns. Retail investors are also increasingly demanding sustainable investment products.

Despite the promising outlook, the sustainable finance market faces several challenges. The high upfront costs of sustainable projects, such as renewable energy installations and sustainable infrastructure development, can deter potential investors. Overcoming this requires innovative financial strategies and public–private partnerships.

Transition Finance

Development under G-20 Framework

Since 2016, the G-20 has engaged in discussions on the topic of green finance. During China's G-20 presidency that year, it played a pivotal role by initiating the establishment of the G-20 Green Finance Study Group, now known as the Sustainable Finance Working Group (SFWG), fostering global consensus on green finance.

Recently, green and sustainable finance markets have expanded rapidly, primarily focusing on "pure green" activities. Support for more diverse investments necessary for a comprehensive climate transition, including in greenhouse gas-intensive sectors, has remained limited. Accordingly, certain sectors face increasing difficulties in accessing bank loans and capital market funding (G-20 SFWG 2022b).

The 2020 G-20 Sustainable Finance Roadmap was a key milestone in green and sustainable finance. It outlined 19 actions to build consensus on transition finance. At the G-20 Bali Summit in 2022, G-20 Leaders approved the "2022 G-20 Sustainable Finance Report," introducing the G-20 Transition Finance Framework. This framework guides the integration of climate considerations into finance, urging capital providers to manage their investments to help mitigate climate risks and support low-carbon activities.

The framework includes 22 principles, organized into five pillars (G-20 SFWG 2022b): identifying transitional activities, enhancing reporting transparency, developing transition-related financial instruments, creating supportive policy measures, and assessing potential negative impacts from transition investments.

Financial Instruments

In recent years, a diverse array of transition finance instruments has emerged globally, with debt-based products dominating the landscape. These include use-of-proceeds green or transition bonds, sustainability-linked loans, fixed-term deposits, and reimbursable loans—all designed to fund activities that support decarbonization and the broader energy transition. Equity-based instruments are also gaining traction, such as transition-focused buyout funds, venture capital, and mezzanine financing, which are particularly well-suited for highly leveraged firms and small and medium-sized enterprises (SMEs) adopting new low-carbon technologies. To further support these instruments, risk mitigation tools like transition risk insurance and credit enhancement mechanisms are increasingly being deployed.

Other innovative financing mechanisms include asset-backed securities (ABS), real estate investment trusts (REITs), blended finance structures, and exchange-traded funds (ETFs). These products are designed to mobilize capital for transition activities, provided that the underlying assets align with credible decarbonization objectives and do not compromise financial stability.

In China, sustainability-linked financial products—such as green and transition bonds and loans—have become key tools in transition finance. By Q3 2023, 13 Chinese issuers had launched 16 sustainability-linked bonds, signaling growing domestic interest in performance-based instruments.

A flagship initiative in China is the Carbon Emission Reduction Facility (CERF), launched by the People's Bank of China (PBoC) in 2021. CERF mobilizes social capital for clean energy and carbon reduction by offering low-cost funding to financial institutions. These institutions, in turn, extend carbon reduction loans at interest rates close to the loan prime rate (LPR). The PBoC reimburses up to 60% of the loan principal for qualifying projects at a concessional rate of 1.75%. As of November 2023, the CERF had a balance of CNY 491.1 billion, supporting over CNY 1,019.4 billion in transition-related lending, with support set to continue through 2027. Accessible to financial institutions with nationwide licenses, CERF has become a major vehicle for advancing China's carbon peaking and neutrality goals, while enhancing market awareness and scaling up low-carbon investments.

Transition finance is playing an increasingly important role in supporting sustainable development, with sustainability-linked loans (SLLs) emerging as a key instrument in GCC countries to facilitate the shift toward a low-carbon economy. The adoption of SLLs reflects the region's broader efforts to diversify economies away from hydrocarbon dependence and advance national sustainability agendas.

In Saudi Arabia, Vision 2030 incorporates explicit sustainability targets, with companies such as Aramco issuing debt instruments aimed at reducing carbon intensity and expanding renewable energy investments (Saudi Aramco 2022). Similarly, in the UAE, the Dubai Electricity & Water Authrotiy (DEWA) utilizes SLLs to finance solar power projects under the Dubai Clean Energy Strategy 2050, which targets a 75% clean energy share by 2050 (DEWA 2023).

SLLs not only link financing terms to sustainability performance but also enhance the attractiveness of GCC financial markets to international investors, while reinforcing alignment with global environmental goals (World Bank 2022). Nonetheless, key challenges persist—particularly the absence of standardized sustainability metrics and the region's continued reliance on fossil fuels—necessitating robust risk management frameworks to ensure credibility and effectiveness.

Market Potential for Transition Finance

The market potential for transition finance is substantial, driven by growing international commitments to decarbonization and climate resilience. Over the past decade, multiple global agreements have underscored the importance of transition finance, with the Paris Agreement, a legally binding treaty ratified in 2016 by 195 parties (194 countries and the EU), serving as a cornerstone. The agreement provides a long-term framework to guide global efforts toward reducing emissions and adapting to climate change. According to the International Energy Agency (IEA), an increasing number of countries are committing to long-term net-zero emissions goals, with many targeting 2050 as a critical milestone (IEA 2021).

To accomplish these targets, regulators and policymakers worldwide are working to integrate sustainability into national and international financial and economic systems. The EU is leading these efforts, developing regulations such as the Climate Transition Benchmarks Regulation, Taxonomy Regulation, and the Sustainable Finance Disclosure Regulation (SFDR), to drive climate action and responsible investment. These frameworks have not only strengthened the EU's own transition finance market but have also provided models for other jurisdictions.

Globally, governments are taking active steps to support investments in carbon-intensive industries undergoing transition. For example, Japan's Climate Transition Bonds aim to raise $1 trillion by 2050 for decarbonization projects, including 20 trillion Japanese yen (JPY) ($130 billion) in sovereign bond issuances. Similarly, at the 2021 United Nations Climate Change Conference (COP26), then-U.K. Prime Minister Rishi Sunak announced the goal of making the United Kingdom the world's first net-zero financial center, supported by the creation of the Transition Plan Taskforce to ensure credible corporate transition plans.

In China, transition finance is central to the country's carbon peaking and neutrality roadmap. In 2021, President Xi Jinping unveiled the "1+N" policy framework, comprising a national long-term strategy ("1") and a series of targeted action plans ("N") to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. These plans aim to increase non-fossil fuel energy to 20% by 2025, 25% by 2030, and over 80% by 2060.

Transition finance plays a complementary role to green finance in China, providing targeted support to high-emitting sectors. The PBoC has actively promoted transition finance and introduced a sector-focused framework to accelerate low-carbon transformation in steel, coal-fired power, building materials, and agriculture sectors.

Similarly, GCC countries are increasingly engaging in transition finance, though the complexity and cost of shifting from hydrocarbon-based economies pose significant challenges. Countries like Saudi Arabia and the UAE have made notable progress by integrating transition finance into broader sustainable finance frameworks. As members of the G20, both have contributed to the global sustainable finance agenda, as recognized in the 2022 G20 Sustainable Finance Report.

While Saudi Arabia and the UAE are leading regional efforts, other GCC countries are also taking meaningful steps to embed sustainable finance practices into their policy and regulatory frameworks. Achieving long-term decarbonization goals will require deeper government— private-sector collaboration, enhanced capacity building, and alignment of financial strategies with sustainability targets.

In summary, transition finance is a critical enabler of the global shift to a low-carbon economy. Realizing its full potential will depend on international cooperation, the sharing of best practices, and the effective mobilization of capital toward credible and inclusive transition pathways.

Role of Regulators

Policy Framework

Regulators play a critical role in shaping, guiding, and enforcing policies that support the transition to a sustainable financial system, particularly in developing countries. In China, PBoC serves as the central financial regulatory authority and has taken a leading role in advancing the country's green finance agenda.

In recent years, the PBoC has intensified its promotion of green development, yielding notable results. By the end of 2020, China had issued approximately CNY 12 trillion ($2 trillion) in green loans—the highest globally—and CNY 800 billion ($120 billion) in green bonds, ranking second worldwide. These financial instruments have been instrumental in supporting China's broader green and low-carbon transition.

The PBoC identifies three core functions of green finance: resource allocation, risk management, and market pricing. These functions guide capital toward environmentally beneficial projects, improve climate-related risk oversight, and contribute to the development of carbon markets. To operationalize these functions effectively, the PBoC promotes a five-pillar framework, which encompasses the standard system, regulation and information disclosure, incentive and constraint mechanisms, product and market systems, and international cooperation (China Banking and Insurance News 2022).

In the GCC region, Saudi Arabia and the UAE lead government efforts to institutionalize sustainable finance, while other member states are developing localized green finance frameworks. Across the region, stakeholders increasingly recognize the strategic importance of integrating ESG principles—to both align with international standards and attract sustainability-linked capital that supports national decarbonization and development objectives.

As global momentum toward sustainability accelerates, the GCC's growing commitment to green finance positions the region as an emerging hub in the global low-carbon transition. All six GCC countries have launched sustainability-focused initiatives as illustrated in Table 8.1. For example, Saudi Arabia's Green Initiative (SGI) aims to reduce emissions by a level equivalent to more than 4% of global emissions through a major shift to clean energy (Government of Saudi Arabia 2021). Qatar's National Vision 2030 targets a 25% reduction in greenhouse gas emissions, supported by a robust sustainability agenda (State of Qatar 2022).

In parallel, most GCC countries have adopted voluntary sustainability reporting standards, including the Saudi Exchange ESG Disclosure Guidelines, the Dubai Financial Market ESG Reporting Guide, the Qatar Stock Exchange ESG Guidance, Boursa Kuwait's ESG Reporting Guide, and the Bahrain Bourse ESG Reporting Guide.

Table 8.1 Green finance infrastructure in GCC countries

Category	*Saudi Arabia*	*UAE*	*Qatar*	*Kuwait*	*Bahrain*	*Oman*
Sustainability Pledges	Net-zero by 2060; 130 GW renewables by 2030; circular economy N/A	40% emission reduction by 2030; 30% renewables by 2031; carbon neutral by 2050	25% emissions cut by 2030; 35% recycled materials in construction	Net-zero by 2060; 15% renewables by 2030	Net-zero by 2060; 30% emission reduction by 2035; 20% renewable energy target	17% emission cut by 2030 (vs. 2021); 88% by 2050; 20% renewables by 2027
Green Finance Framework	In place at commercial banks, government level	In place across banks, corporations, national level	At the bank level	At the bank level	N/A	For sovereign debt
ESG Reporting Standards	Voluntary at stock exchange level	Voluntary at stock exchange level	Voluntary at stock exchange and Capital Market Authority	Voluntary at stock exchange	Voluntary at stock exchange, central bank level (mandatory by 2025)	Voluntary at stock exchange (mandatory by 2025)
Sustainable Finance Taxonomy	Expected 2026	Under development	N/A	N/A	N/A	N/A
Sovereign Sustainability Bond Program	In place, led by NDMC	In place	In place	N/A	N/A	Under development
Sustainability Indices	N/A	Yes	Yes	N/A	N/A	N/A
Sustainable Finance Training Program	Under development	Unconfirmed	Unconfirmed	Unconfirmed	N/A	Unconfirmed

Source: Authors' research adapted from the Atlantic Council (2022). Official GCC government resources, 2024.

Saudi Arabia and the UAE have led in issuing sustainable sovereign financial instruments, such as green bonds and Islamic sukuk, while Oman and Qatar are expected to launch similar initiatives in the near term. However, the region still faces several structural challenges. Direct sustainability incentives—such as tax credits or green subsidies—are generally lacking. Additionally, hydrocarbon revenue taxation remains politically and economically sensitive, given its central role in national income generation.

To address fragmentation and enhance policy coherence, the GCC Secretariat has supported efforts to develop a unified green finance framework. Key initiatives include the establishment of Arab Sustainable Development and Environmental Finance Network (ASDEFNet) and the adoption of unified ESG indicators by the GCC Exchanges Committee (Saudi Exchange 2024). These regional efforts promote harmonization, capacity building, and knowledge sharing, laying a stronger foundation for long-term sustainable finance integration across the GCC.

Standards and Taxonomies

Since 2018, the PBoC has taken a leading role in advancing green finance standardization through the Working Group on Green Finance Standards. Guided by the principles of clarity, practicability, and alignment with international norms, the PBoC has been actively constructing a comprehensive green finance standards framework.

Notably, since 2021, three major standards have been officially released. They include the "Green Bond Endorsed Projects Catalogue (2021 Edition)" (PBoC, NDRC, and CSRC 2021), the "Guidelines for Financial Institutions Environmental Information Disclosure" (PBoC 2021a), and "Financing Instruments for Environmental Rights and Interests" (PBoC 2021b). An additional 15 standards are under development, covering critical areas such as ESG evaluation and carbon accounting.

Several of these standards are being piloted in selected regions to assess feasibility and gather feedback for broader implementation. The PBoC has conducted transition finance studies across four key sectors—steel, coal-fired power, building materials, and agriculture—while local governments in cities like Huzhou and Shanghai have initiated their own transition finance standards, laying the groundwork for nationwide application.

China has also advanced international harmonization efforts, notably through the development of the China-EU Common Ground Taxonomy (CGT). This joint framework identifies 72 economic activities deemed climate-friendly by both jurisdictions, allowing financial products aligned with the CGT to gain greater recognition in international markets.

Further progress was marked in 2023 when the Green Finance Committee facilitated the issuance of 193 green bonds in July and 27 in September (Fan 2023). Additionally, the Insurance Association of China released the Green Insurance Classification Guidelines (2023 Edition) in 2023, which standardize green insurance products, investments, and operational practices (IAC 2023). These guidelines provide clear product categories, quantitative benchmarks, and data protocols—enhancing institutional capacity to offer green insurance and invest in green assets, while enabling future development of robust evaluation tools.

Several GCC countries are actively developing green finance taxonomies to establish standardized criteria for identifying and classifying environmentally sustainable projects. Among them, the UAE is the most advanced, having released a set of "Design Principles" in late 2023, with the final taxonomy expected to be published soon. Saudi Arabia is formulating its taxonomy under the framework of the Saudi Green Finance Strategy, targeting completion for 2026. However, this timeline may be extended due to the complexity of multi-stakeholder coordination.

Kuwait has introduced green bond guidelines as a preliminary step and is in the process of drafting a broader taxonomy. Similarly, Qatar, Bahrain, and Oman have initiated efforts to develop their own national taxonomies, reflecting a regional shift toward greater alignment with international green finance standards and improved investment transparency.

Despite ongoing advancements, several challenges persist in the development and implementation of sustainable finance standards and taxonomies across the GCC. One major obstacle is to establish clear, consistent criteria for what qualifies as "green," given the diversity of sectors and technologies involved. Regional harmonization of taxonomies requires alignment with global frameworks, while limited institutional capacity and insufficient high-quality environmental data hinder implementation and impact assessment. Additionally, broad stakeholder engagement is essential to drive adoption, ensure regulatory coherence, and mobilize capital toward national and regional sustainability goals.

Disclosure and Reporting

Climate-related information disclosure has become a central focus of financial policy and regulation, particularly from 2023 onward, as ESG disclosures gain prominence. A key driver behind this trend is the International Sustainability Standards Board (ISSB), established by the International Financial Reporting Standards (IFRS) Foundation. In June 2023, the ISSB issued two foundational standards: IFRS S1 (general requirements) and IFRS S2 (climate-related disclosures) (IFRS 2023). These standards align with the Task Force on Climate-related Financial Disclosures (TCFD) and mark a major step toward the global harmonization of sustainability reporting.

In China, the PBoC has played a leading role in promoting climate-related information disclosure. In 2021, the PBoC issued guidelines encouraging financial institutions—particularly commercial banks—to report on environmental performance. By 2023, major banks such as the Industrial and Commercial Bank of China (ICBC) and local banks such as the Shanghai Rural Commercial Bank began publishing dedicated environmental and ESG reports. Disclosure has become mandatory in cities such as Shenzhen and Huzhou, underscoring the growing regulatory emphasis on transparency.

Listed companies have also become focal points for ESG disclosure, driven by rising investor demand. The State-Owned Assets Supervision and Administration Commission (SASAC) has mandated ESG reporting for all state-owned enterprises (SOEs) and state-controlled listed firms by 2023. Concurrently, the China Securities Regulatory Commission (CSRC) is guiding stock exchanges in developing ESG guidelines. As a result, approximately one-third of A-share listed companies issued ESG or non-financial reports in 2023, up from one-quarter in 2022. ESG disclosure rates for government-controlled companies exceeded 70%, reaching a historic high.

In a major regulatory advancement, the Shanghai, Shenzhen, and Beijing stock exchanges—under CSRC's guidance—released the "Guidelines for Sustainability Reporting of Listed Companies" in April 2024, effective from May 1, 2024 (Shi and Guo, 2024). These guidelines require companies listed on indices such as the SSE 180, STAR 50, SZSE 100, and ChiNext, as well as cross-listed firms, to publish 2025 sustainability reports by 2026. Other companies are encouraged to report voluntarily. The guidelines prioritize climate-related issues, mandating disclosure of Scope 1 and Scope 2 carbon emissions and scenario analysis.

Complementing this, on May 27, 2024, China's Ministry of Finance released the "Sustainability Disclosure Standards for Business Enterprises—Basic Standard," forming part of a broader disclosure system that includes thematic standards and application guidelines (Ministry of Finance of China 2024). A climate-specific disclosure standard is expected by 2027.

In the GCC region, sustainable finance frameworks are embedded in strategic agendas and national green initiatives. However, stock exchanges are playing a pivotal role in institutionalizing ESG disclosure. Countries are progressing at different speeds. The Qatar Stock Exchange (QSE) mandated ESG reporting starting in January 2022, while the Abu Dhabi Securities Exchange (ADX) and Saudi Arabia's Tadawul introduced reporting requirements for 2023 and 2024, respectively. The Dubai Financial Market (DFM) continues to offer voluntary guidelines.

Though all GCC exchanges reference global standards such as the Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB), approaches vary. UAE exchanges, for example, offer flexible frameworks: the ADX includes detailed ESG metrics and targets, while the DFM allows companies to tailor disclosures to industry-specific operations. The QSE has adopted a more prescriptive model through its 2021 ESG Guidelines, requiring listed companies to report on environmental and social performance with a focus on corporate governance and risk management, referencing the UN PRI.

Saudi Arabia's Tadawul launched an ESG reporting framework in 2021 that encourages standardized disclosure based on GRI and SASB but remains among the least prescriptive in the region. Similarly, the Bahrain Bourse introduced ESG guidelines aligned with GRI and SASB and made ESG reporting mandatory in 2022.

Oman and Kuwait remain in the early stages of ESG disclosure development. While Oman continues to monitor international best practices, it has yet to publish a comprehensive ESG reporting framework. Kuwait, for its part, encourages

ESG disclosure among listed companies but currently lacks binding reporting requirements. The Kuwait Stock Exchange is actively engaging with stakeholders to identify and develop best practices for ESG reporting. A promising regional advancement occurred in January 2023, when the GCC Exchanges Committee introduced a set of unified voluntary ESG indicators for listed companies (Saudi Exchange 2023), signaling a step toward greater harmonization of ESG standards across the region.

In contrast, disclosure guidance for green and sustainability-related debt instruments remains fragmented. Global organizations such as the International Capital Market Association (ICMA) and the Loan Syndications and Trading Association (LSTA) have introduced widely adopted frameworks including the Green Bond Principles (GBP), Social Bond Principles (SBP), Green Loan Principles (GLP), Social Loan Principles (SLP), Sustainability-Linked Bond Principles (SLBP), and Sustainability-Linked Loan Principles (SLLP).

GCC countries and financial institutions have generally aligned their green financing frameworks with these global principles, incorporating requirements for impact measurement and volume reporting. However, while sovereign green debt frameworks are in place, many green projects continue to rely on funding from sovereign wealth funds and private banks using their own internal criteria. This complicates investment decisions based on ESG reporting and raises concerns around greenwashing. As a result, independent third-party verification has become an essential safeguard across the region's debt markets.

Roadmap for China–GCC Partnership

Strengthening China–GCC Cooperation in Sustainable Finance

Economic ties between China and the GCC states have deepened considerably. Both parties have implemented financial market reforms to facilitate greater cross-border access. For instance, Dubai has aligned its trading week with international markets, while Saudi Arabia has eased foreign ownership restrictions on equities. In parallel, China is expanding international access to its domestic equity markets through Hong Kong and is developing key infrastructure such as the Cross-Border Interbank Payment System (CIPS) and central bank digital currencies (WEF 2024).

Green finance is emerging as a core dimension of this partnership. Chinese private investment is increasingly flowing into renewable energy projects across the GCC. This collaboration has taken the form of joint ventures, technology transfer, and direct financial investment. A notable example is Saudi Arabia's ACWA Power, which issued a 1.8 billion SAR green sukuk in 2023—highlighting the potential of Islamic green finance in the region (ACWA Power 2024). From China's perspective, such instruments are aligned with its strategy to fund Belt and Road Initiative (BRI) projects.

Chinese financial institutions are becoming more involved in regional green finance. The PBoC has supported projects like Hassyan and Al Dhafra in the UAE.

In 2023, the PBoC issued a $770 million BRI green bond, while the Industrial and Commercial Bank of China (ICBC) Dubai branch launched a $600 million carbon neutrality bond focused on regional green projects (Xinhua Net 2023). Notably, the flow of green capital is bidirectional: the First Abu Dhabi Bank issued the GCC's first CNY-denominated green bond, underscoring the growing interconnectivity of financial markets.

Beyond financing, both sides are investing in green finance infrastructure. The UAE and China are planning to establish a Green Finance Center in Abu Dhabi, designed to facilitate knowledge exchange, standard-setting, and financial innovation. This initiative leverages China's institutional expertise in green finance and the UAE's position as a regional financial hub.

The importance of institutional dialogue was reaffirmed at the China–GCC Forum for Industries and Investment, held in May 2024 in Xiamen, where parties reiterated their commitment to finalizing the FTA outlined in the 2004 Framework Agreement for Economic Cooperation. Despite 10 negotiation rounds, several issues remain unresolved. Nonetheless, the Joint Action Plan for 2023–2027 includes priority areas such as services trade, digital trade, and financial technology cooperation (Ministry of Foreign Affairs of the Kingdom of Saudi Arabia 2022).

Differentiated Drivers and Shared Opportunities

China and the GCC approach sustainability transitions from distinct starting points. For China, the imperative is to decarbonize an energy-intensive industrial economy, driven by both domestic environmental concerns and international market expectations for greener supply chains. Achieving these goals requires strong support from the financial sector.

In contrast, the GCC economies are seeking to diversify away from hydrocarbon dependence, using sustainable finance as a tool to attract private capital and develop new low-carbon industries. This transition is essential for long-term fiscal stability and economic sustainability.

China's dominance in the renewable energy supply chain, coupled with the GCC's expanding clean energy ambitions, provides a strong foundation for joint climate investment initiatives. Furthermore, ongoing regulatory reforms in both regions are enhancing financial market access, creating strategic opportunities for new partnerships, innovative sustainable finance solutions, and deeper integration of capital markets in support of the global energy transition.

A Roadmap for China–GCC Sustainable Finance Cooperation

To build a robust sustainable finance partnership, China and the GCC should pursue cooperation through three strategic pillars:

Policy Dialogue: There have been a number of bilateral dialogues between China and GCC countries, including on financial cooperation and joint efforts on climate change. It is important to include green and transition finance into these policy dialogues, especially for the attention of financial regulators in China and GCC countries.

Harmonizing Standards: Standard setting is an important component of green and transition finance policy frameworks. Harmonizing standards between China and the GCC countries is crucial to lowering transaction costs. This includes green taxonomies, transition finance principles, ESG disclosure and reporting guidelines, as well as guidance on scenario analysis and transition pathway development.

Connecting Products and Markets: With aligned standards, market actors can design innovative green and transition finance products accessible to investors in both regions. Over time, capital, credit, and carbon markets can be progressively interconnected.

These pillars form the basis of a phased roadmap for cooperation:

In the short term, China–GCC cooperation should focus on green investment projects and establish an official sustainable finance partnership mechanism to facilitate regulatory dialogue and initial alignment on taxonomies and reporting standards.

In the medium term, transition finance presents significant potential for deeper cooperation, as both China and the GCC can leverage their respective strengths in capital and technology to support the decarbonization of carbon-intensive sectors.

In the long term, market connections will enhance cooperation as adequate green and transition finance products and sufficient investors emerge. Market connections can develop across capital markets, credit facilities, and carbon trading platform, enabling the development of a diverse and mature suite of sustainable finance instruments.

Conclusion

The evolving landscape of sustainable finance and transition investment highlights the financial sector's crucial role in advancing low-carbon economies. It is essential to distinguish between green finance, which directly supports environmentally beneficial projects, and transition finance, which aids carbon-intensive industries to become sustainable. While China has established itself as a global leader in green bond issuance, GCC countries are increasingly steering their financial strategies toward sustainability to reduce economic reliance on hydrocarbons.

Regulatory frameworks and policy interventions are crucial in shaping the markets for sustainable finance. For both China and the GCC, priorities include harmonizing standards, improving information disclosure, and fostering cross-border cooperation to address systemic risks—such as greenwashing—while ensuring alignment with the Paris Agreement and broader climate commitments.

The China–GCC sustainable finance roadmap outlined in this chapter offers a strategic foundation for deepening collaboration. It emphasizes three core pillars: policy dialogue, standard harmonization, and the development of integrated financial markets that can support innovation in green and transition finance products.

Ultimately, the success of these efforts relies on a shared commitment to the UN SDGs and the effective mobilization of each side's comparative advantages. Through strategic partnerships, China and the GCC can jointly mobilize the financial, technology, and regulatory resources needed to advance a resilient, inclusive, and sustainable global economy.

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9 China–GCC Collaboration on Renewable Energy Supply Chain

Haiyan Qin, Li-Chen Sim, and Steve Griffiths

Overview of the Renewable Energy Industry in the GCC

Current State of the Renewable Power Market

The Middle East possesses solar and wind resources that exceed the global average. Yet, the region trails behind all others—except Central America and the Caribbean—in the actual deployment of solar and wind energy, contributing just 0.9% to global renewable power generation in 2022 (IRENA 2024). The six countries of the Gulf Cooperation Council (GCC) are a microcosm of this trend. Despite being endowed with some of the world's most favorable solar conditions, two to three times greater than much of Europe (IRENA 2016), the gap between operational and prospective solar capacity remains significant. Oman and Saudi Arabia, for example, rank sixth and seventh globally in practical photovoltaic (PV) potential (ESMAP 2020), yet their realized solar deployment still falls short relative to announced or under-construction projects (GEM 2023).

Notwithstanding the above, the deployment of utility-scale solar power has accelerated in the past few years. The United Arab Emirates (UAE) is the frontrunner, accounting for more than 60% of the bloc's total renewables capacity and close to 70% of renewable energy investments. In 2022, it led its GCC peers in generating 5% of its electricity from renewable sources, ahead of Oman in second place with 4% renewable generation (Table 9.1). In Oman and Saudi Arabia, the pace and scope of renewable deployment is rapidly catching up.

The GCC states have compelling strategic and economic motivations to accelerate the adoption of renewable energy. Growing electricity demand necessitates an expansion in power generation capacity. Investing in renewables not only supports the efforts of the GCC countries to diversify their economies beyond hydrocarbons but also fosters the development of local industries and job creation. Crucially, increasing the share of renewable energy enhances the carbon competitiveness of domestically produced industrial goods in the global marketplace.

The GCC also offers several favorable conditions for the development of renewable power, which have contributed to consistently low bid prices for solar and wind projects. The GCC countries boast exceptional solar irradiation and strong wind resources, coupled with abundant, low-cost desert land suitable for large-scale

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Table 9.1 Renewables in the GCC

Country	*Installed capacity of wind and solar (MW)*			*Power generation of wind and solar (MWh)*		
	2018	*2023*	*Share of total electricity capacity (2023)*	*2018*	*2022*	*Share of total power generation (2022)*
Bahrain	7	60	0.60%	12	84	0%
Kuwait	46	114	0.56%	55	1899	2%
Oman	26	722	6.23%	49	1670	4%
Qatar	24	805	7.22%	8	8	0%
Saudi Arabia	87	2991	2.94%	266	2839	1%
UAE	601	6006	14.02%	1204	7753	5%

Source: IRENA (2024)

Note: MW, megawatts; MWh, megawatt hours.

renewable installations (with Bahrain as a notable exception due to its limited land availability). Competitive and transparent auction mechanisms have successfully attracted both domestic and international developers. Long-term power purchase agreements (PPAs) spanning 20–25 years, typically backed by state-owned offtakers and supported by sovereign guarantees, provide financial certainty for investors. In addition, attractive financing conditions have made utility-scale renewable energy projects especially viable. Continued improvements in policy and regulatory frameworks are further strengthening the investment climate for renewables across the GCC.

Outlook for the Renewable Power Market

The outlook for renewable power in the GCC is mainly driven by developments in the two largest electricity markets, Saudi Arabia, and the UAE. The bloc could become one of the fastest growing markets globally and a global hub for clean energy technologies (Goldman Sachs 2023). Solar is expected to comprise the bulk of these capacity additions, with Saudi Arabia expected to surpass the regional leader, the UAE, around 2026 (Razzouk and Rudgard 2023).

All GCC countries, with the exception of Qatar, have established a mix of renewable energy, emissions, and net-zero targets (IRENA 2023). The UAE appears well-positioned to meet its goal of achieving a 44% clean energy capacity by 2050, supported by clear strategic roadmaps, a strong pipeline of projects led by procurement agencies in Abu Dhabi and Dubai, advanced regulatory capabilities, effective governance, and solid financial standing. Per Goldman Sachs, with clean energy already contributing 28% to the UAE's power mix in 2023, its 32% target by 2030 is well within reach (Goldman Sachs 2025). A recent Energy Institute survey found that over 60% of energy professionals in the UAE expect the nation to meet or surpass its 2050 energy diversification target (Energy Institute 2023).

While a unified, cross-emirate renewable energy framework could provide added coherence—since energy policy remains under the jurisdiction of individual emirates rather than the federal government—its absence does not significantly deter key stakeholders such as developers, equipment suppliers, auditors, surveyors, and engineering firms (Sim and Young 2025).

Saudi Arabia is rapidly expanding its renewable energy industry as part of Saudi Vision 2030, aiming to diversify its energy portfolio and create new economic growth. The country has set ambitious targets, seeking to generate 50% of its electricity from renewables, reaching an installed capacity of 130 gigawatts (GW) by 2030. Government initiatives, including the National Renewable Energy Program (NREP) and the Saudi Green Initiative, are fostering investment and technological innovation for renewables. Large-scale solar and wind projects, such as the 1.5 GW Sudair Solar PV plant and the 400 MW Dumat Al Jandal Wind Farm, are driving the market transformation.

The outlook for utility-scale renewable energy in the GCC appears promising and is supported by several key developments. One major driver is the electrification of transport. Many GCC cities are making significant investments in modernizing and expanding their public transit systems, including metro, tram, and bus networks, to reduce their reliance on fossil fuels. Another important factor is the electrification of desalination. The GCC accounts for approximately 44% of global desalination capacity (Jägerskog and Barghouti 2022), and growing water demand is driving the need for additional plants. Newer facilities are increasingly adopting high-efficiency, renewable-powered technologies such as reverse osmosis and solar-powered desalination processes.

These trends are being further supported by the emergence of battery energy storage systems (BESS), which help store energy and stabilize the grid by mitigating the intermittency of renewable sources. Both the UAE and Saudi Arabia have recently issued tenders for standalone BESS projects, indicating a growing momentum in this area.

Lastly, green hydrogen offers a potential pathway for economic diversification and an expansion of the GCC's renewable energy market. While numerous green hydrogen projects have been announced, only one—Saudi Arabia's Neom project—has reached a final investment decision (FID), underscoring the significant challenges in scaling up from concept to implementation. Large-scale green hydrogen development requires substantial capital, robust infrastructure, and clear demand signals to become commercially viable.

Solar and Wind Supply Chains

China has maintained its competitive edge in the global renewable energy market for over a decade. This can be attributed to economies of scale driven by strong domestic demand as the country accelerates its own renewable energy expansion. In 2022, Chinese companies produced nearly 85% of the world's solar panels, a sharp increase from 55% in 2010 (IEA 2022a). Notably, Chinese-manufactured solar panels were priced 57% lower than those produced in the United States (U.S.)

and European Union (EU) (Wood Mackenzie 2023a). This dominance is further reflected in global module sales, with Chinese companies occupying the top four positions in the first half of 2023 (Trendforce 2023).

However, China's leadership is less pronounced in other parts of the solar value chain. In the inverter market, Huawei and Sungrow accounted for over 50% of global inverter sales in 2022. Yet strong competition remains from non-Chinese manufacturers such as Growatt (U.S.), SMA (Germany), and Power Electronics (Spain), which have benefited from supportive renewable energy policies in their home markets (Wood Mackenzie 2023b). The global tracker market is even more diversified. In 2021, the top five tracker companies—primarily based in the U.S. and Spain—had a near 70% market share, making it significantly less China-centric (Nextracker 2022a).

In contrast, the supply dynamics of the wind turbine sector follow a different trajectory. Chinese turbine manufacturers, historically concentrated on serving the domestic market—still the world's largest market for wind power—are now increasingly expanding abroad. A new generation of Chinese firms, drawing on domestic experience and cost advantages, is targeting emerging markets such as South America and the Middle East, where barriers to entry are generally lower than in the more mature markets of North America and Europe. This international push is further supported by cost competitiveness, with Chinese wind turbines priced at less than half the global average (Blackburne 2022).

China's global influence extends into the Gulf's renewable energy supply chains. In the GCC, most components used in solar and wind power projects are imported, with China being the predominant supplier (Table 9.2). China has been the major supplier of solar PV panels for projects developed in GCC countries as well as for projects across Asia developed by GCC-based companies such as Masdar, ACWA Power, AMEA Power, and Fotowatio. In contrast, European and American firms maintain a strong presence in the supply of inverters and trackers for these projects (Annex 1). Notably, Spain's PV Hardware has leveraged rising demand from Gulf developers by establishing its first overseas tracker manufacturing facility in Saudi Arabia.

Table 9.2 Top three suppliers of solar modules (assembled and non-assembled) in selected Gulf States, by import value

2022	*Oman*				*UAE*				*Saudi Arabia*		
	Share 2023 (%)		*Share 2022 (%)*		*Share 2023 (%)*		*Share 2022 (%)*		*Share 2023 (%)*		*Share (%)*
China	78.6	China	83.5	China	99.1	China	98.8	China	98.9	China	99.9
UAE	16.0	UAE	8.4	Vietnam	0.4	Canada	0.17	USA	0.9	Germany	0.04
South Korea	0.2	Denmark	1.5	India	0.16	United Kingdom	0.16	Austria	0.04	Austria	0.02

Source: UN Comtrade (2024).

In the wind energy sector, GCC projects were largely supplied by American and European turbine manufacturers before 2020. In recent years, however, Chinese companies such as Goldwind and Envision have increasingly secured tenders in both the GCC and in countries like Uzbekistan, where developers such as Masdar and ACWA are actively involved (Annex 2). As a result, Saudi Arabia and Uzbekistan have emerged as important markets for Chinese wind turbine exports (Figure 9.1). One contributing factor is the lower level of scrutiny from GCC developers of the social and environmental sourcing of turbine materials and components. This has reduced procurement barriers and given Chinese manufacturers a competitive advantage in the region.

The GCC states have a limited footprint in the global value chain of renewable energy technologies. This is partly due to their historically slow uptake of renewable energy and relatively small market size, both of which have constrained the growth of local manufacturing.

Consequently, there are currently only a handful of component producers in the Gulf. For example, Bahrain's Solar One, launched in 2017 as the country's first solar panel manufacturer, operates with a modest 40 MW module capacity, significantly smaller than Trina Solar's 500 MW plant in Thailand and 5 GW facility in Vietnam. Similarly, QSTec in Qatar, a polysilicon producer for the PV industry, appears to be largely inactive.

By contrast, Masdar Solar in Saudi Arabia has established a more substantial manufacturing footprint, with a production capacity of 1.2 GW for solar cells. It is well-positioned to benefit from Saudi Arabia's growing portfolio of solar projects. Masdar Solar also enjoys strategic advantages from being part of the Bin Omairah Group, a prominent power industry contractor, which enhances its competitiveness within the region's renewable energy landscape.

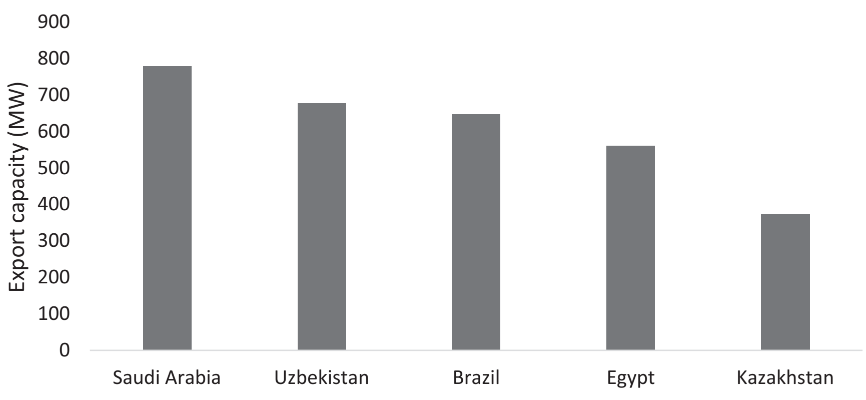

Figure 9.1 Top export destinations of China-made turbines.

Source: CWEA (2024).

Investment in Local Content

Local content requirements (LCRs) have become an increasingly prominent feature of renewable energy policies worldwide over the past few decades. These measures compel businesses to utilize a minimum share of domestically produced goods or locally provided services, with the aim of supporting national industries, generating employment, and advancing energy diversification. Between 1999 and 2015, at least 21 countries adopted or announced LCRs, and since 2015, an additional ten countries have implemented similar measures (PIIE 2021).

The GCC states are actively implementing policies and initiatives to enhance local content in the renewable energy sector. Saudi Arabia has made significant strides in embedding LCRs within its renewable energy framework. The NREP mandates increasing local content in renewable projects, aiming for 75% localization by 2030. The Local Content and Government Procurement Authority has been instrumental in setting methodologies for accounting LCRs.

While the UAE does not have a federal LCR policy specific to renewable energy, individual emirates have launched initiatives to promote local participation. Abu Dhabi's Department of Energy has introduced guidelines to increase local content in government procurement, encouraging the involvement of domestic suppliers and contractors in renewable energy projects.

Oman has formalized its approach to local content through the National Policy for Local Content (2024–2030), which emphasizes the development of domestic industries and services in the energy sector. The Majd initiative, launched in 2024, aims to enhance local content in the energy and mineral sectors by focusing on four main pillars: policy development, capacity building, supplier development, and performance monitoring. These efforts are complemented by the In-Country Value (ICV) program, which sets minimum local content requirements for state-tendered renewable projects.

Qatar's Tawteen program, launched by QatarEnergy, focuses on enhancing local content in the energy sector by developing a robust local supply chain and promoting the participation of domestic companies in energy projects. The program includes setting minimum local content requirements for engineering, procurement, and construction (EPC) contracts, as well as operations and maintenance services.

Foreign direct investment (FDI) in renewable energy-related manufacturing remains relatively limited across the Gulf region. However, countries such as Saudi Arabia, the UAE, and Oman—buoyed by ambitious renewable energy goals, credible project pipelines, local content incentives, and a strong execution record—are well-positioned to attract the bulk of this investment. In 2024, Saudi Arabia's Public Investment Fund (PIF) announced strategic partnerships with Chinese firms like Jinko, TCL, and Envision to boost domestic manufacturing capacity for solar PV and wind turbines. Similarly, Trina Solar and GCL unveiled plans to establish large-scale solar manufacturing facilities in the UAE, while Hanan Drinda announced similar intentions in Oman. It is estimated that up to 40% of the solar supply chain can already be sourced domestically, supported by existing capabilities in civil and electrical engineering, as well as the availability of key materials such as cabling, steel, cement, and aluminum (AlOtaibi et al. 2020).

However, it is important to note that, even when accounting for all announced localization projects, China is expected to maintain its dominant position in global clean energy manufacturing, with its share of solar PV and wind turbine production projected to remain around 79% and 64%, respectively, by 2030 (IEA 2023a). This underscores the challenge that, while LCRs may successfully stimulate initial domestic production, transforming these sectors into globally competitive industries remains significantly more difficult.

Overview of the Renewable Energy Industry in China

To achieve its 2060 carbon neutrality goal, the Chinese government has introduced a comprehensive set of national and local policies to guide and accelerate the development of renewable energy. Key policies among these are the 14th Five-Year Plan for Renewable Energy Development and the Action Plan for Reaching Carbon Peak Before 2030, which aim to refine strategic priorities and establish clear targets for the renewable energy sector. These policy initiatives have significantly propelled the growth of wind, solar, and hydrogen power, positioning them as central pillars in China's broader low-carbon transition, power system modernization, and long-term ambition to build a zero-carbon electricity system.

The installed capacity of renewable energy in China has increased significantly. According to the National Energy Administration of China, by the end of 2023, the country's installed renewable capacity reached 1,515 GW. For the first time in its history, its renewable power capacity surpassed coal-fired power, with renewables now accounting for more than 50% of its total installed power generation capacity. Additionally, total renewable power generation exceeded 3,000 terawatt hours (TWh), supplying about one-third of the nation's total electricity consumption. Notably, wind and solar alone generated 1,450 TWh, contributing around 16% of China's total electricity consumption, reflecting its rapid shift toward clean energy.

Solar PV

China's solar PV industry continues to advance at a remarkable pace. Following over a decade of rapid development, it has emerged as one of the few strategic sectors in which China holds a strong international competitive edge. It also plays a crucial role in driving the country's broader energy transition. Currently, China leads the world in key aspects of the solar PV sector, including its manufacturing scale, technological sophistication, market expansion, and industrial system integration (CPIA 2023).

China's newly installed solar PV capacity reached a record high in 2023, with an addition of 216 GW of grid-connected PV systems. This brought the country's total cumulative grid-connected PV capacity to over 600 GW, securing its position as the global leader in both annual and cumulative installations. Of this total, distributed PV systems accounted for 254 GW, while centralized PV power stations contributed 354 GW. Looking ahead, new installations in 2024 are projected to exceed 200 GW, pushing the cumulative installed capacity beyond 810 GW.

China's solar PV industry features a fully integrated value chain, spanning from upstream high-purity silicon production and midstream solar cell manufacturing to downstream construction and the operation of PV power plants. According to the International Energy Agency (IEA) (2023a), key segments of the PV supply chain—such as polysilicon, wafer, cell, and module manufacturing—are highly concentrated in China, reinforcing the country's pivotal role in the global industry.

The scale of China's solar PV sector continues to grow rapidly. Data from the China Photovoltaic Industry Association show that in 2023, output across major segments, including polysilicon, wafers, cells, and modules, grew by more than 64% year on year, with the industry's total output value surpassing 1.75 trillion yuan. Wafer production reached approximately 622 GW, up 67.5%, while cell production hit around 545 GW, marking a 64.9% annual increase.

Polycrystalline Silicon

In 2023, China's polysilicon production reached 1.43 million tons, representing a 66.9% year-on-year increase. In 2024, with the rollout of technological upgrades and new production capacity by polysilicon manufacturers, output is projected to exceed 2.1 million tons. A key driver of this growth is the advancement in granular silicon technology, which has reduced energy consumption to below 15 kilowatt hours (kWh) per kilogram. Notably, XG Science and Technology's fluidized bed reactor (FBR) method has achieved a production capacity of 600,000 tons of granular silicon.

Wafer

In 2023, China's national silicon wafer production reached approximately 622 GW, marking a 67.5% year-on-year increase. With leading manufacturers continuing to ramp up their capacity, total production is expected to exceed 935 GW in 2024. The industry has seen ongoing debate over standard wafer sizes—specifically between 182 millimeter (mm) and 210 mm formats. In response, Zhongheng Shares introduced the 210R rectangular wafer, which enables solar modules to achieve an additional 10 Watts (W) of output, further enhancing efficiency.

Cell

In 2023, China's battery cell production reached approximately 545 GW, reflecting a 64.9% year-on-year increase. National production is projected to exceed 820 GW in 2024. Currently, passivated emitter and rear cell (PERC) technology remains the mainstream choice for photovoltaic modules, having achieved an industrialized conversion efficiency of 23.5%—near its theoretical limit. Among the next-generation high-efficiency cell technologies, tunnel oxide passivated contact (TOPCon) offers a favorable balance of performance and cost, making it the preferred option for most new production lines. In contrast, heterojunction technology

(HJT) and back-contact cells (XBC) hold smaller market shares. Looking ahead, tandem cells that combine perovskite and silicon layers represent a key avenue for future development. These cells have a theoretical conversion efficiency of up to 35%, significantly surpassing the 29.4% efficiency ceiling of conventional single-crystalline silicon cells.

Module

China remains the global leader in solar PV module production, driven by its vertically integrated supply chain, large-scale manufacturing capacity, and continued technological innovation. In 2023, the country significantly expanded its module output, supported by advances in high-efficiency cell technologies such as PERC, TOPCon, and emerging bifacial and tandem cell designs. Manufacturers have also optimized module performance through innovations like larger wafer formats, half-cut cells, and reduced-gap designs. As demand grows both domestically and internationally, particularly for high-efficiency and bifacial modules, China's PV module production is expected to continue expanding rapidly, reinforcing its dominant position in the global solar market.

Wind Power Industry

China's wind power installation continues to demonstrate strong and sustained growth, reinforcing its status as the global leader in both onshore and offshore wind development. In 2023, the country added approximately 75 GW of new wind power capacity, increasing its cumulative installed capacity to 470 GW—representing a 1,000-fold expansion over the past two decades. China has ranked first globally in annual wind power installations for 15 consecutive years, with its share of the global market rising from less than 30% in 2012 to over 50% in 2023 (GWEC 2023a). The offshore wind sector has also seen significant progress, reaching 37.69 GW by 2023, with Jiangsu and Guangdong provinces each exceeding 10 GW. The sector is increasingly shifting toward large-scale, clustered developments in deeper offshore locations.

China has also solidified its role as the world's largest manufacturing hub for wind power equipment. By 2023, it was exporting turbines to 54 countries, with Southeast Asia emerging as a key destination. The country now accounts for over 60% of global wind equipment production and has developed a comprehensive value chain encompassing project development, construction, equipment manufacturing, research and development, certification, and financial services (GWEC 2023b).

Blade Materials

Blade material manufacturers are intensifying the research and industrial application of advanced materials, with carbon fiber emerging as a key focus. A substantial increase in carbon fiber production capacity is anticipated over the next three to five years. To meet rising demand, domestic producers such as Jilin Chemical

Fibers, Zhongfeng Shenying, and Shanghai Petrochemical are rapidly scaling up their supply capabilities.

Blades

China's wind turbine blade manufacturing sector has expanded significantly, with more than 100 production facilities established nationwide and an estimated total production capacity of approximately 120 GW. Blade manufacturers in China can be broadly categorized into two groups: specialized suppliers and integrated turbine manufacturers with in-house blade production capabilities. Leading specialized suppliers include Sinoma Technology, Times New Materials, and Shanghai Alang. In contrast, major turbine manufacturers such as Mingyang, Sany Heavy Energy, and Envision produce blades internally as part of their vertically integrated operations. The presence of foreign blade manufacturers in the Chinese market remains limited. For instance, LM Wind Power has established manufacturing facilities in Jiangyin and other locations, though the bulk of its production is intended for export.

Bearings

Chinese manufacturers are now capable of producing all major types of wind turbine bearings, although market share varies due to differences in technological advancement across companies. For onshore wind turbines with capacities ranging from 5 to 10 MW, bearings produced by Luoyang Bearing, Wazhou Bearing, Xinqianglian, and Zhuzhou Research Institute are widely used. In 2024, main shaft bearings for turbines of 10 MW and above have begun entering small-scale deployment.

Notable progress has also been made in the offshore wind segment. Zhuzhou Research Institute has successfully developed 25 MW main shaft bearings, while Luoyang Bearing has already deployed units exceeding 20 MW. Meanwhile, companies like Tianma are actively advancing high-capacity bearing technologies to meet the growing demands of the offshore wind market.

Converters

China's converter production capacity is adequate to support the annual installation of 60–75 GW of wind turbines. Leading domestic suppliers include Hope Wind, Sungrow Power Supply, RIFENG Electric, and Haitai Control. In recent years, domestic manufacturers have steadily gained market share, gradually displacing international players such as ABB and Emerson.

Wind Turbines

China hosts approximately 15 major wind turbine manufacturers, with only two international firms—Vestas and GE—active in the domestic market. This limited foreign presence underscores the growing dominance of Chinese enterprises in the sector. By the end of 2023, 132 domestic final assembly facilities had been established nationwide by these 15 manufacturers, collectively providing an annual design production capacity of around 54,000 turbine units, equivalent to 289 GW.

Leading Chinese manufacturers include Goldwind Science & Technology, Mingyang Smart Energy, Envision Energy, Zhejiang Windey, and United Power, with a combined production capacity exceeding 50 GW. Among these, Goldwind holds a market share of 19.7%, followed by Envision (18.7%), Windey (13.1%), and Mingyang (12.8%).

China also leads in the development of high-capacity wind turbines. As of 2023, the largest wind turbine in the country connected to the grid had a rated capacity of 16 MW. The largest offshore wind turbine delivered reached 20 MW, while the largest onshore model reached 11 MW. Furthermore, turbines with capacities of up to 22 MW (offshore) and 15 MW (onshore) have been released, representing the highest single-unit capacities globally.

Understanding and Managing the Risks in Renewable Supply Chains

The current state of global solar and wind energy supply chains is characterized by challenges and strategic responses aimed at derisking, with a particular focus on enhancing security, resilience, and sustainability (IEA 2023b). The solar industry, for instance, has faced significant supply chain disruptions since 2020, including price increases and trade restrictions partly due to geopolitical tensions and allegations of human rights abuses in key mining and manufacturing regions such as Xinjiang, China. These disruptions underscore the vulnerability of the solar supply chain and highlight the need for diversification in manufacturing and sourcing practices to mitigate risks (Mulvaney and Bazilian 2023).

Case Study: Masdar's Derisking Strategy

We provide a deep dive into the Abu Dhabi-based and emirate-owned power developer, Masdar, to analyze how the company perceives and manages risks to its largely China-centered supply chain. The findings relate only to those risks pertaining specifically to China–GCC supply chains, and not to supply chains in general.

Masdar (formally known as the Abu Dhabi Future Energy Company) is focused on utility-scale investments in clean and renewable energy globally. As of March 2023, it had 34 operational projects, 13 projects under construction, and four committed projects, which accounted for 12.7 MW of its total gross generation capacity, or 5.4 MW of the proportional share of its project capacity (Masdar 2023). Masdar has targeted the production of 100 GW of gross renewable energy capacity globally by 2030 through acquisitions and greenfield investments. It plays a key role domestically in supporting clean energy and net-zero targets, as well as the country's diversification away from a hydrocarbon economy. Its mission is "to help maintain the UAE's leadership in the global energy sector" through commitments and investments made with other countries on renewable energy (Masdar 2023).

Masdar's responses to supply chain risks in its renewable energy business are concentrated on risk mitigation (to reduce the probability of a risk occurring or to reduce its impact on business) and risk transfer (to outsource a risk that is very likely to occur, or that will have a significant impact on its business, to a third party).

Risk Mitigation Strategies

Masdar encourages a wide variety of companies to participate in tenders for EPC contracts; no direct bilateral agreements are used to appoint EPCs. The aim is to mitigate risks related to the quality of third-party contracting services. While price is the most important consideration, there are key criteria that an EPC contractor must meet as part of Masdar's pre-qualification exercise in order to be invited to bid for a contract. These criteria include evidence of a robust health, safety, and environment management system, the company's financial health, and previous experience with large international projects. From the pool of pre-qualified contractors, Masdar then awards the EPC contract to the company with the lowest bid price. Chinese EPC companies have won several contracts, but there is a good level of diversity (Sim and Griffiths 2024b). In turn, the appointed EPCs organize competitive tenders for the required equipment.

For many years, Masdar relied on EPC contractors to deliver projects and undertake operations and maintenance (O&M) for them. Several years ago, however, Masdar unveiled a new strategy to reduce delays and cost overruns by appointed EPCs that could result in reputational damage to Masdar as the project developer. In 2016, it created an in-house subsidiary, Masdar Specialized Technical Services (MSTS) Company. This approach is similar to that used by ACWA Power of Saudi Arabia, which relies exclusively on in-house O&M services provided by its wholly-owned subsidiary, NOMAC, for all of its power and desalination projects. With O&M accounting for 10–20% of the renewables value chain, cutting out third-party O&M providers appears to be sensible (Korchurov and Beyer 2024).

For most solar power projects, an interim O&M agreement is concluded with the project's EPC contractor covering a defect liability period of two years, after which MSTS will take over for the remainder of the PPA duration. As for wind projects, Masdar contracts the turbine supplier to perform O&M. MSTS has begun to undertake a balance of plant O&M in some cases, with the eventual aim of undertaking O&M for all wind projects once MSTS ramps up its expertise.

Since wind and solar plants have a variety of critical components, Masdar tries to ensure that such equipment is based on standard, instead of proprietary, technology that is not linked to any particular vendor. This allows alternative manufacturers to be more easily identified in case the original supplier becomes insolvent and can no longer supply the critical component. Cases in point include Wuxi Suntech, a leading Chinese solar panel manufacturer, which filed for bankruptcy in 2013, and Sunergy California, another panel manufacturer and subsidiary of China's Sunergy, which filed for bankruptcy in 2021. Components for solar power offer more flexibility than for wind. For instance, string inverters and modules can be substituted for those of another brand; a solar power system can also accommodate a mix of solar modules as long as wattage and voltage are addressed. This mitigates risks to the long-term viability of renewable power projects.

An example of this was at Al Dhafra, currently the world's largest single-site solar photovoltaic project. Developed by Masdar, 2 GW worth of n-type, bi-facial solar panels was supplied by three manufacturers: JinkoSolar (520 MW), Trina (800 MW), and Suntech (680 MW).

Masdar encourages its EPC contractors to recycle materials from the construction phase, where the majority of waste will be generated, and also during the operations phase. These materials comprise mostly packaging materials like wooden pallets and cartons. Demonstrated recycling practices are also included in the proposals from pre-qualified EPCs. While Masdar is in discussions about imposing a certain level of recycling on a wider range of materials as a requirement, there are currently no mandatory targets.

Like other products, solar panels and wind turbines are subject to cost inflation from rising commodity, freight, fuel, and labor prices. To manage potential cost increases, Masdar purchases some components directly from manufacturers and in bulk quantities through its subsidiary, Source Trading Company (STC), and then sells them to the relevant EPCs at premium prices. STC was involved, for example, in the procurement for Masdar's Nur Navoi, Jizzakh, Samarkand, and Sherabad projects in Uzbekistan, for Garadagh in Azerbaijan, and for the Abu Dhabi wind program (Masdar 2023). Such direct and bulk purchases also allow Masdar to demand better product warranties and technical parameters compared to the standard terms offered by the same manufacturers. Since EPCs are spared from having to hedge against price inflation for such equipment, they have accepted the role played by STC.

Masdar has leveraged Abdu Dhabi's diplomatic heft for delivery issues related to supply chains in developing countries. The government of Abu Dhabi indirectly owns 95.71% of Masdar's share capital (Masdar 2023). The relationship with its principal has helped to facilitate access to investment opportunities as well as to governmental discussions aimed at supporting and easing logistics bottlenecks in countries where it operates. The urgency of resolving such bottlenecks is underlined by Masdar's participation in a growing number of utility-scale wind projects, including a 2 GW wind farm in Uzbekistan and a 1 GW wind farm in Kazakhstan. Unlike solar components, which can be transported using multi-modal options, road transport is the only realistic mode for delivering giant wind turbine towers and blades to remote project sites in landlocked Central Asia.

Risk Transfer Strategies

Apart from comprehensive insurance programs covering each stage of a power project, such as pre-bid, pre-financial close/notice to proceed, and construction and operational periods, Masdar's risk transfer strategy also includes obtaining product and performance warranties from equipment suppliers. Given that a solar panel's output production will naturally degrade during its lifespan, a solar panel performance warranty guarantees that it will meet or exceed a baseline of electric power output, while a product warranty covers any physical defects. Generally, solar panels from Chinese suppliers have a much shorter product warranty period than their global peers while their performance warranties are on par with global competitors (Noor 2023; Solar Quotes 2023).

To de-risk China-based environmental, social, and governance (ESG) challenges, Masdar obliges suppliers and EPCs to legally comply with international forced labor laws and with sanctions and export controls (Masdar 2022). In 2022, for example, an international consultant was engaged to verify the traceability of materials and labor conditions at Goldwind's turbine manufacturing facility in Gansu, China, for Masdar's Zarafshan wind project in Uzbekistan (IFC 2022). Masdar also routinely commissions third parties to perform environmental and social impact assessments prior to construction. Such assessments identify risks, propose remedial efforts, and consult local stakeholders. All these steps involve some degree of risk transfer to third parties. To assuage concerns that EPCs from China are simply importing Chinese labor and materials for Belt and Road projects in host countries (Hillman and Tippett 2021), Masdar procures local labor and resources where possible. For example, a concrete batching plant will be developed by a local Uzbek concrete company to service the Zarafshan wind project for which China's SEPCO III is the EPC (IFC 2022).

Overall, Masdar assessed its vulnerability to the impact of a supply chain disruption from China on its business operations as low. This was largely attributed to the company's own prudent risk mitigation and risk transfer practices, as well as to the close multifaceted relations between its principal, the government of Abu Dhabi, and China.

Policy Suggestions for China–GCC Collaboration

As China and the GCC states deepen their collaboration in the renewable energy sector, ensuring the resilience and sustainability of supply chains becomes increasingly important. This is particularly relevant given the growing interdependence of wind and solar energy technologies. The IEA has suggested a framework to de-risk supply chains for clean energy technologies. It includes five approaches, namely diversify, accelerate, innovate, collaborate, and invest (IEA 2022b). Borrowing from this framework, we suggest the following strategies to improve the resilience of GCC–China wind and solar supply chains (see Table 9.3). Subsequent paragraphs in this section will elaborate upon these strategies.

Diversifying the Supply Chain System

Global industrial competition is gradually evolving from pure technological rivalry to a more comprehensive contest encompassing technological systems, industrial

Table 9.3 Approaches and strategies to strengthen China–GCC solar and wind supply chains

Approach	*Risk to be addressed*	*China–GCC strategy*
Diversify	Supply chain concentration	Create a complete ecology of industry clusters Develop critical minerals mining industry in the Gulf • Encourage local procurement for projects led by Chinese EPC firms • Develop Gulf-based recycling industry to reduce demand for raw materials
Accelerate	Delay in rolling out and scaling up new clean energy technology	• Accelerate technology development and innovation • Accelerate the establishment of mutual recognition systems for standards and accreditation
Collaborate	Lack of alignment between public and private efforts and between governments	Strengthen the resilience and diversification of the China–Gulf clean energy supply chain cooperation mode
Invest	Inadequate financing for clean energy investment and to up skill labor force in developing countries	Material and training support to upskill and reskill the Gulf workforce

Source: Authors' analysis.

frameworks, and integrated ecosystems. Industrial clustering has become a fundamental factor of development, with a global shift toward integrated upstream and downstream collaboration, replacing the traditional fragmented, point-to-point investment model with a focused industrial cluster approach.

In specific regions, the concentration of enterprises and institutions with interconnected upstream and downstream relationships in the new energy sector fosters the development of regional industrial clusters. These clusters form cooperative and symbiotic networks, creating highly integrated ecosystems characterized by tight supply chain coordination, enhanced efficiency, and economies of scale. By leveraging the synergies between enterprises, technology, and talent, these industrial clusters cultivate resilient and highly competitive industrial systems, maximizing the advantages of collaborative innovation and industry aggregation.

This new supply chain model is characterized by scale leadership, strong international competitiveness, innovation leadership, and a complete industrial ecosystem. Globally influential enterprises lead the industry, attracting numerous component manufacturers that cluster together to form strong industrial hubs. Continuous technological innovation and iteration drive the development of disruptive and cutting-edge technologies, fostering ongoing industrial transformation and positioning these clusters as centers for new technological breakthroughs. Additionally, the model ensures a well-integrated ecosystem, where high-end resources are efficiently aggregated and optimized, enhancing overall industry efficiency and competitiveness.

Diversification efforts in the GCC energy sector have gained momentum in recent years, mainly driven by local content requirements in Saudi Arabia and Oman. As a result, China–GCC clean energy supply chains stand to benefit from expanding manufacturing capacity in the Gulf, aligning with regional industrial policies while also strengthening supply chain resilience (Sim and Griffiths 2024a). A key strategy for achieving this is encouraging local procurement, particularly for materials such as steel for wind towers, aluminum for solar module frames and racks, and cables for power transmission that can be produced locally by existing companies. A successful example of this is U.S.-based Nextracker, which partnered with Saudi steel companies to develop specialized production lines that incorporate local steel in solar tracking systems used in the Sakaka and Al Kahfah solar plants. The Sakaka project alone required 14,000 tons of steel, accounting for over 45% of the total value of trackers provided by the foreign supplier for that project (Nextracker 2022b). However, local content requirements need to be reviewed periodically to be in line with local industrial capabilities so that such requirements are not punitive, thereby disincentivizing renewable power projects in the short term as well as exports of locally made solar and wind components in the medium term (Sim and Young 2025; Scheifel, Bräuning, and Probst 2022).

Additionally, China–GCC collaboration across renewable energy supply chains can benefit significantly from the development of a robust recycling industry. This would help reduce reliance on raw materials, mitigate risks associated with geographically concentrated refining operations, and prevent toxic waste from entering landfills and the environment. Solar PV modules are 99% non-hazardous, with 95% of their materials—including glass, aluminum frames and racks, copper wires, and plastic junction boxes—being easily recyclable. Recycling aluminum consumes 95% less energy compared to primary production (European Aluminum and SolarPower Europe 2023). Similarly, wind turbines are 85–95% recyclable, with recoverable materials including steel, copper wiring, electronics, and gearing.

However, economic barriers hinder large-scale recycling efforts. In the U.S., for example, recycling PV modules costs $15–$45 per module, compared to $1–$5 per module for landfill disposal (DOE 2022a). Challenges are even greater for wind turbine blades, as efficient recycling or repurposing methods have yet to be developed.

Recycling facility development in the GCC is still in its early stages, as most renewable energy equipment will not reach the end of its service life for at least 20 years. However, investing in material recycling facilities now could provide the GCC states with a strategic advantage, positioning them as leaders in sustainable resource management and strengthening their role in the global clean energy supply chain. As GCC countries rapidly expand their renewable energy capacities, the eventual decommissioning of solar panels and wind turbines will generate significant waste, creating both environmental and economic challenges. With increasing global regulations on sustainability and battery content requirements, such facilities could position the GCC as a strategic hub for processed materials exports. Free trade agreements with the U.S. and Europe offer a further competitive advantage in supplying recycled minerals for electric vehicles and renewable energy storage. By leveraging low-cost renewable energy sources for recycling operations, the GCC can strengthen its role in the global clean energy transition, mitigate waste-related environmental risks, and drive long-term economic diversification beyond fossil fuels.

Accelerate the Research and Development of Technologies and Innovation

A joint research and development center and innovation platform should be established, such as the China–GCC Joint Innovation Center for Renewable Energy, with a focus on advancing key technologies in photovoltaics, hydrogen energy, and energy storage. In the photovoltaic sector, collaborative efforts should target the development of next-generation high-efficiency technologies such as perovskite and tandem solar cells. For wind energy, joint research could address lightweight, flexible large-scale blade designs, advanced materials, and integrated turbine system technologies. In the hydrogen sector, priority areas include the development of low-cost proton exchange membrane (PEM) electrolyzers and innovative green hydrogen storage solutions, such as liquid ammonia and organic liquid carriers.

In parallel, a green technology research and development fund should be established jointly by China and the GCC states to support pilot and demonstration projects. This fund would prioritize initiatives such as green hydrogen projects in Saudi Arabia's Neom, the UAE's Masdar, and integrated solar PV and hydrogen hubs. The goal is to accelerate the commercialization and large-scale deployment of advanced green technologies across the region.

Accelerating the Establishment of Mutual Recognition Systems for Standards and Accreditation

China's National Quality Inspection Center for Offshore Wind Power Equipment has achieved international recognition, with its certifications accepted by over 30 countries. Notably, they are recognized by countries including the U.S., Australia, Sweden, South Africa, and Thailand. This widespread acceptance underscores China's adherence to international quality benchmarks in the wind power sector. The center's certifications are backed by key accreditations issued by the China Inspection Body and Laboratory Mandatory Approval (CMA) and the China Metrology Accreditation (CAL) from the Certification and Accreditation Administration of the People's Republic of China (CNCA). The accreditation from the China National Accreditation Service for Conformity Assessment (CNAS) also confirms that the center meets international standards for testing and calibration laboratories, enhancing the credibility of its certifications.

To support the growth of renewable energy industries in the GCC, Chinese standards and accreditation institutes could play a more active role with local stakeholders. Key initiatives may include promoting international mutual recognition systems, establishing multilateral certification frameworks, advancing global standardization of testing and certification, innovating cross-border service models, and accelerating bilateral collaboration.

Collaboration on Joint Investments

As previously noted, the Gulf region's domestic manufacturing capacity for solar and wind components remains limited, with existing facilities generally insufficient to support the scale of upcoming multi-gigawatt renewable energy projects. In response, several China-based firms have announced plans to establish manufacturing operations in the region. However, none of these ventures have yet become operational. Even if only a portion of these joint initiatives are realized, their proximity to the Gulf's rapidly expanding clean energy infrastructure would significantly strengthen the resilience and diversification of China–Gulf clean energy supply chains.

While such joint ventures may be structured as private sector undertakings, the financial strength, strategic objectives, and broad partnership networks of Gulf sovereign wealth funds position them as more viable long-term collaborators for privately owned Chinese clean energy firms (Mayall 2024). A notable example of this model is the 2024 partnership between the Renewable Energy Localization Company—an entity under Saudi Arabia's PIF—and multiple Chinese solar and wind technology companies. This collaboration represents a significant step toward localizing renewable energy manufacturing within the Gulf region.

Investing in the Labor Force for Renewable Energy

The clean energy workforce is expanding rapidly, with green hiring outpacing overall recruitment rates globally (IEA 2023c). However, the supply of skilled labor has not kept pace with the growing demand for expertise in low-carbon energy technologies. A key challenge is that workforce training and education systems—both globally and in the GCC—continue to produce more professionals suited for fossil fuel industries rather than the renewable energy sector (Vakulchuk and Overland 2024).

In the GCC countries, businesses are encouraged to make efforts to bridge this skills gap through vocational training programs. In Bahrain, Green Innova has partnered with the Nasser Vocational Training Center to offer specialized courses in renewable energy. Similarly, ACWA Power collaborates with Saudi Arabia's Higher Institute for Water and Power Technologies in Riyadh, integrating the Renewable Energy and Occupational Safety program into the latter's curriculum. In Oman, Shams Global Solutions has teamed up with an international renewable energy education provider to deliver certified solar PV training. Meanwhile, LONGi, one of China's largest solar module manufacturers, launched its Middle East and Africa Training Center in Dubai in 2023 to enhance workforce capabilities in the region.

Given that Chinese companies frequently serve as EPC contractors for solar and wind projects across the GCC, they have a strong incentive to invest in workforce training and upskilling. To support the local labor market, they could establish independent training centers offering certification programs for installers, designers, and engineers, accredited by local authorities. Alternatively, partnerships with existing vocational institutes—as demonstrated by the examples above—could provide effective training pathways. Partnerships between Chinese companies and Gulf-based research institutes with an active renewable energy focus and good records of commercialization, such as King Abdulaziz City for Science and Technology in Saudi Arabia, would also be beneficial. One key target group for such initiatives would be fossil fuel industry workers at risk of job displacement due to digitalization. These workers already possess many transferable technical skills, making them well suited for clean energy roles. For instance, the United Kingdom government successfully retrained 4,000 oil and gas workers in green energy skills with an investment of approximately £17 million ($21 million) (Nissan 2023). A similar strategic investment in workforce development could help accelerate the transition of GCC states to low-carbon economies while ensuring they have sufficient talent pipelines for renewable energy expansion.

Annex 1 Component Suppliers for Solar Power Projects in the GCC or by GCC Power Developers.

Component	*Project name, location*	*Lead developer*	*Supplier, country of origin*
Panel	Sudair, Saudi Arabia	ACWA Power	LONGi, China
	Jeddah, Saudi Arabia	Masdar	
	Red Sea project, Saudi Arabia	ACWA Power	
	Al Kharsaah, Qatar	Total & Marubeni	
	Jubail desalination plant, Saudi Arabia	ACWA Power	
	Garadagh, Azerbaijan	Masdar	
	Al Dhafrah, UAE	Jinko Power & Masdar	Trina, China
	Noor Abu Dhabi, UAE	Jinko Power & Marubeni	Jinko Solar, China
	Mohammad bin Rashid (phase 5), UAE	ACWA Power	JA Solar, China
		ACWA Power	
	Ar Rass II, Saudi Arabia	ACWA Power	
	Al Kahfah, Saudi Arabia	Fotowatio	
	Mafraq II, Jordan	Masdar	
	Nur Navoi, Uzbekistan	ACWA Power	
	Kom Ombo, Egypt		
	Mesaieed, Qatar	QatarEnergy	
	Ras Laffan, Qatar	QatarEnergy	
	Abydos	AMEA Power	
	Ibri II, Oman	ACWA Power	Jolywood, China
	Sakaka, Saudi Arabia	ACWA Power	Zhejiang Chint, China
	Cirata floating solar, Indonesia	Masdar	Sungrow, China

(*Continued*)

Annex 1 (Continued)

Component	*Project name, location*	*Lead developer*	*Supplier, country of origin*
	Mohammad bin Rashid (phases 1 and 2), UAE	ACWA Power	First Solar, U.S.
	Al Husainiyah, Jordan	AMEA Power	Philadelphia Solar, Jordan
Inverter	Noor Abu Dhabi, UAE	Jinko Power & Marubeni	Ingeteam, U.S.
	Sakaka, Saudi Arabia	ACWA Power	Huawei, China
	Nur Navoi, Uzbekistan	Masdar	
	Ibri II, Oman	ACWA Power	Sungrow, China
	NEOM, Saudi Arabia	ACWA Power	
	Al Shuaibah, Saudi Arabia	ACWA Power	
	Mohammad bin Rashid (phase	ACWA Power	
	4), UAE	QatarEnergy	
	Al Kharsaah, Qatar	Masdar	
	Garadagh, Azerbaijan	ACWA Power	
	Kom Ombo, Egypt	QatarEnergy	
	Mesaieed, Qatar	QatarEnergy	
	Ras Laffan, Qatar		
	Sudair, Saudi Arabia	ACWA Power	Voltamp, Oman
	Mafraq I and Mafraq II, Jordan		ABB, Switzerland
	Mohammad bin Rashid (phase 3), UAE	Masdar	GE, U.S.
	Cirata floating solar, Indonesia	Masdar	SMA, Germany
Tracker	Mohammad bin Rashid (phase	ACWA Power	Nextracker, U.S.
	5), UAE	Masdar	
	Cirata floating solar, Indonesia	ACWA Power	
	Sakaka, Saudi Arabia		
	Al Kahfah, Saudi Arabia	ACWA Power	
	Ar Rass II, Saudi Arabia	ACWA Power	PV Hardware, Spain
	NEOM, Saudi Arabia	ACWA Power	
	Jeddah, Saudi Arabia	Masdar	
	Al Shuaibah, Saudi Arabia	ACWA Power	
	Kom Ombo, Egypt	ACWA Power	
	Al Kharsaah, Qatar	QatarEnergy	Ideematec, Germany
	Mafraq I and II, Jordan	Fotowatio	
	Al Dhafrah, UAE	Masdar, EDF &	Arctech, China
	Ibri II, Oman	Jinko Power	
	ASB Al Shubakh, Saudi Arabia	ACWA Power	
	Garadagh, Azerbaijan	ACWA Power	
	Tashkent Riverside,	Masdar	
	Uzbekistan	ACWA Power	
	Sherabad, Uzbekistan	Masdar	
	Mesaieed, Qatar	QatarEnergy	Trina, China
	Ras Laffan, Qatar	QatarEnergy	
	Jizzakh, Uzbekistan	Masdar	
	Samarkand, Uzbekistan	Masdar	
	Nur Navoi, Uzbekistan	Masdar	
	Abydos, Egypt	AMEA Power	GameCharge, U.S.

Source: Authors' compilation.

Annex 2 Wind turbine suppliers for wind projects in the GCC or by GCC power developers in Asia.

Project name, location	*Lead developer*	*Supplier, country of origin*
NEOM green hydrogen, Saudi Arabia	ACWA Power	Envision, China
Bash, Uzbekistan	ACWA Power	
Dzhankeldy, Uzbekistan	ACWA Power	
Amunet wind, Egypt	AMEA Power	
UAE wind projects, UAE	Masdar	Goldwind, China
Zarafshan, Uzbekistan	Masdar	
Dhofar, Oman	Masdar	GE, U.S.
Tafila wind, Jordan	Masdar	
Dumat Al-Jandal, Saudi Arabia	ACWA Power	Vestas, Denmark

Source: Authors' compilation.

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10 Prospects for China–GCC Energy Efficiency Cooperation

Dongmei Chen, Mohammad Aldubyan, and Hong Zhu

Introduction

Accelerating energy efficiency improvements could deliver over a third of all carbon dioxide CO_2-emitting emission reductions between now and 2030 in a pathway aligned with reaching net-zero emissions by 2050 (IEA 2024a). Realizing this potential requires energy efficiency improvements to achieve an average annual rate of approximately 4%. However, in practice, the global rate of improvement has declined from an average of 2% per year during the 2010–2019 period to just 1% in 2023–2024 (IEA 2024a). Enhanced policies, investments, and the adoption of energy-efficient technologies are crucial to reversing this trend and meeting international energy and climate objectives.

China has been a global leader in rapidly reducing its energy intensity over the past decade. The country achieved an improvement in annual energy intensity, defined as the energy required to produce a unit of economic output, of at least 4% during the 11th Five-Year Plan (FYP) period (2006–2010) and the 12th FYP period (2011–2015) (Zhang and Adom 2018). From 2013 to 2023, China maintained an average annual economic growth rate of 6.1%, while its energy consumption grew at an average rate of only 3.3% per year, leading to a 26.1% decline in its energy intensity during this period (NBS 2024). The most significant consecutive improvements in energy efficiency occurred between 2011 and 2016, with the highest annual rate of improvement (7%) recorded in 2016 (IEA 2024a). Despite these advancements, the rate of energy efficiency improvement has decelerated in recent years, with annual progress dropping to 2.7% in 2021, 0.1% in 2022, and only 0.7% in 2024 (NBS 2024).

Energy consumption in GCC countries has been rising rapidly. Between 2004 and 2014, final energy consumption grew at an average annual rate of 6.8%, significantly higher than the global average of 1.8% (Alarenan et al. 2019). This surge has largely been driven by the expansion of energy-intensive sectors in GCC countries, increased use of air conditioning for cooling and fast-growing populations. In response, GCC nations have actively enhanced energy efficiency across various sectors to curb consumption, reduce emissions, and meet their sustainability targets.

Saudi Arabia, the largest and most energy-intensive GCC country, has accelerated its efforts to improve sectoral energy efficiency. Since its establishment in

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2010, the Saudi Energy Efficiency Center (SEEC) has made notable progress in reducing primary energy consumption and cutting CO_2 emissions by focusing on the building, transport, and industrial sectors, which together account for 90% of the Kingdom's final energy consumption. The SEEC estimates that in 2020, 2021, and 2022 energy savings amounted to 357, 435, and 492 thousand barrels of oil equivalent (BOE) per day, respectively, using 2019 as the baseline year (SEEC 2023). This means that the total savings from efficiency programs by the end of 2022 could have been equivalent to 30% of Saudi oil exports to China in 2023, accounting for around 9% of Saudi Arabia's total primary energy consumption of around 2 billion BOE in 2023 (EIA 2024).

In the United Arab Emirates (UAE), the National Program for Energy and Water Demand-Side Management was launched in 2021 to support the ambitious sustainability objectives outlined in the UAE National Energy Strategy and the UAE Water Security Strategy. As of 2023, the program had achieved a cumulative reduction of 11.2 million tons of CO_2 emissions (WEF 2024), significantly contributing to the country's Nationally Determined Contribution (NDC) under the Paris Agreement.

Notably, the UAE has also played a leading role in advancing global energy efficiency cooperation. It championed the inclusion of a target to double the rate of global energy efficiency improvement in the Global Stocktake outcomes at the 2023 UN Climate Change Conference (COP 28). It subsequently led the establishment of the Global Energy Efficiency Alliance at the 2024 UN Climate Change Conference (COP 29) to support the realization of this goal by 2030 (Economy Middle East 2025).

The challenges in achieving high rates of energy efficiency improvement differ significantly between China and the GCC states. Over the past decades, China has established a robust policy and institutional system for energy savings and efficiency. However, the effectiveness of its traditional energy-saving policies has gradually diminished, and efforts to enhance efficiency through more stringent measures are increasingly constrained by competing priorities—particularly economic stabilization and job creation in the wake of the post-COVID-19 slowdown (IEA 2024a). For the GCC states, the long-standing practice of low administered energy prices for consumers represents one of the biggest challenges to improving energy efficiency (Alarenan et al. 2019). This issue is further compounded by the absence of long-term policy enforcement and monitoring systems, institutional and capacity constraints, and a lack of financial incentives to encourage the adoption of energy-efficient technologies.

Addressing these challenges requires comprehensive policy reforms, the continued development of energy management systems, and increased investment in energy-efficient technologies at the national level. International cooperation and knowledge exchange could also play critical roles in overcoming these barriers. A notable step in this direction was taken on October 20, 2023, when the Chinese National Energy Conservation Center and the SEEC co-hosted the first China–Saudi Energy Efficiency Technology Workshop focused on exploring energy efficiency opportunities in Saudi Arabia. While this marks an early stage of bilateral cooperation on energy efficiency between China and the GCC states, it highlights the significant potential for deeper engagement. Both sides stand to benefit from enhanced collaboration in areas such as policy innovation, harmonization of standards and regulatory frameworks, technology transfer, and scaling up energy efficiency markets and services across the region.

The Role of National Targets

The success China has achieved in energy savings can be attributed to strong political commitment at the highest levels, coupled with effective organization and the implementation of multi-program initiatives at provincial and local levels. Since 2006, energy intensity reduction has been embedded as a mandatory target in China's national planning system. The government has set ambitious energy intensity reduction targets over the past decades: 20% for the 11th FYP, 16% for the 12th FYP, 15% for the 13th FYP, and 13.5% for the 14th FYP.

Target setting is a collaborative process that integrates bottom-up negotiations with top-down directives, facilitating alignment between central and local governments. The central government holds the authority to approve the targets for each FYP and to review and evaluate the performance of provincial governments annually in terms of their progress toward meeting these goals. Energy efficiency targets have been integrated into the performance appraisal system for governors and provincial leadership since 2006, making them a critical element of accountability. This integration has motivated provincial governments to take their targets seriously, ensuring that goals are cascaded to lower administrative levels, such as prefectures and counties, fostering a system of shared responsibility and collective action.

China has established robust policy incentives to achieve its mandatory targets. These include subsidies for upgrading or phasing out outdated capacity, green financing for energy efficiency projects, tax incentives for energy efficiency investments, and the promotion of advanced technologies.

The effectiveness of national targets also relies on strong institutional capacity and specialized expertise. Improving energy efficiency across various sectors requires a diverse set of skills in engineering, policy, and finance. Key elements include capacity building for enterprise engineers and energy managers, training for government officials at all levels, fostering expertise in developing and promoting energy-efficient technologies, and strengthening the capabilities of third-party service providers, banks, and investors. China has established over 1,600 energy conservation supervision centers nationwide. These agencies, operating under government authority, conduct regulatory inspections and provide technical services, covering all provinces, 90% of prefectures, and 45% of counties (De Gouvello, Song, and Taylor 2021).

China's targeting system continues to evolve, offering valuable insights for other nations on linking energy efficiency improvements with climate goals. Since 2010, China has incorporated a binding target for carbon emissions intensity reduction (measured by emissions per unit of gross domestic product [GDP]) within its national planning system. The country has also emphasized the alignment between energy intensity reduction, total energy consumption control, and carbon emission intensity reduction targets and measures. In 2024, China announced a shift from regulating energy consumption and intensity to focusing on carbon emissions and intensity (Government of China 2024). From 2026 to 2030, the focus will be on reducing the intensity of carbon emissions while maintaining oversight of total emissions. After peaking emissions in 2030, the priority will shift to total emissions control, with intensity control taking a secondary role.

GCC states have announced ambitious energy efficiency and sustainability targets as part of their broader vision to reduce carbon emissions and enhance energy security. Each country has set specific goals, ranging from improving energy efficiency across key sectors to increasing the share of renewables in the energy mix. To ensure effective implementation, various supportive mechanisms and enforcement programs have been introduced, including regulatory frameworks, energy efficiency centers, and incentive-based initiatives.

Saudi Arabia has announced energy efficiency targets as part of Saudi Vision 2030 and the Saudi Green Initiative. The country established the National Energy Efficiency Program in 2003 and the SEEC in 2010 to strengthen the institutional framework and coordinate national efforts to improve energy efficiency across key sectors, including buildings, industry, and transport.

While the country does not yet have a binding economy-wide energy efficiency target, several sector-specific targets and policies are in place to improve energy intensity and reduce overall energy consumption. Between 2015 and 2020, the SEEC set a target for the industrial sector to improve its energy intensity by around 1% each year. The second cycle of this program, which runs from 2020 to 2025, has scheduled energy intensity improvement targets of 3.2% for steel, 4.7% for cement, and 7% for petrochemicals, compared to a 2018 baseline (Howarth et al. 2021). An achievable but strong annual improvement target for the country could generate more significant energy efficiency gains: by using the Model With Energy, Growth and Intergenerational Redistribution-Saudi Arabia (MEGIR-SA), Gonand (2016) estimated that an annual increase of 4% in future energy efficiency would result in 1 million barrels per day of avoided domestic energy consumption for Saudi Arabia by 2030.

The UAE has set ambitious targets to expand its renewable energy capacity, increase its share of clean energy, and improve its energy efficiency from now through 2030 and up to 2050. In its National Energy Strategy 2050, launched in 2017 and updated in 2023, the country outlines a long-term framework to balance rising energy demand with the sustainable use of natural resources. The strategy defines key milestones for 2030, including improving individual and institutional energy consumption efficiency by 42%–45% compared to 2019, tripling its renewable energy capacity relative to 2022 levels, and increasing its share of clean energy to 30% (UAE Government 2024a).

As part of its National Water and Energy Demand Management (DSM) program, the UAE also aims to reduce energy demand by 40% across its transport, industry, and built environment sectors—currently the three largest energy consumers—by 2050. Additionally, the program targets a 50% reduction in water demand in its agriculture and built environment sectors by 2050 (UAE Government 2024b). In its third NDC, the UAE committed to reducing its greenhouse gas emissions by 47% by 2035 relative to their 2019 levels (UAE Government 2024c). Together, these policy measures reinforce one another, accelerating decarbonization and driving significant improvements in energy efficiency.

Oman has set a specific energy efficiency target to achieve 6 megajoules (MJ) of energy consumption per United States dollar of GDP by 2050. This target is part of the broader National Strategy for an Orderly Transition to Net Zero, which also includes increasing the share of renewable energy in electricity production to 30% by 2030, 70% by 2040, and 100% by 2050 (Government of Oman 2022). To support these objectives, Oman has established the Oman Net Zero Centre, which is responsible for developing strategies, overseeing energy efficiency projects, and providing technical support to both government and private sectors. Additionally, the Authority for Public Services Regulation has launched the Our Sustainable Energy campaign to raise awareness about clean energy and promote responsible consumption, aiming to enhance energy efficiency across various sectors.

Bahrain's National Energy Efficiency Action Plan, launched in 2017, targets a 6% reduction in the country's energy consumption by 2025, aligning with its Economic Vision 2030 and international climate commitments (BSCE 2017). The plan includes 22 initiatives across key sectors, such as mandatory energy efficiency standards for buildings, fuel efficiency regulations for vehicles, and the promotion of renewable energy technologies like solar and wind. These measures aim to enhance resource efficiency, reduce carbon emissions, and support Bahrain's transition to a more sustainable energy system (BSCE 2017).

Qatar has integrated energy efficiency into its broader sustainability framework, aligning with its National Vision 2030 through initiatives like the Qatar National Environment and Climate Change Strategy, which focuses on optimizing resource use and enhancing climate resilience. QatarEnergy's Sustainability Strategy targets a 25% reduction in greenhouse gas emissions intensity in liquefied natural gas (LNG) facilities and 15% in upstream operations by 2030, with an emphasis on energy efficiency improvements (QatarEnergy 2023). Additionally, the Qatar National Renewable Energy Strategy aims to increase the share of renewable energy share in Qatar's power mix to 18% by 2030, primarily through solar projects. These efforts reflect Qatar's commitment to a more sustainable and energy efficient future (QatarEnergy 2023).

Kuwait's energy efficiency efforts have been pursued by the Kuwait Institute for Scientific Research (KISR) since the early 1980s when the first energy conservation code went into force in 1983. Accordingly, the KISR has focused on pursuing energy efficiency by conducting several applied research projects, including updating the national energy conservation code, energy auditing, demand-side management, home automation, and assessing the efficiency of air-conditioning systems, among others (Belaïd, Aldubyan, and Hejazi 2023). Kuwait has set a target to meet 15% of its electricity demand from renewable energy sources by 2030. The country has also set energy efficiency targets to reduce energy consumption by 10% in the residential and industrial sectors, as well as to improve power generation efficiency by 5% in the utility sector (RCREEE 2024). Additionally, the KISR (2023) has implicitly discussed improving energy efficiency in all government buildings by 30% by 2025 and 50% by 2050 and achieving a 50% reduction in the refining sector's emissions by 2040.

Industrial Energy Efficiency Strategy

Industry is the most energy-consuming and CO_2 end-use sector globally. In China, industry's share of total primary energy consumption has remained around 70% over the last decade (NBS 2024). In the GCC, the industrial sector constitutes a significant share of total final energy consumption, reflecting the bloc's reliance on energy-intensive industries that support economic growth and export revenues. The UAE leads, with industry accounting for 52% of its energy use, followed by Qatar at 40%, Bahrain at 36%, Kuwait at 30%, and Oman at 24% (IEA 2025). The industrial sector in Saudi Arabia consumes about 44% of the country's total primary energy consumption (SEEC 2025). These high shares are largely due to the prevalence of sectors such as petrochemicals, oil refining, metals, fertilizers, and gas processing, which form the industrial backbone of many GCC economies. The variation across countries highlights differences in industrial structure and scale, with some states more heavily focused on upstream oil and gas operations, while others have diversified into manufacturing and heavy industry.

The question of how industrial energy efficiency supports economic growth is thus particularly important for both China and the GCC states. China is home to some of the world's most advanced and efficient industrial plants, but it also faces challenges with inefficient facilities operating at suboptimal scales. Disparities in scale, technology, and management sophistication persist across various industries. To address these issues, China has implemented over 105 national energy efficiency benchmark standards, covering key sectors such as steel, non-ferrous metals, petrochemicals, and power. These standards establish three energy intensity levels—limit, access, and advanced—aligned with its industrial strategies. The limit value targets outdated capacity for elimination, the access value imposes stricter requirements for new projects, and the advanced value guides performance improvements and upgrading (Chen et al. 2018). This unique system offers valuable lessons for using standards as policy tools to implement industrial strategies.

China's implementation of key industry-oriented initiatives, known as the Top 1,000 Program in the 11th Five-Year Plan (FYP), the Top 10,000 Program in the 12th FYP, and the Key Enterprises Energy Conservation Initiative (also known as the 100–1,000–10,000 initiative) in the 13th FYP, has achieved energy savings greater than any other programs. The energy use of the top 1,000 enterprises accounted for 33% of China's total energy use in 2004, while the top 10,000 enterprises represented 60% of China's total energy use in 2010. In addition to mandatory targets and financial incentives, the program emphasized capacity building for energy managers, encouraged the adoption of energy service companies (ESCOs) to facilitate energy-saving projects, and promoted advanced technologies through government-supported demonstration projects.

GCC states are increasingly investing in local industrial sectors as part of broader economic diversification strategies. Key focus areas include petrochemicals, aluminum, steel, fertilizers, food processing, and high-tech manufacturing. Special economic zones and industrial cities—such as Jubail and Yanbu in Saudi Arabia, Sohar in Oman, and the Khalifa Industrial Zone in Abu Dhabi—have seen rapid expansion. At the same time, policies aimed at strengthening local manufacturing and enhancing small- and medium-sized enterprise (SME) participation in supply chains are gaining momentum. These developments underscore the growing importance of advancing and promoting energy efficiency best practices across the industrial sector.

The SEEC has focused its efforts on developing the necessary policies, regulations, and procedures to improve the efficiency of energy-intensive sectors. During the first phase of the Saudi Energy Efficiency Program (2011 to 2019), Saudi Arabia achieved a decrease in the energy intensity of its electric arc furnace process of 2%, with a 2.8% energy intensity reduction in cement factories, 4.2% in clinker plants, and 2.9% in petrochemicals (Saudi Ministry of Energy 2024). The second phase of the program (2020–2025) expanded the framework to include aluminum and other subsectors. Companies covered by the program are required to achieve the second quartile of the benchmark approved by the SEEC in the baseline year. This initiative also aims to improve feedstock utilization efficiency for primary raw materials, such as hydrocarbon cracking, ammonia, methanol, propane dehydrogenation, isobutylene, and benzene–toluene–xylene. Additionally, the SEEC has promoted the cultivation of energy efficiency management by providing guidance manuals and training tools to help facilities across various industrial sectors implement energy management systems (ISO 50001) (SEEC 2025).

The UAE's DSM program aims to improve energy efficiency in the industrial sector by 33% by 2050, targeting the six main industrial sectors in the UAE that contribute most to high energy consumption. These initiatives include the ISO 50001 certification, submission of DSM improvement plans every three years, and annual reporting of energy demand and emissions to the relevant government authority (UAE Government 2024c). In the iron and steel sector, key strategies include the use of hydrogen, low-carbon electricity, carbon capture, utilization, and storage (CCUS), efficiency improvements, and increased reliance on scrap metal. Similarly, the cement and clinker sector is exploring fuel switching, alternative heat sources, and clean electricity while utilizing clinker substitution, efficiency improvements, and CCUS to drive emission reductions.

In Qatar, the Qatalum aluminum smelter, a joint venture between QatarEnergy and Norsk Hydro, has implemented targeted energy efficiency improvements in its operations. According to its 2023 Sustainability Report, these efforts led to a 0.9% reduction in natural gas usage in both the smelter and power plant, despite increased production levels. This achievement reflects Qatar's broader strategy to enhance operational efficiency and reduce emissions across heavy industries (Qatalum 2023).

In Oman, the government has developed a dedicated industrial energy efficiency policy in collaboration with the United Nations Industrial Development

Organization (UNIDO) and the Environics Trust. The policy aims to promote cost-effective energy-saving interventions across the industrial sector, such as optimizing motor systems, improving compressed air efficiency, and upgrading boiler performance. This initiative provides a structured approach to integrating energy efficiency within industrial operations and supports Oman's broader goals of economic diversification and emissions reduction in line with its Net Zero 2050 commitment (Environics Trust 2025).

Building Energy Efficiency Improvement

China's building sector has been a major driver of economic growth, employment, and local government revenues. Over the past decade, it has expanded rapidly, with newly added building floor space exceeding 900 million square meters (m^2) annually since 2011. Despite growing concerns in recent years over market oversupply, weakening demand, and rising debt levels, the sector remained active, adding 998 million m^2 of new floor space in 2023 (Statista 2024).

While some key initiatives were introduced earlier, the early 2000s saw a significant acceleration of efforts to enhance energy efficiency in both new and existing buildings. These efforts focused on improving design, construction methods, and materials; reforming central heating system designs; and implementing stringent energy efficiency standards for and labeling of household appliances (De Gouvello, Song, and Taylor 2021). Specific building energy efficiency targets were first introduced during the 11th FYP. In the 14th FYP, the Chinese government set goals to complete energy-saving retrofits for 350 million m^2 of existing buildings and to construct 50 million m^2 of ultra-low and near-zero energy consumption buildings by 2025 (Government of China 2022).

Energy-related standards are central to improving building energy efficiency in China. These include energy efficiency design standards, retrofitting technical codes, assessment standards for green and low-energy buildings, as well as energy-consumption quotas. Many national standards for building energy efficiency are tailored to specific climates, such as those for heating zones, hot summer/cold winter regions, and hot summer/warm winter regions. These allow for prescriptive or performance-based approaches to ensure that heating and cooling energy use remain below specified limits. Local governments often develop stricter standards tailored to their contexts.

Public buildings play a critical role in improving energy efficiency within the building sector. By 2020, China's total building floor area reached 69.6 billion m^2, with 80% designated for residential use and 20% for public buildings. Despite their smaller share, public buildings account for over 40% of the sector's carbon emissions, with a carbon intensity of 58.6 kilograms of CO_2 per m^2 ($kgCO_2/m^2$), compared to 28.1 $kgCO_2/m^2$ for urban residential buildings and 18.3 $kgCO_2/m^2$ for rural residential buildings (CABEE 2023). While progress has been made in energy-efficient renovations, challenges persist in maintaining provincial and city-level energy monitoring systems. Between 2007 and 2013, over 11,000 public buildings in 18 pilot regions installed real-time energy consumption monitoring systems, but many ceased operations within two to three years due to insufficient funding for maintenance and updates (Zhou et al. 2024).

Like China, the GCC states have placed strong emphasis on using regulatory measures, such as building energy codes, to promote a more sustainable built environment. All GCC countries have introduced or updated their building energy codes to enhance insulation, heating, ventilation, and air conditioning (HVAC) efficiency, lighting, and building material standards.

Saudi Arabia has taken major steps to enhance energy efficiency in its building sector through regulations like the Saudi Building Code (SBC 601 & 602), which mandate thermal insulation and energy-efficient materials in residential and commercial buildings. The country has also introduced minimum energy performance standards for appliances, ensuring that air conditioners, lighting, and other electrical equipment meet stringent energy efficiency criteria. Additionally, the government established Tarshid, the National Energy Services Company, to retrofit existing buildings with better energy efficiency.

The UAE has implemented comprehensive energy efficiency initiatives in its building sector through strict regulations, sustainable urban development, and financial incentives. The Estidama Pearl Rating System in Abu Dhabi and Dubai's Green Building Regulations enforce high-efficiency standards, requiring improved insulation, energy-efficient lighting, and advanced HVAC systems. Sustainable developments such as Masdar City and Sharjah Sustainable City incorporate solar energy, passive design, and water recycling to achieve near net-zero energy consumption. Additionally, financial incentives, including retrofit programs by Etihad ESCO, support energy-saving upgrades in government and commercial buildings.

Oman has introduced several energy efficiency initiatives in the building sector as part of its National Strategy for an Orderly Transition to Net Zero, aiming for a 30% reduction in energy demand by 2050 through enhancements in air conditioning efficiency and building insulation (Government of Oman 2022). A significant step forward includes the signing of the country's first Energy Services Performance Contract with the Ministry of Housing, targeting a 39% reduction in energy consumption across government buildings (Times of Oman 2024). Furthermore, private-sector initiatives are promoting sustainable construction practices by incorporating eco-friendly materials and energy-efficient designs.

Kuwait has also initiated several energy efficiency measures in the building sector, starting with its Energy Conservation Code of Practice, originally introduced in 1983 and updated in 2014, which sets mandatory standards for insulation, lighting, and HVAC systems. The Kafa'a program, initiated by the Electricity and Water Authority (EWA) in Bahrain, aims to save approximately 975 gigawatt hours (GWh) of electricity and reduce carbon emissions by about 488,000 tons by 2040 by enhancing energy efficiency in both private- and public-sector buildings (Government of Bahrain 2025).

Given their extreme summer temperatures, space cooling is a critical component of building energy efficiency in the GCC states. In Saudi Arabia, buildings account for over 50% of total electricity consumption, and, on extremely hot days, residential electricity demand can contribute up to 70% of the peak load. To improve the energy performance of cooling equipment, the government launched the High-Efficient Air Conditioning Initiative in 2018, providing subsidies to consumers for upgrading to higher efficiency air conditioners. By the end of 2021, this initiative benefited 125,000 citizens and promoted the production of 20 highly efficient air conditioning models (Belaïd and Massie 2023). In Qatar, large-scale electricity efficiency programs indicate that implementing energy-efficient cooling systems alone could decrease annual electricity consumption by 28%, with an additional 20% reduction possible through the use of thermal insulation in walls and roofs (Krarti et al. 2017).

Building Efficient Transport Systems

China has made continued efforts to accelerate the development of multimodal transport and increase the share of railways and waterways used for freight transport. By the end of 2023, China extended its railway mileage to 159,000 kilometers (km), roads to 5.35 million km, and waterways to 128,000 km (China ESG30 2024). The country has established the world's largest network of high-speed rail and highways. The number of cargo and multifunctional airports in China reached 254 and 399, respectively, by 2022, reflecting rapid growth in the aviation sector. China's overall domestic freight volume increased from 41 billion tons to 55.7 billion tons during 2013–2023 (China ESG30 2024).

Despite these efforts, road transport remains a cornerstone of China's transportation sector. Road vehicles consistently account for over 60% of the country's total transportation services and contribute approximately 80% of transportation-related (CO_2) emissions (IEA 2022). To improve fuel efficiency in vehicles, China has introduced and updated fuel economy standards for passenger vehicles, light commercial vehicles, and heavy-duty vehicles since 2004. The introduction of Corporate Average Fuel Consumption (CAFC) standards in 2012 further requires automakers to meet sales-weighted average fuel consumption limits across their fleets, driving continuous improvements in vehicle fuel efficiency.

Since 2015, China has emerged as a global leader in new energy vehicle (NEV) adoption and the expansion of charging infrastructure. NEVs accounted for 31.6% of new vehicle sales, with a total stock reaching 20 million in 2023 (China ESG30 2024). Additionally, the country had deployed nearly 8.6 million electric charging stations and over 450 hydrogen charging stations by the end of 2023 (NEA 2024). The Government of China (2020) has also set a target for NEVs to constitute the majority of new vehicle sales by 2035.

GCC countries are increasingly prioritizing transport energy efficiency as part of their broader sustainability and emission reduction goals. Key initiatives include investments in public transport infrastructure, such as metro and light rail systems in Dubai, Riyadh, and Doha, aimed at reducing reliance on private vehicles. Efforts are also underway to promote electric mobility, with growing support for electric vehicle (EV) adoption, the expansion of charging infrastructure, and national targets in countries like the UAE and Saudi Arabia.

The GCC Standardization Organization (GSO) has played a pivotal role in enhancing fuel economy and the energy efficiency of motor vehicles across member states (GSO 2021). Through the Mutabiq platform, the GSO provides a comprehensive Fuel Economy Guide, enabling consumers to compare vehicles based on their fuel efficiency ratings. This initiative promotes transparency and encourages the selection of energy-efficient vehicles. Additionally, the GSO mandates that all light-duty vehicles (weighing 3,500 kg or less) display a fuel economy label detailing the vehicle's fuel consumption efficiency. This labeling system is part of the broader GSO Certification Scheme, which ensures that motor vehicles and tires comply with relevant Gulf standards before entering the market. Collectively, the GSO's measures aim to standardize fuel economy assessments and promote energy-efficient transportation within the GCC.

In the Saudi market, in particular, the SEEC has implemented several initiatives aimed at improving fuel economy. It introduced a vehicle energy efficiency label for light-duty vehicles (LDVs) in 2014 and updated it to include electric vehicles in 2018. The first phase of the tire anti-rotation specification for LDVs and heavy-duty vehicles (HDVs) was implemented in 2015, followed by the second phase in 2019. Additionally, the Saudi Corporate Average Fuel Economy (CAFE) standards for LDVs were initiated in 2016 and revised at the beginning of 2021. Thus far, CAFE standards have improved the fuel economy of the new fleet by 16% (Saudi Ministry of Energy 2024).

Qatar is actively advancing energy efficiency in its transportation sector through a multifaceted strategy that includes electrification, infrastructure development, and sustainable urban planning. Central to this effort is the Ministry of Transport's initiative to transition the public bus fleet to 100% electric by 2030, with approximately 70% of buses already electrified as of early 2024 (The Peninsula 2024). To support this transition, Qatar has begun developing a local electric bus manufacturing facility in the Um Al Houl Free Zone, which is expected to enhance domestic production capabilities and charging infrastructure (Ministry of Transport 2024a). Complementing these efforts is the Transportation Master Plan for Qatar 2050, which lays out a comprehensive framework for sustainable mobility, reduced energy consumption, and lower transport emissions (Ministry of Transport 2024b). Key elements of this plan include the integration of electric vehicles, the expansion of public transit networks, and the adoption of intelligent transport systems.

The UAE has taken proactive steps to implement CAFE standards to encourage automakers to produce more fuel-efficient vehicles and promote the adoption of hybrid and electric cars. Led by the Emirates Authority for Standardization and Metrology (ESMA), the CAFE standards aim to improve the average fuel economy of new LDVs sold in the country. It is estimated that the UAE fleet's fuel efficiency will improve from an average of 12.1 km per liter in 2013 to 20.8 km per liter by 2028 (Government of Dubai 2018). All vehicles from the 2017 model year entering the UAE will be rated according to their fuel-efficiency levels.

Prospects for China-GCC Cooperation

China and the GCC states differ significantly in terms of their climate, geography, economic development paths, population dynamics, urban planning approaches, industrial structures, and infrastructure networks. As a result, the challenges they face in improving energy efficiency vary across the industrial, building, and transport sectors. Nevertheless, they share numerous common interests and opportunities for collaboration in this area.

The significant presence of energy-intensive industries, such as steel, petrochemicals, cement, and aluminum, alongside ambitions to diversify into consumer-driven service sectors and high-value-added advanced manufacturing, creates a strong foundation for enhanced trade, investment, and policy exchange between China and the GCC states.

Both China and the GCC states have achieved high levels of urbanization. However, significant potential remains for upgrading infrastructure, integrating energy efficiency and renewable energy solutions into buildings, and replacing inefficient appliances. Practitioners in both regions can benefit from exchanging strategies and lessons learned in areas such as developing and enforcing building energy efficiency standards, promoting green building practices, and designing effective incentive mechanisms to encourage energy-efficient behavior, particularly within public institutions. Given the importance of space cooling in the GCC states, programs focusing on high-efficiency air conditioning systems present an opportunity for China–GCC cooperation.

Building more efficient transport systems is equally vital for both China and the GCC states. Over the past few decades, China has heavily invested in railways, subways, and bus rapid transit systems to encourage a transition from private vehicles to public transit. Meanwhile, the GCC states, led by Saudi Arabia, the UAE, and Qatar, have gradually prioritized the planning and construction of railways and subways. China and many GCC states have implemented standards that improve vehicle fuel economy and require automakers to meet sales-weighted average fuel consumption targets. Both sides can work together to enhance the development of testing procedures and compliance mechanisms while engaging in knowledge exchange programs to build regulatory capacities. Additionally, joint research initiatives can provide insights into consumer behavior, market dynamics, and the effectiveness of various policies.

Looking ahead, China and the GCC states can deepen their cooperation on energy efficiency by sharing best policy practices, investing in and advancing the development of efficiency-enhancing technologies, and mobilizing resources to support energy efficiency financing.

Sharing and Coordinating Policy Practices

China's policy approaches and lessons learned in energy efficiency improvement, particularly during its early stages, may serve as a useful reference for the GCC states undertaking similar initiatives. China's experience underscores the importance of integrating technological, institutional, and economic mechanisms to achieve long-term energy efficiency goals. Since the beginning of the 11th FYP, China has focused on setting national energy efficiency targets and encouraging the adoption of energy-efficient technologies. During the 12th FYP period, the emphasis shifted toward institutionalizing energy management systems. Building on this momentum, the 13th and 14th FYP periods marked a strategic pivot toward fostering a business and market-driven ecosystem for delivering energy efficiency services. Although technological advancements have remained critical for energy efficiency improvements, the reform agenda has increasingly shifted to the use of market-based instruments, such as carbon emissions trading schemes and energy price reforms, to drive sustainable efficiency gains (Chen et al. 2018).

Addressing long-term institutional needs and ensuring sustained investment in institutional capacity are critical factors behind the success of China's energy efficiency programs. These factors are equally relevant for strengthening the effectiveness and resilience of similar initiatives in the GCC. China and the GCC states can collaborate to share technical expertise and policy practices, enhancing the development and implementation of comprehensive energy efficiency policy frameworks in the GCC countries.

International cooperation and experience sharing in implementing and updating labeling schemes can assist consumers to identify best-in-class models, while the coordination and harmonization of regulations on minimum energy performance standards can more effectively limit the import and production of inefficient appliances. Furthermore, exchanging knowledge on financial instruments and innovative business models can help drive greater investment in energy efficiency across the GCC.

A best practice sharing platform can play a role in addressing emerging challenges faced by both China and the GCC states. To achieve its carbon peaking and carbon neutrality goals, China must address the flexibility issues arising from a rapidly expanding renewable power system while enhancing synergies between the increased electrification of end-use sectors and improved energy service efficiency (IRENA 2022). Similarly, GCC countries are navigating this transition by accelerating the deployment of renewable power, strengthening grid infrastructure, and harnessing flexibility from diverse resources. Despite notable technological advancements in smart grids, energy storage, and demand-side response, further progress in power markets and regulatory frameworks is essential for both sides to effectively manage the flexibility challenges of a growing renewable power system (IEA 2024b).

Enhanced collaboration is also crucial in addressing the challenges of decarbonizing industrial sectors. Achieving industrial decarbonization requires transformative changes in production, consumption, recycling, and disposal processes (IRENA 2022). However, technologies for electrifying energy-intensive and high-temperature heat applications remain underdeveloped (Lu et al. 2022). Progress is further hindered by the absence of proven best practices for technically feasible and economically viable emission reductions. By sharing lessons learned from demonstration plants and fostering enabling conditions, both sides can accelerate industrial decarbonization.

Advancing Technology Collaboration and Investing in Local Content

The Chinese government has placed significant emphasis on the development and promotion of energy conservation and efficiency technologies to achieve its energy-saving targets. In 2006, the National Development and Reform Commission introduced the Outline of China's Energy Conservation Technology Policy and initiated the National Key Energy-Saving Technologies Promotion Catalogue. Since the catalogue's inaugural release in 2008, more than 4,000 technologies have been proposed and evaluated. Detailed information is provided for the technologies selected, including technical specifications, investment costs, energy-saving potential, and relevant case studies. The catalogue was updated annually until 2018, with each edition featuring approximately 300 energy saving technologies. Building on this initiative, other ministries have developed specific technology catalogs across industrial, building, and transport sectors, and provincial governments have created localized catalogues. Financial incentives, such as tax breaks, subsidies, preferential loans, and public procurements at different levels, are attached to these catalogs to promote the adoption of energy-saving and carbon-reduction technologies.

Technological advancement has not been included as a key enabler for energy efficiency programs in the GCC states. Energy efficiency strategies in major GCC states have traditionally focused on regulatory measures and energy price reforms. However, there is growing recognition that technological advancement is essential for scaling and sustaining energy efficiency gains, especially in areas like building performance, industrial automation, and smart grids. Governments can play an important role in providing guidance on the latest technologies and their applications, helping industries and businesses navigate market complexities and capitalize on emerging opportunities.

China and the GCC states could establish a joint platform to promote the development and use of energy efficiency technologies in the GCC region. China's technological strengths, combined with the market potential of the GCC countries, present opportunities to collaboratively develop innovative products and services tailored to local needs, such as promoting advanced energy efficiency technologies in joint investment projects. Such cooperation has the potential to deliver both environmental and economic benefits to the GCC countries while creating new growth opportunities for Chinese enterprises.

The scope of technological collaboration ranges from widely applied best-available technologies, such as high-efficiency motors, transformers, and waste heat utilization equipment, to advanced system optimization technologies that are relatively novel for achieving sustained energy efficiency improvements. In manufacturing sectors such as steel and chemicals, optimizing the integration of production processes, waste heat recovery, and utility systems can achieve substantial efficiency gains that traditional approaches may not address. Furthermore, advancements in digital technologies—such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics—can facilitate real-time monitoring, predictive maintenance, and dynamic adjustments.

GCC states that have pursued import substitution and employment generation through local industrial development can further build their capacity by jointly localizing energy efficiency technologies in collaboration with Chinese business and technology partners. Such efforts could focus on applications in space cooling and industrial energy system optimization, petrochemical manufacturing, aligning with regional priorities for energy efficiency improvement. In parallel, there is substantial potential for co-developing localized EV supply chains tailored to the specific conditions of the GCC. This includes adapting EV technologies for extreme heat, enhancing mineral processing and battery recycling capabilities, and expanding charging infrastructure across the bloc to support broader EV adoption.

Leveraging Resources for Energy Efficiency Financing

In general, energy efficiency project developers face higher financing barriers than renewable energy project developers. The absence of standards, regulations, and incentive policies may hinder the development of the energy efficiency market. Financial returns from investing in energy efficiency measures may not be attractive enough due to low energy costs. Additionally, the lack of expertise and knowledge presents barriers for local financial institutions in assessing the bankability of energy efficiency projects. Moreover, the scattered nature of small-scale projects and high transaction costs further complicate entry for international players into local energy efficiency markets.

China experienced a similar situation when it began promoting large-scale investments in energy efficiency during its 11th Five-Year Plan. Today, GCC states face comparable challenges, which help explain why their energy efficiency investments remain relatively modest compared to their large-scale energy, industrial, and infrastructure projects. One key factor behind this disparity is the variation in electricity pricing, which significantly affects the payback periods for building retrofit projects. For instance, Oman has the longest payback period, ranging from seven to 30 years for basic retrofits, whereas Qatar and the UAE offer much shorter payback periods of one to six years (Khan et al. 2024).

Showcasing successful business models for energy efficiency financing and sharing case studies can be an effective way to demonstrate potential cost savings and return on investment. Building on early-stage experiences with international financing institutions, China and the GCC states could develop a joint energy efficiency financing program offering technical advisory services and catalyzing lending for energy efficiency projects.

The World Bank and International Finance Corporation (IFC) have supported two major risk-sharing programs in China to expand energy efficiency financing: (i) the World Bank/Global Environment Facility (GEF) China Energy Conservation II Project, which offers partial risk guarantees to ESCOs, and (ii) the IFC/GEF China Utility-Based Energy Efficiency (CHUEE) Program, which provides portfolio risk guarantees to participating banks. These initiatives have been instrumental in scaling up energy efficiency investments in China.

Building on these experiences, institutions such as the Asian Infrastructure Investment Bank (AIIB)—focusing on energy transition in Belt and Road Initiative (BRI) partner countries—and Chinese banks with established energy efficiency portfolios could play a similar role. By offering partial risk guarantees for joint energy efficiency financing programs, they could help borrowers access commercial funding that might otherwise be unavailable due to credit constraints, while also enabling more favorable loan terms, such as lower interest rates or longer maturities, by mitigating lender risk.

The program could also provide tailored training packages for local banks, including policies, real case studies, transaction structuring, and ESCO lending. Technical support from experienced international financial institutions and Chinese banks could help develop in-house technical capacity for local banks and foster cooperation among various stakeholders. Meanwhile, the governments of GCC states could provide tax credits, subsidies, or grants for joint energy efficiency financing programs to offset initial capital costs and encourage investment in energy efficiency technologies and services.

Increasing investment in the GCC energy efficiency market can be supported by various financial instruments. In particular, off-balance sheet arrangements with ESCOs and project financing to fund large-scale upgrades and industrial clusters are becoming more prevalent. ESCOs deliver efficiency based on contracts tied to energy performance and are key enablers of investment. China's ESCO market has evolved into the world's largest, with investments surpassing $20 billion in 2022 and 2023, accounting for about half of the global total (IEA 2024a). China's experience in creating regulatory frameworks and incentives for ESCOs could inform GCC policymakers in developing supportive legal and financial environments. While Saudi Arabia and the UAE have seen rapid growth of ESCOs, most of them are state-backed super ESCOs. By fostering public–private partnerships, the China–GCC collaboration can enhance local ESCO capabilities and advance the development of the GCC's energy efficiency market.

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11 China and the GCC

Prospects for Globalizing Hydrogen Markets

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Introduction

Hydrogen is increasingly recognized as a key enabler of the global energy transition, providing a pathway to decarbonize industries, enhance energy security, and diversify economies. For the GCC countries, hydrogen development is not just a climate strategy but also an economic necessity. As leading hydrocarbon exporters, GCC countries face growing pressure to adapt to evolving global energy policies, including carbon border mechanisms and shifting market preferences.

To sustain long-term economic growth, the GCC must accelerate its shift toward low-carbon energy exports. Hydrogen, as a carbon-free fuel and industrial feedstock, represents the most viable opportunity to decarbonize domestic industries while securing future export markets. By leveraging their abundant renewable resources and cost-competitive fossil fuels, GCC countries are positioning themselves as major global hydrogen suppliers.

The partnership between China and the GCC in hydrogen development is strategically aligned with both parties' long-term energy and economic goals. China, as the world's largest hydrogen consumer and a global leader in clean energy technologies, seeks reliable and cost-effective sources of low-carbon hydrogen to meet its ambitious decarbonization targets. Meanwhile, the GCC countries are actively looking to expand their hydrogen export markets beyond traditional energy trade routes, making China a natural partner.

China's expertise in renewable energy, digitalization, and electrolyzer manufacturing positions its companies as valuable partners in developing the GCC's hydrogen infrastructure. Through joint investments, technology partnerships, and industrial collaboration, China and the GCC can reduce hydrogen production costs, enhance supply chain efficiency, and accelerate the large-scale deployment of hydrogen projects.

For the GCC, collaboration with China offers opportunities to scale up production, integrate advanced technologies, and secure long-term hydrogen offtake agreements. Major GCC hydrogen projects are increasingly engaging with Chinese companies for investment, technology transfer, or supply chain integration.

This chapter begins with an assessment of the GCC's potential in the low-carbon hydrogen market, analyzing both the economic context and the bloc's evolving

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competitive position in the global hydrogen landscape. It then delves into its existing and upcoming collaborations with international partners, with a particular focus on China, and highlights significant joint investments in hydrogen production and export. The chapter concludes by examining challenges to these collaborative ventures—challenges that, while present, should rapidly diminish as the sector scales—and underscores the expanding opportunities across the hydrogen value chain that will drive deeper and more impactful GCC–China cooperation in the hydrogen economy.

Key takeaways from this chapter include the following:

- Some GCC countries are rapidly developing their hydrogen economies to transition away from hydrocarbon dependency and secure new energy export markets.
- China, as a major hydrogen consumer and technology leader, is a natural partner for the GCC's hydrogen export ambitions.
- Strategic collaboration between China and the GCC could potentially accelerate the commercialization of hydrogen, lower production and transportation costs, and position both partners as leaders in the global hydrogen market.

Potential and Economics of Hydrogen Production in GCC Countries

The GCC's Hydrogen Advantages and Global Market Potential

The role of hydrogen for an oil and gas exporting bloc like the GCC revolves around three pillars: sustainability, economy, and innovation. In their Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) under the Paris Agreement, the GCC countries—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE)—have committed to these pillars, with three of them—Oman, Saudi Arabia, and the UAE—including ambitious plans to scale up hydrogen production, focusing on international cooperation to diversify their energy export portfolios and meet their climate commitments. For Oman, Saudi Arabia, and the UAE, hydrogen is now unequivocally identified as essential for decarbonizing their hard-to-abate sectors (e.g., cement production, steel manufacturing, heavy-duty transportation). Furthermore, both the UAE and Oman have robust national hydrogen strategies, targeting 15 million tons per year (Mt/y) and 8.5 Mt/y of low-carbon hydrogen production, respectively, by 2050.

Given their geographic proximity to key demand centers in Europe and Asia, GCC countries can effectively meet the clean energy needs of both markets, providing a significant competitive advantage. Additionally, the bloc boasts one of the lowest levelized costs of electricity (LCOEs) in the world and is exploring the use of alternative precious metals and minerals in the manufacturing of electrolyzers. This presents a unique opportunity for collaboration with Chinese technology innovators and research and development (R&D) specialists to try to generate some of the lowest carbon footprint, low-cost hydrogen supplies globally.

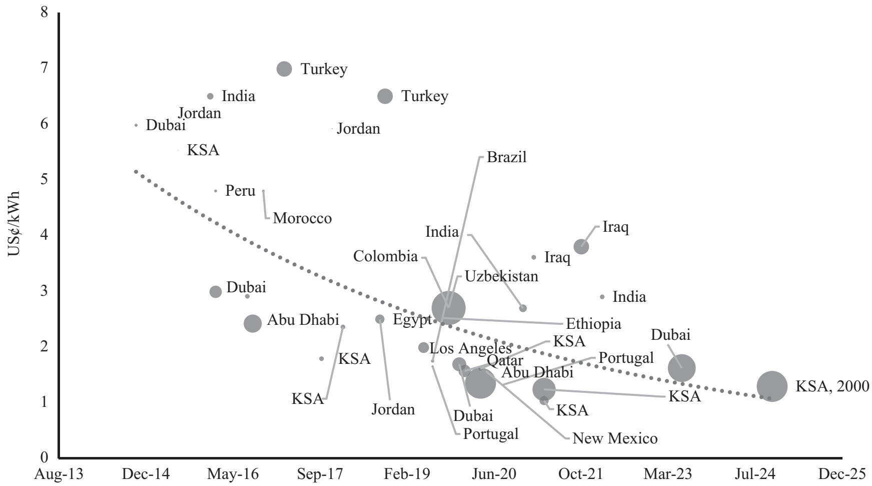

Figure 11.1 Historical solar PV bid costs, project sizes in MW.

Note: kWh, kilowatt hours.

Source: Authors' calculation based on open-source intelligence data and media reports.

Moreover, GCC countries possess natural and engineered competitive advantages for producing low-carbon hydrogen. For blue hydrogen, their competitiveness is driven by low-cost feedstock, efficient deployment of carbon capture, utilization, and storage (CCUS), and established hydrocarbon infrastructure. For green hydrogen, the GCC boasts some of the lowest solar energy costs worldwide, with solar photovoltaic (PV) auction prices reaching as low as $10.4 per megawatt hour (MWh) (Fouad 2024).

GCC countries have achieved extremely low LCOE bids for renewable energy (see Figure 11.1). For example, Saudi Arabia's 600 megawatt (MW) Shuaibah solar photovoltaic project was awarded in April 2021 at $10.4/MWh, then a world record; while the most recent round, in October 2024, attracted a bid of $12.9/MWh for the 2 gigawatt (GW) Al Sadawi PV project (Levesque 2024).

A key challenge for green hydrogen in the GCC is water scarcity, as electrolysis requires large volumes of desalinated water. However, desalination technologies—widely deployed across the member states—ensure a low-cost water supply, with desalination accounting for only about 2% of total hydrogen production costs (Tonelli et al. 2023).

Economic Viability of Blue and Green Hydrogen in the GCC

The economic viability of hydrogen production in the GCC primarily depends on the cost structure of green and blue hydrogen, which is influenced by renewable energy prices, capital expenditure (CapEx), carbon capture and storage (CCS) efficiency, and hydrogen transport costs.

The competitiveness of green hydrogen production depends primarily on the cost of renewable energy inputs (solar, wind), electrolyzer efficiency, capital costs, grid integration, energy storage needs, financing conditions, and offtake agreements. As previously noted, GCC countries benefit from some of the world's lowest renewable energy prices. Given that renewable electricity accounts for approximately 75% of the total levelized cost of hydrogen (LCOH) (authors' estimate), these low energy prices provide a significant cost advantage. However, high initial CapEx for electrolysis infrastructure and uncertain offtake agreements pose investment risks.

For blue hydrogen production, the primary cost driver is the price of input natural gas (or other hydrocarbon feedstock). Factors such as the efficiency and cost of the chosen conversion method (steam methane reforming [SMR], autothermal reforming [ATR], etc.), the level of carbon capture, penalties for non-captured emissions, and the cost of carbon dioxide capture, transport, and storage also affect costs.

GCC countries enjoy some of the world's lowest natural gas prices, making blue hydrogen highly cost-competitive. Natural gas feedstock costs vary by country:

- Saudi Arabia and Qatar: ~\$1.7–\$2.15 per million British thermal units (MMBtu)
- UAE: ~\$3-\$4 per MMBtu (Al-Jubran 2025)
- Oman and Bahrain: ~\$3.39-\$4.00 per MMBtu
- Kuwait: Imports LNG at ~\$5+ per MMBtu

With an SMR efficiency of ~75%, a gas price of \$3 per MMBtu translates to a feedstock cost of ~\$0.45/kg of hydrogen. When combined with capital and operating expenses (~\$0.98/kg), blue hydrogen in the GCC could be produced at ~\$1.40/kg, making it significantly cheaper than green hydrogen in the short term (Singh 2021).

The International Energy Agency (IEA 2023a) estimates that by 2030, green hydrogen costs could range from:

- Oman: \$1.6 per kilogram (kg) IEA 2023b)
- Chile: \$1.4/kg in the northern zone, \$1.8/kg in the central zone, and \$1.3/kg in the southern zone (Alvear et al. 2024)
- US: \$2.3/kg (IEA 2023a)
- Australia: \$1.6 /kg (IEA 2023a)
- Central Europe: \$2.7/kg
- Japan: \$3.8/kg

In a typical GCC green hydrogen project, capital expenditures (\$0.5/kg) and operational costs (\$0.2/kg) remain relatively stable, while electricity costs (\$0.75–\$1.7/kg) drive overall production expenses. Achieving a cost-competitive hydrogen industry in the GCC requires stable financing conditions and long-term offtake agreements (Hasegawa 2023). More recent evaluations, for example, by the IEA (2024) and BNEF (2024), suggest that green hydrogen production costs will rise, at least initially, because of material and equipment cost inflation and higher interest rates. Nevertheless, this does not affect the relative ranking of the GCC.

Despite these challenges, the GCC remains one of the most cost-competitive hydrogen producers globally, with its low-cost energy resources, well-established infrastructure, and supportive government policies providing a strong foundation for long-term hydrogen development.

GCC's Competitive Position in the Global Hydrogen Market

The GCC's geographical location—between Europe and East Asia—gives it a strategic advantage in the global hydrogen market. The bloc benefits from direct access to global shipping lanes via the Red Sea and the Suez Canal, facilitating hydrogen and ammonia exports to major demand centers.

Despite competition from emerging hydrogen-exporting regions, such as North Africa and Australia, the GCC maintains a competitive edge due to some critical factors, including lower financing costs supported by state-backed energy policies and established industrial bases for hydrogen derivatives (e.g., ammonia, synthetic fuels, green steel). Furthermore, the existing hydrocarbon infrastructure that supports blue hydrogen and CCUS development will enable hydrogen exports along with integrated port and transport networks. The GCC's industrial zones—such as Saudi Arabia's Neom, the UAE's Ta'ziz, and Oman's Duqm—are poised to become global hubs for hydrogen production and export.

Hydrogen transport remains a key cost determinant for global market competitiveness. Production is typically utilized in three ways:

1. Pipeline exports (e.g., North Africa to Europe)
2. Conversion to ammonia for shipping to distant markets
3. Local industrial applications (e.g., green steel, synthetic fuels)

The authors' estimated costs of transportation are as follows:

1. Pipeline (1,000 km): ~$0.3/kg
2. Liquefied hydrogen (10,000 km): ~$2.0/kg
3. Ammonia (including conversion): ~$1.5/kg

Given the high costs associated with liquefied hydrogen transport, ammonia remains the preferred export form for GCC hydrogen projects. Shipping distances to key markets and end-use applications further influence competitiveness. For example, transporting ammonia from Oman to Japan (~11,000 km) is cost-effective compared to transporting hydrogen in its gaseous state, while liquefied hydrogen is marginally competitive. In another case, transporting hydrogen from Saudi Arabia to Europe (via Suez) may have lower transport costs, but it faces competition from North Africa, which could supply hydrogen via pipelines.

Unlike the European Union (EU), United Kingdom, and Canada, there are currently no fully operational carbon pricing mechanisms in GCC countries (aside from nascent voluntary markets in the UAE and Saudi Arabia), which reduces direct incentives for hydrogen investment. However, several factors help mitigate this:

- State-backed financing lowers borrowing costs for large-scale projects
- Government support for CCUS and hydrogen infrastructure
- Long-term offtake agreements with major industrial consumers

The UAE's Abu Dhabi Environment Agency (EAD) has initiated greenhouse gas (GHG) measurement and verification programs, which could serve as a foundation for future carbon pricing policies. Despite the absence of explicit carbon pricing, early investments in hydrogen infrastructure position the GCC as a key player in the global hydrogen economy. Future regulatory developments may further enhance investment attractiveness, particularly if carbon pricing mechanisms are introduced.

Hydrogen Cooperation between the GCC and Major Consuming Markets

Cooperation Initiatives between GCC and Major Global Markets

The GCC's hydrogen cooperation initiatives have primarily focused on collaborations with European and Japanese markets, and more recently with Chinese markets. These initiatives encompass investments (both within the GCC and externally), supply agreements, and technology development.

Major industries, such as steel and aluminum, require large-scale hydrogen adoption to meet decarbonization targets and enhance product competitiveness. For instance, green steel production alone could demand approximately 19% of the EU's 2030 renewable hydrogen target (1.9 Mt/y out of 10 Mt/y). However, the EU is falling short of its production targets, with only 3 GW of renewable hydrogen projects reaching the final investment decision (FID) by late 2023. This shortfall highlights the strategic importance of accelerating hydrogen imports to bridge the deficit in the near to medium term.

While entry points along the North Sea coast are the preferred import route, shipping and new pipelines from the GCC via Egypt and Greece are currently under feasibility studies (ZAWYA 2023).

North Africa (Tunisia, Algeria) is considering direct pipeline connections to Europe (Shaw 2025), but these plans remain conceptual:

- Tunisia's hydrogen target: 0.32 Mt/y by 2030, with 0.3 Mt/y designated for export.
- The existing TransMed Pipeline (Algeria–Italy) could be expanded for hydrogen, requiring policy alignment and financial guarantees.

Meanwhile, Germany has launched green hydrogen tenders to supply steel plants in Saarland (Dillinger Steel Mill), Duisburg (Thyssenkrupp), and Salzgitter. Belgium

Table 11.1 Hydrogen market developments in the GCC, 2024–January 2025

Entity	*Market development*	*Details of the market development*	*Date*
Masdar-Daimler (Masdar 2024)	Green H_2 Exports	Memorandum of Understanding (MoU) to export liquid green hydrogen from Abu Dhabi to Europe by 2030, supporting Daimler Truck's CO_2-neutral fleet target by 2039.	January 2024
ADNOC-POSCO (POSCO 2024)	Blue H_2 Production	Joint development of blue hydrogen infrastructure at POSCO's Gwangyang LNG Terminal with operations starting in 2029, integrating CCUS for certification.	February 2024
ADDED and HYCAP (Abu Dhabi Media office 2024)	Industrial H_2 complex	Hydrogen and renewable energy complex in Abu Dhabi, including hydrogen storage, transport, electrolyzer manufacturing, and fuel cell production.	February 2024
Greenzo Energy (Nair 2024)	Green H_2	Supply a 1 MW alkaline electrolyzer to produce 400 units of electricity per hour using green hydrogen for Oman's airport.	March 2024
ARMS-Pure Hydrogen (ZAWYA 2024b)	H_2 Trucks	Partnership to introduce hydrogen fuel cell commercial vehicles in the UAE by 2025.	September 2024
Ardian-Masdar-PIF (Khan 2024)	Green H_2 Investments	Co-investments in green hydrogen projects in Abu Dhabi and plans to collaborate with PIF on joint ventures in Saudi Arabia.	October 2024
Masdar & Norway (Čučuk 2024)	Green H_2	Agreements with Equinor and others to develop green hydrogen infrastructure in Europe, targeting hard-to-abate sectors.	October 2024
Shuangliang H2 (Prabhu 2024)	Green H_2 System	Supply of green hydrogen production systems for the 300 kt/y ACME ammonia project in Oman, with completion by 2025.	December 2024
Hydrom & Belgium (Habibic 2024b)	H_2 Cooperation	MoU to advance green hydrogen projects, focusing on joint research, industrial partnerships, and regulatory frameworks for hydrogen import and distribution (ZAWYA 2024a).	December 2024
Wisdom Motor & OIA (Fuel Cells Works 2025)	H_2 Transport	Agreement to explore local hydrogen vehicle manufacturing in Oman.	January 2025

Source: Authors' compilation based on open source intelligence data and media reports.

has partnered with Oman to facilitate research, industrial partnerships, and regulatory frameworks for hydrogen imports (Landini and Amante 2023).

While the EU remains a key partner, the GCC is deepening hydrogen collaboration with Japan, South Korea, and China. For instance, Japan's energy firm JERA and the UAE's state-owned oil company ADNOC signed a strategic collaboration agreement to work together on clean hydrogen and ammonia. Additionally, Japan and Saudi Arabia signed the Lighthouse Initiative to develop clean energy projects in areas such as hydrogen and ammonia, e-fuels, carbon recycling, direct air capture, and critical minerals.

Commercial engagements with China are primarily focused on clean energy and technology, which yield benefits for hydrogen projects. Partnering with Chinese clean technology companies serves two long-term strategic objectives: (1) expanding the GCC's energy exports to China beyond conventional energy and (2) positioning the GCC as a leading proponent of the energy transition in China. Furthermore, partnering with GCC countries allows China to offload surplus production from its clean energy supply chain, especially when the domestic market is saturated. A detailed discussion regarding cooperation with China is presented in Section 6 of this chapter.

Major Joint Investments in GCC Hydrogen Production and Export

International energy companies and financiers play a crucial role in financing, technology supply, and the development of low-carbon hydrogen projects across Qatar, Oman, Saudi Arabia, and the UAE. These investments target hydrogen production, export infrastructure, and industrial applications.

Current stakeholders in GCC hydrogen projects are primarily from Europe, Asia, and North America, and this presence is expected to grow. Joint investments along the GCC hydrogen value chain unlock numerous benefits, not only for the receiving GCC countries but also for these companies, as they engage in various segments of the value chain. They gain access to competitive energy resources, an early mover advantage in shaping government support and policy frameworks, a strategic market position for exports and future energy security, supply chain integration and localization, a dynamic innovation ecosystem, and opportunities to establish manufacturing hubs and service networks within the GCC. This not only reduces their operational costs but also aligns with the GCC's focus on economic diversification and job creation, creating a pathway for international companies to build a long-term presence in a key growth market. Moreover, collaborating with national energy giants provides access to capital, infrastructure, and expertise, while also ensuring a reliable customer base for advanced hydrogen solutions, as the GCC's energy players are among the world's largest oil and gas exporters.

Securing firm offtake commitments has been identified as the key issue for most low-carbon hydrogen projects to proceed. In a nascent sector like hydrogen, attrition is expected where the business case may not be strong enough. However, this is not the case for the GCC countries, where hydrogen projects are considered highly credible due to the GCC's reliability as a trusted oil and gas trading partner

Table 11.2 Major hydrogen projects in the GCC countries

Country	*Low-carbon hydrogen production target by 2030*	*Low-carbon hydrogen production target by 2050*	*Main hydrogen type targeted*	*Key energy resource required*	*Major projects*
Saudi Arabia	2.9 Mt/y with 1.93 Mt/y of blue hydrogen	*n/a*	67% Blue, 33% Green	Natural Gas with CCUS, Renewable Energy (solar and wind)	NEOM Helios (2026): $8.5B green hydrogen project (ACWA Power, Air Products, Thyssenkrupp). Yanbu Green Hydrogen (2029): $6.5B project (PIF, KEPCO, POSCO, Samsung C&T).
UAE	1.4 Mt/y	15 Mt/y	50% Blue, 50% Green	Natural Gas with CCUS, Renewable Energy (solar)	TAQA & Abu Dhabi Ports (2030): 2 GW green hydrogen plant. Masdar and Uniper (2026): 1.3 GW green hydrogen for ammonia export.
Oman	1 Mt/y	8.5 Mt/y	100% Green	Renewable Energy (solar and wind)	Hyport Duqm (Phase 1 by 2026): 1.5 GW green hydrogen (DEME, Uniper, BP). Green Energy Oman (2030): $30B project (Shell, OQ, InterContinental Energy).
Qatar	1.2 Mt/y	*n/a*	100% Blue	Natural Gas with CCUS	QatarEnergy Blue Ammonia (2026): $1.1B project for hydrogen-based exports

Source: Authors' compilation from government announcements: Mirza (2021), Radowitz (2022) and (Eckert, More, and Lewis 2022).

and its low-cost, low-carbon resource base. This positions them well to meet emission standards in Europe, Japan, China, and other markets at the lowest possible cost. They also benefit from strong government backing, whereas European projects have struggled to secure large-scale FIDs despite available funding options like Important Project of Common European Interest (IPCEI) support (Alkousaa 2024).

Conversely, GCC-based companies are actively engaged in international hydrogen investments. Notable players include ACWA Power, a Saudi international power and water company; Masdar; and Amea Power in the UAE. For instance, Masdar has explored investments in Namibia's green hydrogen sector and in green hydrogen production in Azerbaijan, while ACWA Power has signed an MoU with China's Sinopec Guangzhou Engineering Company for potential collaboration in green hydrogen and ammonia production in Saudi Arabia, as well as other projects worldwide to improve technology solutions. Additionally, Oman is set to launch the third round of public bidding for lands designated for green hydrogen projects in the first quarter of 2025 under Hydrom. Winning projects could significantly expand Oman's project pipeline capacity through 2030.

Challenges and Opportunities in Advancing Joint Initiatives

The GCC's hydrogen market is poised for rapid growth to meet national production and export targets. This creates opportunities for joint initiatives between GCC countries and international—including Chinese—companies along the hydrogen value chain, with transformative potential to evolve the sector into a "Swiss Army knife" of decarbonization.

In the production and processing stage, the GCC has several dedicated hydrogen production projects. In the end-use stage, it boasts low-carbon methanol (natural gas with CCUS) projects, sustainable aviation fuels from renewable hydrogen, numerous pilots and demonstrations around hydrogen in transport, and ongoing

Table 11.3 Key growth opportunities for international businesses in the GCC hydrogen value chain

Production and processing	Low-cost renewable hydrogen projects, grid expansion, battery storage, alternative storage technologies (molten salt), electrolyzer manufacturing, pipeline development, low-water electrolysis solutions.
Transportation	Pipeline expansion and retrofitting, materials compatibility for hydrogen transport, advanced steel tubes, welding technology, and high-efficiency hydrogen transport solutions.
Storage and distribution	Compressed air energy storage, localized manufacturing of alternative storage solutions, large-scale hydrogen storage pilots, high-pressure tube trailer manufacturing.
End use	Industrial applications (steel, aluminum, cement, fertilizers), power generation, long-haul transport, refueling stations, and hydrogen infrastructure development.

Source: Compiled by the author based on industry observations and expertise.

plans for renewable and natural gas with CCUS-based hydrogen usage in core sectors such as steel, aluminum, and cement to meet aggressive decarbonization targets.

The storage and distribution segment has been relatively underexplored but is receiving increasing attention for unique opportunities that align with the interests and capabilities of Chinese companies within hydrogen value chains. One promising sub-segment is supply chain optimization. The GCC's hydrogen targets will necessitate supply chains that extend beyond the manufacture of electrolyzers and their components to include system integration, ancillary services, pressure vessels for transportation, essential and/or critical materials substitution, end-of-life material recovery or recycling, storage solutions (such as self-contained storage pods), and circularity within storage and distribution systems.

While electrolyzer manufacturing might be the more commonly pursued opportunity, major GCC players like the UAE and Saudi Arabia are focused on building local capabilities for more carbon-efficient, low-risk profile electrolyzer subcomponents that contribute to lower-cost, higher-efficiency, and low lifecycle carbon-intensity electrolyzers. This strategy can differentiate them from regional competitors who are also strongly pursuing electrolysis-based hydrogen.

For example, the UAE is developing a pressurized alkaline electrolyzer manufacturing facility with Belgian manufacturer John Cockerill, which will rely on nickel and nickel alloy for the end product—now a volatile commodity subject to price spikes and bottlenecks following Russia's invasion of Ukraine. Suppliers of subcomponents that use less volatile, more environmentally friendly, and cost-effective essential/critical materials can enhance the UAE's electrolyzer manufacturing capabilities in a way that drives down costs more effectively. Similarly, Saudi Arabia has signed an MoU with India to ensure reliable and resilient supply chains for materials used in low-carbon hydrogen, including those for electrolyzers.

Chinese companies specializing in project development, Engineering, Procurement, and Construction (EPC) services, and electrolyzer technologies (including Original Equipment Manufacturers, OEMs) may face competition from existing players in the GCC hydrogen value chain but can capitalize on a relatively unsaturated landscape in the midstream segments—namely transport, storage, and distribution. Areas such as ecosystem and sector integration, digitalization and automation, and logistics (from compression and liquefaction to storage and distribution) present opportunities where Chinese companies can capture significant market share, leveraging their well-established and mature businesses.

Apart from the hydrogen value chain, hydrogen innovation is a crucial overarching consideration that can provide R&D opportunities across different stages of technology development. This encompasses the innovation cycle from basic and applied research to demonstration and large-scale deployment. In the GCC, hydrogen innovation opportunities extend from basic research to patent activity, with basic and applied research often focusing on technologies that globally have a lower technology readiness level (TRL). However, these can be pursued as niche specializations in the GCC due to strong support for R&D, available funding opportunities, and established connections with technology specialists, such as Masdar in the UAE. These initiatives often involve next-generation technologies with a longer-term commercialization outlook.

Patent activity supports cutting-edge technologies at a higher TRL that show potential for demonstration, scale-up, and commercialization in the short to medium term. The current focus is predominantly on the storage and distribution segment of the hydrogen value chain, which has been relatively underexplored in the GCC. For Chinese R&D companies, engaging with the appropriate stakeholders (including counterpart R&D institutions, technology providers and developers, academia, and media institutions) can indicate areas of commercial implementation and scale-up.

For China, joint investments with the GCC align with its goals of diversifying investment partnerships, positioning the GCC as a strategic ally in renewable energy and green hydrogen partnerships. China's expertise and the GCC's ambition for sustainable development are closely aligned, extending into technological cooperation. Partnerships in this space could become emblematic of a broader trend toward South–South cooperation, where strategically aligned emerging economies can bypass traditional Western-dominated energy systems and create new growth opportunities.

Hydrogen Storage and Transport: Advancements and Obstacles Within the GCC Cooperation Context

Advancements in Hydrogen Storage and Transport for Global Trade

Currently, global hydrogen storage and transportation technologies primarily include pipeline transportation, high-pressure gaseous hydrogen, cryogenic liquid hydrogen, organic liquid hydrogen carriers, solid-state hydrogen storage, ammonia storage, and methanol storage. Countries adopt varying strategies based on their industrial capabilities and infrastructure. Europe focuses primarily on hydrogen pipeline networks, repurposing existing natural gas infrastructure to establish a 23,000 km hydrogen pipeline by 2040. Japan is developing high-pressure gaseous (88 megapascals[1] [MPa]) and cryogenic liquid hydrogen storage, leading Asia's liquid hydrogen market with a two-thirds market share. In February 2022, Japan completed the world's first successful maritime transportation of liquid hydrogen. South Korea is actively developing liquid hydrogen refueling stations and transoceanic transportation supply chains for both liquid ammonia and liquid hydrogen. China primarily focuses on high-pressure gaseous hydrogen storage and transportation while simultaneously developing multiple hydrogen storage and transportation pathways. Currently, hydrogen transportation is typically carried out using 20 MPa long tube trailers. China is planning and constructing a diversified hydrogen storage system that mainly includes pipeline hydrogen transportation and cryogenic liquid hydrogen storage, supplemented by liquid ammonia (methanol) and solid-state hydrogen storage (CAPID, Hydrogen Energy Industry Promotion Association 2023).

Table 11.4 Key hydrogen storage and transport technologies

No.	*Technology*	*Key developments*
1	High-pressure gaseous hydrogen	Mass production of 70 MPa type-IV cylinders, 98 MPa stationary storage, and 52 MPa high-volume cylinders.
2	Pipelines	5,000+ km of hydrogen pipelines globally, with 85% in the United States (U.S.) and Europe, operating at 10.3 MPa max pressure.
3	Liquid hydrogen storage and transport	U.S. and Russia lead in liquefaction (below 12 kWh/kg); U.S. storage tanks reach 3,500 m^3, while Russia produces 1,400 m^3 tanks.
4	Solid-state hydrogen storage	High storage density; relies on rare-earth & Ti-Mn-based alloys; Japan's Toshiba developed 1000 cubic meters (m^3) of hydrogen storage with 38 kg/m^3 density.
5	Organic liquid hydrogen storage	Japan's Chiyoda uses MCH (methylcyclohexane, 6.2% H_2 mass density); toluene is cost-effective for dehydrogenation.

Source: China Association for Promotion of Industrial Development, Hydrogen Energy Industry Promotion Association (2023).

Future hydrogen distribution will integrate pipelines, large-scale liquid hydrogen, high-pressure gas, organic liquid carriers, and solid-state storage, thereby creating efficient multi-modal transport networks.

GCC Initiatives in Hydrogen Storage and Transport

Currently, the UAE and Oman have issued their national hydrogen strategies, and the parallel development of blue hydrogen and green hydrogen is set to become a crucial pathway for hydrogen energy development in GCC countries. In 2017, Saudi Arabia began developing the Neom city, which will be powered entirely by renewable energy and will incorporate a green hydrogen industry to accelerate the realization of the Saudi Vision 2030 strategy. The UAE is committed to reducing carbon emissions across its entire industrial chain, with plans to achieve carbon neutrality by 2050. Leveraging its resource advantages, the country plans to develop its hydrogen energy industry, expanding blue hydrogen production through CCUS technology and incorporating the production of green hydrogen from renewable sources such as wind and solar into its development plans.

Against the backdrop of carbon neutrality, Middle Eastern countries are strategically transitioning from being fossil fuel exporters to hydrogen energy exporters. In the long term, GCC countries have significant potential for green hydrogen supply. They are actively advancing their renewable energy development, with both the UAE and Oman actively pursuing ambitious national hydrogen strategies, targeting 15 million metric tons per year and 8.5 million metric tons per year of low-carbon hydrogen production, respectively, by 2050. Beyond meeting domestic demand, the low-carbon hydrogen produced in the GCC will be extensively exported to key markets such as Europe and East Asia. By that time, GCC countries are likely to store and transport hydrogen in various forms, including liquid hydrogen, hydrogen-containing compounds, hydrogen metallurgy products, and green hydrogen-based petrochemical products.

Challenges and Obstacles in Hydrogen Storage and Transport

Compared to other major fuels, hydrogen has a high energy density per unit mass but a low energy density per unit volume. For example, the volumetric energy density of hydrogen at ambient conditions is only about one-third that of natural gas. When compared to liquid fuels like gasoline, hydrogen's volumetric energy density is approximately 1/3000 that of gasoline. Transporting and storing hydrogen in a high-density state presents significant technical challenges due to its low volumetric energy density. In applications such as automotive fuel storage, both mass and volumetric energy density are important considerations. Therefore, developing hydrogen storage and transportation technologies that can match the energy density of fossil fuels in both mass and volume is crucial to overcoming the key challenges associated with hydrogen storage and transport.

The energy efficiency of hydrogen storage and transportation is also a vital consideration. Typically, efficiency is evaluated based on the heating value of hydrogen. The energy consumed for transportation and storage as a percentage of hydrogen's heating value serves as an important metric; ideally, this percentage should be below 10%.

Currently, the primary methods for hydrogen storage and transportation include high-pressure gas, liquid hydrogen, and material-based hydrogen storage. The technological and economic feasibility of hydrogen storage and transportation are crucial areas of research.

China–GCC Cooperation: Catalyst for Advancing Global Hydrogen Markets

China's Hydrogen Market and Policy Development

According to the "China Hydrogen Development Report 2023" (Department of Energy Conservation and Technology Equipment, National Energy Administration, Beijing Guoqing Zhonglian Hydrogen Energy Technology Research Institute [2024]), by the end of 2023, China's hydrogen production capacity exceeded 49 million metric tons per year, representing a 2.3% increase compared to 2022, with production surpassing 35 million metric tons. The hydrogen produced primarily serves as an intermediate raw material in industrial processes such as ammonia and methanol synthesis, as well as refining. In recent years, China's water electrolysis hydrogen production capacity has rapidly expanded. According to the China Hydrogen Alliance Research Institute, by the end of 2022, China had completed and put into operation 36 renewable energy water electrolysis hydrogen production projects, with a combined production capacity of 56,000 metric tons per year (Fu et al. 2023. Additionally, 35 projects were under construction, with a combined production capacity exceeding 170,000 metric tons per year.

In the industrial sector, China is setting a benchmark for combining large-scale renewable energy hydrogen production with extensive hydrogen utilization. In 2022, the number of hydrogen industrial demonstration projects grew significantly, with several landmark green hydrogen chemical and hydrogen metallurgy projects commencing construction. For instance, Sinopec has constructed a green hydrogen project in Xinjiang province, which was put into operation in 2023. This green hydrogen refinery integration demonstration project will produce 20,000 metric tons of green hydrogen annually, reducing carbon emissions by approximately 485,000 metric tons per year by replacing natural gas-based hydrogen production. The National Energy Group is developing the first full hydrogen energy industry chain ecological project in Ningxia, with a hydrogen production capacity exceeding 20,000 cubic meters per hour. This project will supply hydrogen to coal-to-liquid projects like Ningxia Coal Industry and to hydrogen refueling stations. These initiatives position China at the forefront of global hydrogen metallurgy. The advancement of hydrogen demonstration projects in the industrial sector will explore feasible pathways for deep decarbonization. Given the substantial hydrogen demand in this sector, industrial hydrogen energy demonstration projects can help lower hydrogen supply costs and stimulate the application of hydrogen energy in other fields.

China–GCC Strategic Partnership: A Catalyst for Global Hydrogen Market Expansion

GCC countries hold vast potential for cooperation with China in the hydrogen sector. The GCC boasts abundant wind and solar resources, providing a unique advantage in the development of renewable energy and green hydrogen production. On December 8, 2022, during a state visit to Riyadh, Chinese President Xi Jinping witnessed the signing of a Memorandum of Understanding (MoU) between Saudi Arabia and China on hydrogen energy and encouraging direct investment between the two countries (People’s Republic of China and Kingdom of Saudi Arabia 2022). The UAE, Oman, and other GCC member states are also comprehensively planning their hydrogen industries. These countries are actively promoting the transition to low-carbon energy and the development of renewable energy-based hydrogen production, accelerating the production and export of hydrogen energy and positioning themselves as key players in the global hydrogen market.

The Trade in Hydrogen Energy and its Derivative Products

Although long-distance maritime transportation of liquefied hydrogen has been demonstrated, it is expected that, in the foreseeable future, the primary mode of international hydrogen trade will involve hydrogen-containing chemical carriers and low-carbon products manufactured using green hydrogen, rather than the direct transport of liquid hydrogen itself.

The trade of ammonia and methanol between China and GCC countries in 2023 is shown in the table below. Based on the hydrogen content of 17.6% in ammonia

Table 11.5 Major hydrogen product trade between China and GCC countries in 2023

Country	*Ammonia, metric tons*		*Methanol, metric tons*	
	Source of China's imports	*China export destination*	*Source of China's imports*	*China export destination*
Saudi Arabia	181,933		2,162,662	
Qatar	14,800		255,786	
Kuwait	—		—	
Oman	32,189		3,654,144	
UAE	731		2,245,224	
Bahrain	8,398		11,072	
GCC total	238,052	0	8,328,888	0
World total	693,045	185,438	14,553,045	149,657

Source: General Administration of Customs of the People's Republic of China (n.d.).

and 12.5% in methanol, China imported a total of 1.083 million metric tons of hydrogen equivalent from GCC countries in 2023.

Collaboration on Relevant Technological Equipment

China is the world's largest manufacturer of water electrolysis equipment. Leveraging its manufacturing and cost advantages, Chinese companies should seize the significant opportunity presented by the deepening of China–GCC hydrogen industry cooperation. This involves promoting the export of Chinese electrolyzer equipment, proton exchange membranes, hydrogen storage and transportation equipment, and related engineering services.

Investment Project Collaboration

China and GCC countries have established close cooperation in the energy and petrochemical sectors, laying a solid foundation for future hydrogen collaboration. Notable projects include the Tianjin Petrochemical joint venture between Sinopec and SABIC (Argaam 2023) and the YASREF refinery, inaugurated in 2016 and jointly attended by President Xi and King Salman (Aramco 2016). These projects reflect deepening economic ties and mutual trust, providing momentum for scaling up cooperation into hydrogen energy. Combined with China's comprehensive capabilities across the hydrogen value chain—production, storage, transport, and utilization—this creates strong potential for bilateral investment partnerships.

While the Middle East still trails in hydrogen and fuel cell technologies, its strength in blue hydrogen production and abundant renewable energy gives it a strategic advantage in developing green hydrogen. This aligns well with China's strategy for industrial expansion into overseas green energy markets.

The GCC countries are implementing a coordinated model linking "solar energy development—seawater desalination—water electrolysis for hydrogen production—export of green hydrogen" (China Association for Promotion of Industrial Development (CAPID), Hydrogen Energy Industry Promotion Association 2023. "International Hydrogen Energy Technology and Industry Development Report 2023." Beijing: China Economy Publishing House 2023). This approach supports the build-out of complete industrial chains, from photovoltaics and concentrated solar power (CSP) to hydrogen production and storage, creating strong alignment with Chinese energy infrastructure capabilities.

Progress and Trends in China–GCC Hydrogen Cooperation

China and GCC countries, particularly Saudi Arabia, have been advancing numerous cooperative projects in the hydrogen sector. Since December 8, 2022, significant agreements and MoUs on hydrogen and related fields have been signed between China and Saudi Arabia. This collaboration aims to accelerate efforts in climate change mitigation, green industry development, and the transition towards sustainability. Both countries are maximizing synergies across the hydrogen value chain to jointly establish a global hub for hydrogen energy industry excellence (see Table 11.6).

Table 11.6 Recent China and GCC hydrogen cooperation initiatives

Entities	*Targeted Sector*	*Details of the Cooperation*	*Date*
Guangdong Province—Saudi Aramco	Petrochemicals, hydrogen, ammonia	MoU to enhance cooperation in petrochemicals, hydrogen energy, and ammonia sectors.	March 2023
China Energy Construction—Saudi AGIC—Morocco's Gaia Energy	Green ammonia	MoU for a green ammonia project with 1.4M tons/year capacity, 2 GW PV + 4 GW wind power.	April 2023
Energy China Group and Power China–ACWA Power	Green hydrogen	Strategic cooperation agreements on green hydrogen projects.	May 2023
Jiangsu Guofu Hydrogen Energy Equipment and Broaden Energy—ADNOC	Hydrogen infrastructure	Won bid for hydrogen production and refueling station project.	June 2023
China Southern Power Grid and Mingyang Smart Energy Group—ACWA Power	Green hydrogen and ammonia	Strategic MoU signed at China–Saudi conference for green hydrogen and ammonia.	September 2023
Zhongguancun Hydrogen and Fuel Cell Technology Innovation Industry Alliance—Dubai Chamber of Commerce—Daxing Zone	Hydrogen innovation	Agreement to establish China–Arab hydrogen industry innovation platform in Beijing.	April 2024

Source: Authors' compilation based on OSINT data and media reports.

China–GCC Hydrogen Cooperation: Opportunities, Potentials, and Challenges

For the GCC countries, green hydrogen represents a crucial pathway to diversify from sole reliance on oil production, achieve energy supply and export transformation, and promote low-carbon development. For China, green hydrogen is a strategic initiative to develop renewable energy, facilitate renewable energy integration, promote low-carbon development, and ensure energy security. Given the GCC's status as a net energy exporter and China's position as a net energy importer, there are clear opportunities for collaboration in the field of green hydrogen.

The potential for cooperation between China and the GCC countries in the field of hydrogen is significant. In hydrogen production, GCC countries possess abundant renewable energy resources and have ambitious goals for green hydrogen development. China has already operationalized several green hydrogen production projects, providing valuable experience that can support the GCC countries in their green hydrogen initiatives. The potential for cooperative investment between both sides is substantial.

In terms of hydrogen trade, products such as synthetic ammonia and methanol are the main downstream products of hydrogen. Currently, China has a substantial demand for synthetic ammonia and methanol from GCC countries, and this trend is expected to continue. Due to the higher cost of green hydrogen and China's reliance on coal rather than low-carbon energy sources like oil and natural gas, importing synthetic ammonia and methanol from GCC countries benefits both China's low-carbon development goals and the hydrogen industry development in GCC countries.

In key technological aspects, China has made rapid advancements in hydrogen energy technology, particularly in the field of electrolysis. Both alkaline electrolysis and proton exchange membrane (PEM) electrolysis technologies have matured significantly. According to recent reports, alkaline electrolysis units capable of producing 3,000 normal cubic meters per hour (Nm^3/h) of hydrogen have been successfully deployed. The combination of resources from GCC countries and China's technological expertise presents enormous potential for collaboration.

China and GCC countries still face several challenges in their cooperation on hydrogen. One critical challenge is that, despite the GCC countries' advantages of abundant renewable energy resources leading to comparatively lower green hydrogen costs than those in China, substantial reserves of petroleum and natural gas continue to undermine the economic competitiveness of green hydrogen and its downstream products. Specifically, the lower cost structure associated with products derived from local petrochemical inputs presents a significant barrier to the competitiveness of green hydrogen options. Similarly, in China, products derived from petrochemical resources also remain cheaper compared to their green hydrogen-based counterparts, further highlighting the prevailing global economic disadvantage of green hydrogen under existing market conditions. Consequently, establishing a robust regulatory framework combined with targeted policy incentives is essential to overcome these cost disparities, enhance market competitiveness, stimulate investments, and accelerate the broader adoption and development of sustainable hydrogen technologies.

Second, both China and GCC countries are planning green hydrogen projects with downstream processing products, such as green ammonia or green methanol. Both sides aim to export these products to countries and regions like the EU that have carbon pricing mechanisms, setting the stage for potential future competition between them.

Third, the high cost of hydrogen storage and transportation poses an obstacle to cooperation between the GCC and China. Currently, hydrogen trade is primarily limited to intra-regional pipeline supply, such as that within Western Europe. Due to the challenges of storing and transporting hydrogen, there is virtually no transcontinental or transoceanic hydrogen trade. For China and the GCC countries, green hydrogen trade will mainly rely on hydrogen carriers in the form of chemicals (such as ammonia and methanol) in the near term. In the long term, as storage and transportation technologies for liquid hydrogen advance and costs decrease, the direct storage, transportation, and trade of green hydrogen will become feasible and will be prioritized.

Fourthly, since carbon reduction policies in both China and GCC countries do not yet encompass hydrogen and its downstream products, insufficient carbon pricing significantly impacts the competitiveness of green hydrogen and its downstream products. This situation, compounded by the higher costs of green hydrogen and its downstream products, poses a significant obstacle to the industry's development.

Finally, both China and GCC countries lack unified and coordinated certification for green hydrogen and its downstream products. In the future, there is a need to advance bilateral or multilateral certification policies for green hydrogen and related products to facilitate the development of green hydrogen industries in both regions.

Note

1 A unit of pressure measurement in the International System of Units.

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12 Challenges and Opportunities in CCUS

Synergizing Efforts in China and GCC Countries

Xiaoliang Yang, Abdullah Alkhedhair, and Abdullah Alabduly

Introduction

CCUS is a suite of technologies developed to reduce CO_2 emissions from industrial processes and power generation. CCUS involves capturing CO_2 at its source, such as factories or power plants, preventing it from entering the atmosphere. Once captured, the CO_2 can be utilized for industrial purposes (such as enhanced oil recovery or the production of chemicals) or permanently stored in geological formations deep underground. In recent years, CCUS has evolved to encompass negative emission technologies like direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS). DAC captures CO_2 directly from the atmosphere, and BECCS captures CO_2 emitted during the combustion of biomass. The traditional CCUS project is sometimes referred to as "point source CCUS," while DAC and BECCS are called "carbon removal technologies."

The GCC, established in 1981, is an intergovernmental political and economic union of six countries bordering the Arabian Gulf: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE. These nations, classified as developing countries, share a common economic structure characterized by a heavy dependence on oil and gas exports. As of 2022, the GCC countries combined contribute approximately 25% of global oil production and around 10% of global natural gas production (EIA n.d.). Despite their significant reliance on fossil fuels, the GCC countries are committed to addressing climate change and diversifying their economies away from a reliance on fossil fuels. They are pursuing economic diversification strategies with co-mitigation benefits. The GCC countries emphasize the importance of supporting the most cost-effective mitigation options that effectively reduce the impacts of climate change rather than focusing solely on reducing fossil fuel use. This approach can help accelerate the energy transition while minimizing adverse socio-economic effects on developing countries, particularly fossil fuel-dependent economies. They view CCUS technologies as a practical solution for managing carbon emissions and achieving climate goals, all while ensuring a sustainable energy transition. All GCC countries have incorporated CCUS into their climate action plans.

CCUS has become a crucial tool in transitioning to a carbon-neutral economy in China, given its heavy reliance on fossil fuels like coal. In September 2020,

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President Xi Jinping announced China's goals to peak its carbon emissions by 2030 and achieve carbon neutrality by 2060. This commitment spurred significant climate actions, including the introduction of the "1+N" climate policy framework in 2021. Under this framework, various ministries, including the National Development and Reform Commission (NDRC), the Ministry of Science and Technology (MoST), the Ministry of Industry and Information Technology (MIIT), and the Ministry of Ecology and Environment (MEE), have developed detailed implementation plans. CCUS has been highlighted in many of these policy actions, offering a scalable solution for deep decarbonization in key sectors and regions.

Structured into six sections, this chapter begins with an overview of climate efforts in China and the GCC countries, highlighting the role of CCUS in their decarbonization strategies. It then examines the status of CCUS development in both China and the GCC countries through the lens of projects. The following section explores the policy landscape and challenges for CCUS in China and the GCC. Finally, the chapter discusses the rationale for collaboration between the two regions and how they can work together to accelerate CCUS development and deployment.

Climate Efforts of GCC Countries and China

GCC Countries

The GCC countries face the dual challenge of adapting to the impacts of climate change while ensuring energy security throughout the transition to cleaner energy sources. In response, they are implementing various climate change mitigation and adaptation measures, including investing in low-carbon and negative emission technologies, promoting renewable energy, enhancing energy efficiency, utilizing cleaner energy options, developing clean and low-carbon hydrogen technologies, and fostering collaboration with regional and international partners. Their ultimate goal is to help the global energy system transition to net-zero emissions, including providing cleaner fossil fuels, recognizing the bloc's continued role as a leading energy provider to the world. The GCC countries emphasize the importance of supporting the most cost-effective mitigation options that effectively reduce the impacts of climate change rather than focusing solely on reducing fossil fuel use. This approach can help accelerate the energy transition while minimizing any of its adverse socio-economic effects on developing countries, particularly fuel revenue-dependent countries.

The GCC countries have intensified their focus on addressing climate change by integrating climate actions into their diversification plans. Five GCC countries, including Saudi Arabia, the UAE, Kuwait, Bahrain, and Oman, have pledged to achieve net-zero emissions by either 2050 or 2060 (UNFCCC n.d). Qatar is not formally committed to achieving net-zero CO_2 emissions but is actively pursuing emission reduction strategies.

The GCC countries have announced ambitious climate change initiatives, each influenced by their national circumstances. Saudi Arabia aims for net carbon neutrality by 2060, launching several climate initiatives, including the Saudi Green Initiative (SGI) and the Middle East Green Initiative (MGI), while promoting the circular carbon economy (CCE) approach (Saudi and Middle East Green Initiatives 2022). The SGI initiative includes more than 77 climate initiatives, including the deployment of CCUS. The UAE has committed to net-zero emissions by 2050. It has updated its Nationally Determined Contribution (NDC) to accelerate this goal, pledging a 40% reduction in carbon emissions by 2030 (UNFCCC n.d). UAE Energy Strategy 2050 explores scenarios for achieving climate targets, including increasing clean energy, reducing fossil fuel use, and implementing CCUS (UAE Government 2017). Similarly, Oman has announced its commitment to achieving net-zero emissions by 2050. It aims to reduce greenhouse gas (GHG) emissions by 21% by 2030 and increase the share of renewable energy in its power generation to 35%-39% by 2040. Oman has identified six key decarbonization technologies to facilitate this transition, which include implementing CCS and exploring negative-emission solutions (Ministry of Energy and Minerals, Sultanate of Oman 2022). Qatar, while not yet committing to a net-zero target, is making notable efforts to reduce its carbon footprint. As part of Qatar National Vision 2030, Qatar aims to reduce its GHG emissions by 25% by 2030 (Government Communications Office, State of Qatar 2021). QatarEnergy is developing a carbon capture roadmap for the country's energy sector (GE 2022). Bahrain and Kuwait have established 2060 as their target year to reach net-zero emissions. Bahrain targets reducing GHG emissions by 30% by 2035 (UNFCCC n.d). Kuwait aims to attain carbon neutrality within its oil and gas sector by 2050, with a 7.4% reduction in GHG emissions by 2035 and a 15% increase in renewable energy use.

China

Turning to China, the "1+N" climate policy framework forms the cornerstone of the country's carbon neutrality efforts. It consists of two core documents, "1," the overarching guidance, titled "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy"; and the "2030 Peaking Plan," known as the "Action Plan for Carbon Peaking Before 2030." These two documents were issued by the Chinese Communist Party Central Committee and the State Council in October 2021. The "N" includes a range of policies or action plans for various sectors such as energy, industry, transportation, and urban development, among others. They encompass supporting measures related to science and technology, carbon sinks, statistical accounting, inspection and assessment, and safeguarding policies for fiscal, financing, and pricing methods. CCUS is mentioned in the core policy documents and most sectoral plans. From these documents, the main policy message for CCUS is clear: The Chinese government will support demonstrations of integrated industrial-scale CCUS projects between now and 2030 to make this technology commercial-ready thereafter.

What is the Role of CCUS in GCC Countries and China

GCC Countries

Efforts to combat global climate change have traditionally focused on replacing fossil fuels with cleaner alternatives. However, this approach presents challenges, including potential socio-economic impacts on developing countries and concerns about energy security (Babonneau et al. 2023). Recent studies emphasize the need for a comprehensive approach considering all energy options and relevant technologies (i.e., IEA 2020a; IPCC 2023). While clean technologies are crucial, fossil fuels are projected to remain a major component of the future global energy system, with OPEC estimating that fossil fuels will account for 69% of the energy mix by 2045 (OPEC 2023). Substantial investment in clean energy is essential for achieving climate goals, with estimates of the amount needed ranging from $2 to $4 trillion by 2030 (i.e., IEA 2022a). Renewable energy requires a rapid and substantial increase by 2030 to meet global climate goals, and clean hydrogen production needs to increase six-fold by 2050 (Truby, Philip, and Lorentz 2023).

CCUS technologies present a cost-effective solution for achieving climate and sustainability goals while continuing to utilize fossil fuels. CCUS provides many advantages, including capturing emissions from existing infrastructure and providing a sustainable solution for hard-to-abate sectors. The Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) highlight the necessity of deploying CCUS to meet net-zero targets in a cost-effective manner (IPCC 2023; IEA 2022b). However, current CCUS deployment rates are below projections, and significant investments are needed to scale up the technology. While CCUS may not offer the sole means for the GCC and China to achieve their climate goals, it can drive significant carbon reductions while ensuring the sustainability of their income sources.

The GCC countries recognize the importance of CCUS in climate change mitigation and consider it a key technological solution to facilitate their energy transitions. They view CCUS as a potential pathway to achieving their ambitious climate goals while ensuring continued economic growth. All GCC countries have included CCUS in their NDCs.

Beyond climate change mitigation, CCUS adoption in the GCC region can facilitate low-carbon hydrogen production, which is expected to play a crucial role in a decarbonized future. The GCC countries are particularly well-suited for implementing CCUS due to their concentration of high-emitting industries, their abundant carbon sequestration capacity, and the proximity of potential storage sites, making them ideal locations for establishing CCUS hubs (OGCI 2021). Subsurface reservoirs and extensive datasets make the GCC countries advantageous for CCUS deployment, giving them a significant advantage over other regions and a strategic and economic foundation for promoting and developing CCUS technology. By strategically investing in CCUS technology, the GCC countries can effectively balance their net-zero ambitions with continued demand for their fossil fuel reserves in a decarbonized future. The GCC countries currently have three major CCUS facilities and ambitious plans for future deployment, as outlined in Table 12.1.

Table 12.1 CCUS targets and climate ambitions in the GCC

Country	*NDC inclusion*	*CCUS targets*	*Key climate ambitions*
Saudi Arabia	Included	44 Mtpa CO_2 by 2035	• Net zero by 2060 • Climate initiatives: Saudi Green Initiative (SGI) and Middle East Green Initiative (MGI) • 278 Mt CO_2 q reduction by 2030 • 50% renewable energy by 2030 • 4 Mt green and blue hydrogen by 2030
United Arab Emirates	Included	10 Mtpa CO_2 by 2030	• Net zero by 2050 • Climate initiatives: UAE Energy Strategy 2050 • 40% GHG reduction by 2030 • 44% renewable energy by 2050
Qatar	Included	Over 11 Mtpa CO_2 by 2035	• No net-zero target • Climate initiatives: Qatar National Vision 2030 • 25% GHG reduction by 2030 • Carbon capture roadmap for the energy sector under development
Oman	Included	15% carbon abatement from CCUS by 2050	• Net zero by 2050 • Climate initiatives: The Sultanate of Oman's National Strategy for an Orderly Transition to Net Zero • 21% GHG reduction by 2030 • 35%–39% renewable energy by 2040 • 8.5 Mt green hydrogen by 2050
Bahrain	Included	No target	• Net zero by 2060 • Climate initiatives: National Energy Strategy • 30% GHG reduction by 2035 • 20% renewable energy by 2035 • Quadrupling mangrove coverage
Kuwait	Included	No target	• Net zero by 2060 • Net zero in oil and gas by 2050 • 7.4% GHG reduction by 2035 • 15% renewable energy by 2030

Note: Mtpa, million tons per annum; Mt, million tons.

China

Similarly, in China, CCUS has gained momentum as the country has made substantial strides in its climate actions since 2021. CCUS was once considered a strategic reserve technology but has now emerged as an integral component of China's technology framework for achieving carbon neutrality. CCUS is now widely recognized for playing three pivotal roles within China's commitment to carbon neutrality (Zhang, Yang, and Lu 2023): (1) CCUS is a critical option with the potential to achieve large-scale net-zero emissions from fossil fuel energy utilization, primarily since coal still generates more than half of China's electricity; (2) it offers a practical technological solution for effecting deep decarbonization in industries that present inherent challenges to reducing emissions; (3) it serves as a means to deliver carbon-negative solutions by offsetting existing emissions and addressing non-point sources of CO_2 , like DAC and BECCS.

This consensus on the role of CCUS is grounded in China's existing emissions structure. In 2019, China's energy sector produced 11.1 gigatons (Gt) of CO_2 emissions, accounting for approximately one-third of the global total. The major contributors to these emissions were coal-fired power generation, responsible for 45% of the country's emissions, followed by the iron and steel industry at 12%, cement production at 11%, the chemical sector at 5%, and oil refineries at 2% (IEA 2020b). Zhang, Yang, and Lu (2023) present a comprehensive analysis of the role of CCUS in China's journey toward a net-zero future, drawing from the latest three years of literature. It is estimated that CCUS will be required for China to achieve approximately 1,000 Mt of annual CO_2 reductions in 2040, with a potential range of 885–1,196 Mt. By 2050, this demand is projected to increase significantly to nearly 2,000 Mt, and by 2060, the figure may reach around 2,350 Mt. China's thermal power sector is expected to be a primary focus for CCUS applications. On the storage side, Zhong et al. (2023) concluded that onshore basins in China can store up to 448 Gt of CO_2 . In summary, China is uniquely positioned to benefit from CCUS technology in its journey toward carbon neutrality due to its strong demand for CCUS and its favorable geological potential for storing captured CO_2.

What is the Status of CCUS Development in GCC Countries and China

CCUS technology has attracted increased global interest recently, including among the GCC countries and China. There has been a significant increase in investment in CCUS technology, motivated by countries' growing ambitions to achieve net-zero emissions (GCCSI 2022). CCUS is seen as a critical enabler in realizing these ambitions. This section will analyze the current status of CCUS technology, presenting an overview of projects in various stages.

GCC Countries

Recognizing the importance of CCUS, the GCC has launched several large-scale projects, with further projects planned for the near future. These efforts have facilitated significant advancements in CCUS technology for the member countries. The focus will be on large-scale projects, offering insights into the practical implementation of CCUS technology.

State-owned companies, particularly national oil companies (NOCs), have driven most CCUS initiatives in the GCC, demonstrating strong government support. Despite limited economic returns and the absence of robust carbon markets, these companies, unlike international oil companies, are either entirely government-operated or operate within an arm's length of their respective governments. This enables them to invest in long-term, sustainable technologies. All GCC countries, except Kuwait, operate or are planning CCUS projects. Saudi Arabia, the UAE, and Qatar have led the way with large-scale projects, collectively capturing 4.4 Mtpa of CO_2 emissions.

Qatar is home to the GCC's largest operational CCUS project, the Ras Laffan CCUS project. Commissioned in 2019, this project captures 2.2 Mtpa of CO_2 from a gas liquefaction plant and stores it in a dedicated geological storage site. Qatar is further incorporating CCUS into its ambitious energy plans, with the North Field East and North Field South liquefied natural gas (LNG) projects set to capture and store 3.2 Mtpa of CO_2 (QatarEnergy 2023). Additionally, the world's largest blue ammonia project, Qatar's QAFCO-7, will incorporate a 1.5 Mtpa CCS facility, which is expected to start operations in 2026. QatarEnergy (2023) has committed to increasing its total CO_2-enhanced capture to over 11 Mtpa by 2035.

In Saudi Arabia, the Uthmaniyah CO_2 oil recovery (EOR) project, which started in 2015, marked the first operational CCUS project in the GCC. The Uthmaniyah project captures 0.8 Mtpa from a gas separation process and stores it in the Uthmaniyah sector of the Ghawar oil field for EOR. Saudi Arabia also established Saudi Basic Industries Corporation's (SABIC's) CO_2 utilization facility to capture and purify up to 0.5 Mtpa of CO_2 for methanol and urea production. This facility is one of the largest of its kind globally (Alatiq et al. 2021). The country has also set an ambitious target of capturing and storing 44 Mtpa of CO_2 by 2035 (Aramco 2023b). Saudi Aramco, the country's national oil company, plans to establish the region's first CCUS hub in Jubail Industrial City by 2027, with an initial capacity to capture and store 9 Mtpa of CO_2 (Aramco 2023a).

In the UAE, the Al Reyadah CCUS project in Abu Dhabi, launched in 2016, is the world's first large-scale CCUS facility within the iron and steel industry. The project captures 0.8 Mtpa of CO_2 generated during the iron-making process at Emirates Steel Industries. The captured CO_2 is then utilized for EOR in Abu Dhabi National Oil Company's (ADNOC's) oil fields. ADNOC has announced ambitious plans to double its carbon capture capacity to 10 Mtpa by 2030 (ADNOC 2023b). The Habshan CCUS project, the second phase of the Al Reyadah project, will capture and store 1.5 Mtpa of CO_2 from the Habshan gas processing plant by 2026. This will bring the UAE's total CCUS capacity to 2.3 Mtpa by 2030. In addition, ADNOC is exploring investment opportunities in CCUS hubs in the UAE through a strategic collaboration agreement with the United States (U.S.).

Bahrain is currently discussing, via Nogaholding, the establishment of a significant CCUS project in the Awali Field, valued at approximately $4 billion (Penson 2023). In addition, Aluminium Bahrain has announced its intention to consider CCUS technology for its aluminum smelting process (IEA 2023). Similarly, Oman, through its primary oil and gas producer, Petroleum Development Oman (PDO), is actively supporting Oman's decarbonization efforts in the CCUS field. PDO and Shell are collaborating to develop a CCUS project for blue hydrogen production (Middle East Monitor 2023). The status of the GCC countries' CCUS projects is summarized in Table 12.2.

China

On the technology level, since China's 11th Five-Year Development Period (2006–2010), the Chinese government has begun to support the research, development, and demonstration of CCUS technology through its national science and technology programs (ADB 2015). Some early support includes Huaneng Group's 3 kilotons per annum (ktpa) capture pilot project in Beijing in 2008, China Power Investment Group's 10 ktpa capture pilot project in Chongqing in 2010, and Huaneng Group's 120 ktpa capture pilot project in Shanghai in 2009. All three projects were launched to test post-combustion carbon capture technology from coal power plants. As of 2023, the development status of CO_2 capture technologies appears relatively advanced when compared to other CCUS components (ACCA21 2021). China has recently started to explore carbon dioxide removal technologies, including BECCS and DAC. Smith et al. (2024) concluded that innovation in DACCS and BECCS is gaining attention from decision makers in China, leading to modest funding opportunities. In China, road-based transport has been the primary method for CO_2 transportation, as most CCUS pilot projects have been relatively small. A milestone was reached in July 2023 with the full operation of a 109-kilometer CO_2 pipeline connecting Qilu Petrochemical to the Shengli Oilfield, marking China's first commercial-scale CO_2 pipeline with a capacity of 1.7 Mtpa (CGTN 2023).

Since 2021, China's CCUS demonstration projects have expanded notably. As of November 2022, China is home to over 100 CCUS demonstration projects, with a total capture capacity of over 4 Mt, each varying in size and development stage. Around 60 of these projects have already been put into operation. There are now more than 40 projects with an annual capture capacity of 100 ktpa, and over 10 of these have a capture capacity of 500 ktpa (Zhang, Yang, and Lu 2023). Most of the 100 CCUS projects are pilot- and small-scale, only focusing on a part of the CCUS value chain. In August 2022, China achieved a significant breakthrough with the commissioning of its inaugural million-ton CCUS project—the China Petroleum and Chemical Corporation (Sinopec) Qilu Petrochemical-Shengli Oilfield project. This initiative captures CO_2 emissions from coal gasification activities at the Qilu Petrochemical Plant. Following dehydration, liquefaction, and purification processes, the CO_2 reaches a purity level of 99% and is then transported for enhanced oil recovery (STDaily 2022).

In 2022, Huaneng, one of China's largest power producers, announced the construction of a 1.5 Mtpa coal power CCUS project in Zhengning, Gansu, slated for operation in 2025. The captured CO_2 will be stored geologically and used for enhanced oil recovery. China National Petroleum Corporation (CNPC), China's largest oil producer, is constructing several large-scale CCUS demonstration

Table 12.2 GCC CCUS projects' status

Country	*Projects*					*Cumulative capacity (Mtpa CO_2) (Operational and planned)*	*CCUS targets*
	Name	*Capacity (Mtpa CO_2)*	*Status*	*CO_2 source*	*Purpose*		
Saudi Arabia	Uthmaniyah	0.8	2015	NGL recovery plant	EOR	15.4	44 Mtpa CO_2 by 2035
	SABIC/United Plant	0.5	2015	Ethylene glycol production	Methanol and urea fertilizers		
	Petro Rabigh/Gulf Cryo Plant	0.1	2023	Monoethylene glycol production	Food and reuse		
	Jubail CCS Hub	Phase 1 9 Phase 2 5	Expected phase 1: 2027 Phase 2: 2035	Different sources	Storage		
UAE	Al Reyada	0.8	2016	Steel production	EOR	3.8	10 Mtpa CO_2 by 2030
	Habshan (2nd phase of Al-Reyadah)	1.5 (planned)	2026	Gas processing	EOR		
	Hail and Ghasha	1.5 (planned)	Expected 2025	Gas processing	Storage		
Qatar	Ras Laffan CCS	2.2	2019	LNG production	Storage	6.9	Over 11 Mtpa CO_2 by 2035
	North Field East (NFE) and North Field South (NFS)	3.2 (planned)	NFE 2025 NFS 2026	LNG production	Storage		
	Ammonia-7	1.5 (planned)	2026	Ammonia production	Storage		
Oman	44.01 Project Hajar (pilot)	500 tpa	Exploratory	Direct air capture	Storage	N/A	15% carbon abatement from CCUS by 2050
Bahrain	Evaluating CCUS in aluminum smelting	N/A	Exploratory	N/A	N/A	N/A	No target
Kuwait	No significant CCUS activities	N/A	N/A	N/A	N/A	N/A	No target

Note: NGL, natural gas liquids; tpa, tons per annum.

projects, including an integrated 3 Mtpa project at Daqing Oilfield and at Jilin Oilfield (CNPC 2023). Meanwhile, Shaanxi Yanchang Petroleum is planning a 5 Mtpa CCUS project, with a 1 Mtpa industrial demonstration expected by the end of the 14th Five-Year Plan Period (CNWEST 2022).

This momentum continued in 2023. In May 2023, construction began on China National Energy Investment's 3 Mtpa CCUS project in the Ningxia region. The first phase was to capture 500 ktpa of CO_2 from a coal-to-liquids facility for enhanced oil recovery (Xinhua News 2023). In June 2023, China Energy Investment's 500 ktpa coal power CCUS project began full operation in Jiangsu province, becoming the largest CCUS project in Asia's power sector (Ruiling 2023). In the same month, the China National Offshore Oil Corporation (CNOOC) commenced operations at China's first offshore CO_2 storage project. This project is situated on CNOOC's natural gas production platform in the Pearl River Mouth Basin, approximately 190 kilometers (km) southwest of Hong Kong (Hebden 2023). In January 2024, China United Cement Group, part of China National Building Material Group, began operations at the world's largest oxy-fuel cement CCUS project in Qingzhou, Shandong (Yang 2024).

In addition to these projects, China has made progress in developing a CCUS hub. The Guangdong Development and Reform Commission, China National Offshore Oil Corporation, Shell, and ExxonMobil signed an Agreement in June 2022 to explore the development of a CCUS cluster in the Daya Bay area with a capacity of up to 10 Mtpa (ExxonMobil 2022). In November 2022, Sinopec, Shell, Baowu Steel, and BASF announced their partnership on a joint study to launch an open-source 10 Mtpa CCUS project in East China (Shell 2022), and CNPC and BP have jointly planned a CCUS cluster in Hainan province in southern China (Xu 2023).

CCUS Policy Status and Challenges in GCC Countries and China

GCC Countries

The commercialization of CCUS in the GCC remains hindered by several challenges despite its progress, increased momentum, and several demonstration projects. This section reviews GCC-specific challenges, draws insights from regional initiatives, and proposes potential solutions. It also provides an overview of existing and emerging CCUS policies and regulations within the GCC, which are essential for addressing these challenges and accelerating CCUS implementation.

Despite significant investments in large-scale CCUS projects, the GCC lacks a specific policy exclusively governing CCUS technology. The GCC's large-scale projects are primarily driven by climate objectives with direct government investment. While existing environmental and climate regulations provide some guidance, a comprehensive CCUS policy landscape is essential to unlock the potential of CCUS within the bloc. Several GCC countries are currently developing climate policies and regulatory frameworks to address this gap and create a supportive environment for CCUS. The UAE is planning a comprehensive hydrogen policy incorporating CCUS provisions. Saudi Arabia is developing its national CCE framework, which includes CCUS as a major component. Qatar's Global Carbon Council is working on a framework for approved carbon credit issuance within the GCC (Global Carbon Council n.d.). Oman is collaborating with the Global CCS Institute to develop CCUS policies and regulations (GCCSI 2023).

Financial incentives are crucial for promoting CCUS deployment. While large-scale CCUS projects exist in the GCC, the technology is still in its developmental phase and has not yet been fully commercialized. The GCC lacks supportive policies such as tax benefits, carbon pricing, cap-and-trade mechanisms, or demand-side measures. This limits private sector involvement in large-scale CCUS projects, with state-owned NOCs being the primary participants. Ongoing CCUS initiatives in the region are primarily driven by government decarbonization strategies, reducing the need for direct incentives. The significant upfront costs associated with CCUS require supportive mechanisms. Unlike renewable energy, the current policy landscape does not provide direct commercial incentives beyond emissions reduction and EOR applications.

The economic viability of CCUS in the GCC depends on the development of robust carbon markets to create financial incentives for emissions reduction. GCC countries have not yet implemented mandatory emission reduction limits or carbon pricing. However, they have shown interest in international carbon markets as outlined in their NDCs. Several GCC countries, including Saudi Arabia, UAE, and Qatar, have established voluntary carbon market platforms to facilitate carbon credit trading. These platforms enable companies to trade carbon credits voluntarily. Major regional companies, especially NOCs, have set ambitious emission reduction targets, driving demand for these voluntary markets. Qatar was the first country in the region to introduce approved carbon credits and standards through the Global Carbon Council in 2019 (Luomi et al. 2023). Saudi Arabia followed with a regional voluntary carbon market in 2022, facilitated by its Public Investment Fund (PIF). The UAE partnered with the AirCarbon Exchange in 2023 to create a regulated voluntary carbon trading exchange. Saudi Arabia launched its Greenhouse Gas Crediting and Offsetting Mechanism (GCOM) in late 2023 to encourage the adoption of low-carbon technologies, including CCUS (MoEnergy 2023). The country also recently implemented a green financing framework enabling green bond issuance for eligible green projects, including CCUS (MOF 2024).

Another critical aspect of the GCC's current policy landscape is the permitting process. There is currently no explicit or implicit procedure for project permitting, which introduces uncertainty into the development of CCUS projects. While large-scale projects have provided valuable practical experience, the lack of specific CCUS regulations and the predominance of state-owned companies in early demonstration projects contribute to the unclear approval process throughout the CCUS value chain. Given the multifaceted nature of CCUS, the approval process is likely to be divided among different permitting authorities, adding uncertainty and potential challenges for project developers. This issue has caused delays, often lasting several years, to projects in Europe and the U.S. (GCCSI 2022; Kapetaki and Scowcroft 2017).

Another critical policy issue within the CCUS value chain is CO_2 storage, with existing regional policies introducing uncertainty into this area (OGCI 2023). This includes uncertainty on issues such as long-term liability, storage site permitting and characterization, transboundary migration, risk assessment protocols, and transportation logistics. Although there are standards and laws in the oil and gas industry that can partially apply to CO_2 storage, they are not explicitly designed for CCUS and are insufficient to address the unique risks of CO_2 storage. Prioritizing CO_2 storage regulations is crucial, including establishing clear definitions and parameters covering the entire CO_2 storage development process, from resource assessment to site closure, long-term storage liability, and the associated operational requirements such as monitoring, reporting, and verification. It is essential that GCC countries collaborate on formulating agreements governing cross-border CO_2 storage, potentially using existing agreements like the 2009 amendment to the London Protocol and the Kuwait Convention as foundational frameworks. Government support is crucial for successful CCUS adoption.

Managing cross-chain risks is another significant challenge for CCUS implementation due to the interdependencies within the CCUS value chain. Expanding CCUS requires a holistic approach that considers the entire value chain. Addressing this requires a diverse set of skills and knowledge, including CO_2 separation, purification, compression, transport, injection, and monitoring (OGCI 2023). Clustering industries, companies, and operators can effectively address cross-chain risks while enhancing efficiency and cost-effectiveness.

One potential measure to alleviate cross-chain risks is government-driven CCUS networks. This approach involves establishing transportation infrastructure and storage hubs near industrial clusters, reducing the risks associated with individual value chain components, and improving their overall efficiency. This measure holds significant promise for the GCC countries due to the concentration of energy-intensive industries in specific areas. Many of these industries offer low-cost, high-purity capture opportunities, such as petrochemicals, fertilizers, and methanol production (AFRY and GaffneyCline 2022). Furthermore, the proximity of potential CO_2 storage sites to energy-intensive industries further enhances the feasibility of this approach. Afry and GaffneyCline identified 10 promising CCUS clusters situated near potential CCUS hub locations, including Jubail in Saudi Arabia, Northern Qatar, and Abu Dhabi in the UAE (AFRY and GaffneyCline 2022). Their study also evaluated various transportation approaches for the GCC, suggesting that the most suitable model is NOCs owning and managing CO_2 transport and storage infrastructure (AFRY and GaffneyCline 2022). Saudi Arabia is leading the way with the region's first CCUS hub in Jubail.

Another challenge to CCUS development is insufficient research and development (R&D) funding. Increased R&D investment could accelerate the progress of CCUS. The latest IPCC report highlighted that CCUS adoption is currently slower than required to align with the modeled pathways for achieving net-zero emissions (IPCC 2023). GCC countries are committed to advancing CCUS through research and pilot projects. They have implemented national initiatives and have actively engaged in international partnerships, including the Clean Energy Ministerial, Mission Innovation, and Carbon Management Challenge to drive CCUS R&D. Saudi Arabia has launched the SGI and MGI initiatives, incorporating CCUS as part of its climate efforts. Saudi Aramco has established a $1.5 billion sustainability fund, focusing on CCUS as one of its initial priorities (Aramco 2022b). Qatar has a long-term initiative with Shell and Imperial College London to enhance CCUS and cleaner fossil fuel technology capabilities (Meltzer, Hultman, and Langley 2014). The UAE launched the Partnership for Accelerating Clean Energy (PACE) framework to mobilize funding for clean energy and carbon management projects, and ADNOC aims to expand its carbon capture capacity (IEA 2022c).

Despite these efforts, more substantial action is needed. Increasing R&D funding and strengthening collaboration among key stakeholders are essential. R&D investments could drive significant advancements in CCUS technology, reducing its risks and costs. GCC countries must increase their R&D investments and create a supportive environment for CCUS research, similar to the successful path of renewable energy innovation. Initial R&D investments and supportive policies drove the progress in renewable energy. The same approach can accelerate CCUS deployment.

Overall, GCC countries are behind China in terms of the volume of their operations and projects under construction. They also lack comparable supportive policies and regulatory frameworks to drive CCUS adoption. However, the GCC is more advanced and has significant expertise in EOR. These differences between China and the GCC could serve as a basis for identifying potential collaborative opportunities, allowing both entities to leverage each other's strengths and accelerate their respective CCUS development.

China

Since 2021, the Chinese government has intensified the release of its climate-related policy documents, aligning with its commitment to achieve carbon neutrality by 2060. Although no tools have been specifically designed to support CCUS, most of the new policy documents have considered CCUS, including "Outline of the 14th Five-Year Plan for National Economic and Social Development," "Vision 2035 of China," "Action Plan for Carbon Dioxide Peaking Before 2030," "The 14th Five-Year Plan for Scientific and Technological Innovation in the Energy Sector," among others. This reflects several noticeable trends. First, CCUS is no longer confined to China's science and technology policy; it now also features in finance, investment, standards, and industry transition policies. Second, many sectoral action plans, such as those for energy, chemicals and petrochemicals, steel, have incorporated CCUS. Third, sub-national governments show heightened support for CCUS development (Ma et al. 2023). More than 10 subnational governments, including Shanghai, Guangdong, Hebei, Xinjiang, among others, have implemented CCUS R&D programs tailored to local conditions.

A notable policy development is the establishment of the People's Bank of China's Carbon Emission Reduction Facility (CERF), introduced in November 2021 to bolster China's carbon peaking and neutrality objectives. Recognized as the world's first central bank-led monetary policy for carbon emissions reduction, the CERF facilitates low-interest loans to financial institutions, which in turn provide funding to carbon reduction projects across three key sectors: renewable energy, environmental protection and energy conservation, and low-carbon technologies, including CCUS. The CERF emphasizes the importance of transparency and accountability in funded projects, compelling financial institutions to publicly disclose information on their loans and the emission reductions they support. This ensures effective facility utilization, directing funds to projects that contribute to reducing carbon emissions. As of April 2022, the CERF had successfully facilitated over 670 billion yuan in loans for carbon emission reduction projects (Bank of China Research Institute 2023).

Despite China's significant progress in policy integration and financial support for CCUS, like the GCC countries, it faces several challenges in scaling up CCUS deployment. One of the key challenges is the high cost of CCUS technology and the lack of economic incentives. Although China's national carbon market, launched in July 2021, and its voluntary carbon market, rebooted in January 2024, may offer incentives in the future, integrating CCUS into these frameworks will require establishing a robust measurement, reporting and verification (MRV) and crediting system. Additionally, the lack of infrastructure, including CO_2 pipelines and storage sites, and the absence of a clear regulatory framework create uncertainty for investors and delay project decision-making in China.

China–GCC Collaboration to Accelerate Global CCUS Development

The development of CCUS technology is crucial for achieving net-zero emissions. China and the GCC countries have the potential to emerge as global leaders in the development and deployment of CCUS technologies. China, the world's largest emitter of greenhouse gases, and the GCC countries, abundant in fossil resources, share a strong common interest in developing CCUS technologies to address their carbon emissions and achieve climate-related objectives. The GCC and China have been actively involved in developing CCUS technology for an extended period, initiating several demonstration projects with additional projects planned for the near future. Despite these efforts, the pace of CCUS development has fallen short of expectations, posing challenges to achieving net-zero emissions targets. To accelerate the implementation of CCUS technology, a strategic collaboration between the GCC and China is proposed. These regions can make significant progress in CCUS development by leveraging their strengths. While they face unique challenges specific to their contexts, a collaboration would allow them to address common obstacles collectively. For instance, the GCC's expertise in the oil and gas industry could benefit CCUS technology development in China, and China's global technology innovation and manufacturing leadership could contribute to the GCC's CCUS initiatives. The partnership between the GCC and China would not only enhance their individual efforts to reduce carbon emissions but would also have substantial global implications.

Rationales and Foundations for Collaboration

Shared vision and interests—China and the GCC countries encounter shared challenges related to energy production and consumption, marked by a substantial reliance on fossil fuels. China has a high share of fossil fuels in its energy consumption, with coal playing a significant role, constituting approximately 54% of the nation's total primary energy consumption in 2023. Following coal, petroleum accounted for 19% of China's overall energy consumption in the same year (Energy Institute 2024). Despite China's efforts to diversify its energy sources, its energy landscape remains dominated by coal and oil. Similarly, fossil fuels dominate the GCC's electricity generation (Wogan, Pradhan, and Albardi 2017). In 2022, Saudi Arabia, the largest GCC country, generated 67% of its electricity from natural gas and 33% from oil (EIA 2021). Recognizing the need to transition to cleaner alternatives, both China and the GCC countries are committed to diversifying their energy mix to ensure long-term sustainability. Collaboration on CCUS aligns with their mutual goals of embracing cleaner and more sustainable energy sources.

China and the GCC countries are major consumers and producers of fossil energy and maintain a close and interdependent relationship in the oil and gas trade. China's heavy reliance on oil imports from the GCC in 2021, primarily from Saudi Arabia and the UAE, underscores the GCC countries' significant role in China's energy security. This interdependence extends to the GCC's reliance on oil and gas revenues, with both parties having a stake in ensuring global energy market stability. As the world undergoes an energy transition, the collaborative pursuit of CCUS technology emerges as a practical solution to enhancing the sustainability of oil as an energy source. It would help facilitate a smoother transition to a sustainable energy future for both China and the GCC.

The implementation of CCUS offers tangible benefits. For the GCC countries, it presents an opportunity to reduce their carbon emissions while ensuring the continued relevance and sustainability of their oil and gas industries. Concomitantly, for China, it provides a means of achieving emission reduction targets and securing a reliable energy supply. In essence, a partnership between China and the GCC in the development and deployment of CCUS technology is pivotal in addressing their common objectives related to energy security, economic growth, sustainable energy solutions, and climate mitigation. This cooperation stands to enhance their shared interests and contribute to the establishment of a more secure, sustainable, and environmentally friendly energy future.

Accelerate technical expertise and knowledge sharing—Both China and the GCC countries possess significant technical expertise in various aspects of CCUS, including capture, transportation, and storage. For example, the oil and gas industry has extensive experience in characterizing and selecting geological formations suitable for CO_2 storage. This expertise includes understanding subsurface geology, evaluating reservoir properties, and assessing the potential risks associated with CO_2 injection and storage. The GCC has a long history as a major player in the global oil and gas market and its member countries are among the world's leading producers and exporters of oil and natural gas. In 2020, the UAE state-owned oil company ADNOC awarded the world's largest 3D seismic project to the Bureau of Geophysical Prospecting, a subsidiary of China National Petroleum Company. In addition, the GCC and China's oil and gas industry has developed extensive infrastructure for transporting, processing, and storing CO_2 for climate mitigation. This infrastructure, with modifications, can be repurposed or adapted for CCUS applications, reducing the need for new infrastructure. More importantly, both the GCC and China have operational CCUS projects, yielding valuable data and an understanding of the challenges and opportunities of CCUS deployment. Through sharing data and expertise, both entities can learn from each other's experiences, jointly address challenges, and build on their respective achievements. Collaboration between the GCC and China allows knowledge and resources to be pooled, fostering the effective development and implementation of CCUS projects and advancing the technological readiness level of their CCUS technologies.

Establish strategic cooperation—China and the GCC countries have established strong economic ties over the past decades, characterized by significant trade, investment, and infrastructure cooperation. These ties have been mutually beneficial, fostering economic growth and development in both entities. China is now the GCC's largest trading partner, with bilateral trade exceeding $161 billion in 2020 (Pe'er, Graham, and Bhusari 2022). China also has made significant investments in GCC infrastructure projects, including ports, railways, and power plants. Energy has been a cornerstone of the China–GCC relationship. The December 2022 China–GCC summit resulted in agreements on energy cooperation, setting the stage for an all-encompassing energy collaboration. Within this framework, CCUS collaboration can generate economic benefits for both entities. Joint investments and projects in CCUS technologies can create new business opportunities, drive innovation, and contribute to economic growth in China and the GCC countries. Notable companies like Sinopec and Saudi Aramco have already announced partnerships for the development of CCUS projects in the Middle East (Aramco 2022a). This strategic cooperation can facilitate technology transfer, joint ventures, licensing agreements, and training programs.

Proposed Collaborative Mechanisms

Policy collaboration and coordination—China and the GCC countries, both characterized by strong state influence over their economies, can collaborate through policy and regulatory frameworks (Yang, Heidug, and Cooke 2018). China has made significant policy efforts to address its carbon targets, aiming to peak CO_2 emissions before 2030 and achieve carbon neutrality before 2060. These efforts include developing its National Emissions Trading Scheme, encouraging green and climate finance, supporting the development of low-carbon technologies, and promoting green manufacturing. This can serve as a foundation for policy collaboration and coordination on CCUS with the GCC bloc, which is still in the early stages of developing a climate policy framework. Meanwhile, China and some GCC countries are developing specific regulatory frameworks for CCUS activities, providing further opportunities for the two regions to cooperate. Although China has not developed a full CCUS regulatory framework, the lessons it has gained in regulating CCUS demonstrations over the last 20 years can help both China and the GCC countries prepare a comprehensive regulatory framework for the commercial deployment of CCUS projects. A mutually recognized regulatory framework, including requirements for site assessment, monitoring, reporting, a verification system, and quantification, will not only help facilitate two-way CCUS investment but also help amplify their voices on the global stage. A mutually recognized regulatory framework also has the potential to help CCUS projects in China and the GCC trade in each other's carbon markets, offering additional revenue sources for CCUS project developers and investors in China and the GCC. It is proposed that the two regions create formal dialogues to share best practices, lessons learned, policy adaptations, and progress on regulatory advancement related to CCUS deployment. These dialogues would also create a platform for consistent discussions among government officials from China and the GCC countries. Under formal dialogues, a working group between China and the GCC to harmonize regulatory requirements and standards is also suggested.

Joint research—Despite the immense potential of CCUS in mitigating climate change in both China and the GCC, it still faces several technological challenges that hinder its widespread adoption, such as its high costs and low technology maturity. China and GCC countries possess complementary strengths that can accelerate CCUS technology advancement. China has been a global leader in the research and development of CCUS technologies, with experience in large-scale project implementation and cost-effective engineering solutions. In the GCC, the expertise of the respective oil and gas industries, abundant geological storage capacity, and existing oil and gas infrastructure can be quickly repurposed for CO_2 capture and transportation. By fostering technology learning from each other, China and the GCC might speed up CCUS technology development by reducing its overall cost and scaling it up. China and the GCC can establish joint research centers or programs dedicated to CCUS research and development. The respective governments of the GCC and China can organize exchange programs for scientists and engineers through visits, workshops, and conferences, and create joint funding mechanisms to support knowledge sharing.

Facilitating two-way clean investments—The alignment of CCUS standards creates a chance to enhance cross-border trade in CCUS-related products and services. This alignment ensures compatibility and easier interaction between the GCC and China in the trade of CCUS products. Of particular interest is the potential to develop an efficient and cost-effective supply chain for low-carbon hydrogen, which is produced through carbon capture. Both the GCC countries and China have ambitious plans for developing their hydrogen industries. Aligning CCUS standards would enable them to leverage their combined expertise and resources to accelerate hydrogen development and tap into this expanding sector. This industry holds the potential to generate new job opportunities and contribute to overall economic growth. The GCC and China could build a connected carbon market to facilitate cross-border carbon trading. This would require both sides to establish mechanisms and agreements to enable carbon credit trading or allowances across borders. This chapter previously indicated that both the GCC and China should have compatible standards and methodologies for measuring, reporting, and verifying emission reductions from CCUS activities. Chinese and GCC governments could also establish bilateral agreements or treaties to formalize the terms of this linked carbon market, outlining the rules of trading, mutually agreed carbon credits, and dispute resolution mechanisms. CCUS should be prioritized in this interconnected carbon market. A shared registry system that allows both entities to track and record carbon credits will also be needed. These efforts should be consistent with the evolving guidance of Article 6 of the Paris Agreement.

Finally, both sides can establish a dedicated joint investment fund or mechanisms to provide financial support for the development and implementation of CCUS initiatives. Both China and the GCC can negotiate to create bilateral financing agreements specifically for CCUS joint projects that hold promise. China and the GCC can leverage their existing regional platforms, like the Belt and Road Initiative, to promote CCUS investment and attract international partners. Another approach would be to establish a public–private financing partnership between the GCC countries and China to attract private-sector investments to enhance CCUS projects, with a particular focus on the GCC.

While the prospects for China–GCC collaboration on CCUS are promising, particularly given both regions' strong interest in this technology, challenges remain. Differences in their climate policies and regulatory frameworks could pose obstacles to cooperation. Moreover, the mobilization of their resources, both financial and technical, for concrete collaboration will require a coordinated effort to address the complexities of CCUS implementation. Additionally, the lack of harmonized standards and methodologies for project implementation and reporting between the GCC and China could hinder investment and cross-border carbon trading, further complicating efforts to maximize the mutual benefits of such a collaboration. Addressing these challenges will be critical to realizing the full potential of China–GCC CCUS cooperation.

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13 China–GCC Cooperation on Nuclear Energy

Jie Zhou, Dongmei Chen, and Noura Y. Mansouri

Introduction

Nuclear energy has reached a critical juncture in the global energy transition. A notable development emerged from the 2023 United Nations Climate Change Conference in Dubai (COP 28), where a new international consensus was reached. As part of the first Global Stocktake under the Paris Agreement, all 198 signatory countries to the United Nations Framework Convention on Climate Change (UNFCCC) recognized nuclear energy as one of the key technologies requiring accelerated deployment to achieve net-zero carbon emissions. Also at COP 28, 22 countries committed to working together to advance a global aspirational goal to triple nuclear energy by 2050 (NEA 2023a).

This shift in global acceptance underscores the critical role nuclear power can play in achieving climate targets. New nuclear energy technology has a small footprint and can be sited where needed. It complements renewable energy sources and offers additional flexibility that supports decarbonization beyond the power sector, including hard-to-abate industrial sectors.

As of December 2024, there were about 440 reactors operating in 31 countries with a combined capacity of about 400 gigawatts electric (GWe). An additional 65 reactors are currently being constructed in 15 countries, and about 85 power reactors with a total capacity of about 80 GWe are planned and over 300 reactors have been proposed (WNA 2025).

Global nuclear energy capacity is expected to grow substantially. Under the International Atomic Energy Agency's (IAEA's) low-growth scenario, this capacity is projected to increase by approximately 40%, reaching 514 GWe by 2050. In its high-growth scenario, global nuclear capacity could grow to 2.5 times its current level, reaching 950 GWe by 2050 (IAEA 2024a). However, achieving the high-growth scenario will require several enabling factors, including supportive national policies and strategies, improved financing frameworks, significant investments in grid infrastructure, and workforce development.

Under a global framework, China is the most active country in nuclear reactor construction, leading global efforts to expand nuclear energy capacity. As of the end of 2024, China had 58 operational nuclear reactors, 28 reactors under construction, and another 16 reactors approved for construction. Its total capacity of

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operational reactors is expected to reach 110 GWe by 2030 (CNEA 2025). Its cost competitiveness and advancements in nuclear energy, exemplified by technologies like the Hualong One (a domestically developed third-generation pressurized water reactor) and small modular reactors (SMRs), present great potential for collaboration with the GCC states as they pursue nuclear energy and nuclear technologies as part of their broader economic diversification goals.

The Gulf represents a promising market for China to showcase its advanced reactor technologies. This partnership may also allow the GCC countries—who must ultimately secure their own project financing—access for technical support, vendor backed financing options, and cutting-edge designs. Beyond energy supply, cooperation could drive the localization of nuclear supply chains and create job opportunities and skills development. This development could also enhance the Gulf's innovation environment, promoting complementary industries like safety training, regulatory oversight, and advanced engineering.

Nuclear Energy for Sustainable Development

Environmental Benefits

Nuclear power currently ranks as one of the electricity source for reducing carbon emissions. The lifecycle carbon footprint of pressurized water reactors (PWRs) ranges from 5.1 to 6.4 grams of carbon dioxide per kilowatt hour CO_2 (UNECE 2022). Their average carbon footprint is approximately 0.6% of the emissions from coal-fired power without carbon capture and storage (CCS), 1.5% of emissions from natural gas combine cycle (NGCC) power plants, 12.6% of emissions from solar photovoltaics (PV), and 48.3% of emissions from onshore wind power.

From 1971 to 2022, global nuclear power generation has cumulatively reduced carbon emissions by approximately 70 billion tons (IAEA 2022). This equals roughly 20% of all energy-related CO emissions globally over the same period.

Economic Benefits

The levelized cost of electricity (LCOE) for newly built nuclear plants falls within a broad global range, roughly $40 to $90 per megawatt hour (MWh)—but the midpoint of that range can shift markedly by region (IEA and NEA 2020). At the low end (around $40–60 per MWh) are Asian markets such as China and South Korea, where mature supply chains, standardized reactor designs, and lower financing costs prevail. At the upper end (around $70–90 per MWh) are major projects in Europe and North America, where stricter regulatory requirements, higher labor costs, and more expensive capital push costs upward. Even with these higher upfront capital outlays, nuclear power delivers long lived, dispatchable, low carbon electricity that can stabilize grids and hedge against fuel price volatility.

The competitiveness of newly built projects can be improved through the deployment of larger-capacity units, serial and batch construction of standardized reactors, leveraging learning-curve efficiencies, and optimizing plant design. While stricter safety and regulatory requirements, especially in OECD markets, are likely to push baseline overnight capital costs upward, in some cases offsetting part of the savings expected from scale and learning. Even though, the long-term operation (LTO) of existing nuclear plants through life extension and refurbishment remains one of the least cost options, which can lower the LCOE to below $30 per MWh (BNEF 2023).

Nuclear power's cost advantage can be further increased when carbon pricing is applied. At a carbon price of $30 per ton of CO_2 (tCO_2) and a 3% discount rate, the LCOE for nuclear power ranges from $26 to $64/MWh, significantly lower than that of coal ($65–$95/MWh) and natural gas ($61–$133/MWh) (IEA and NEA 2020). As carbon prices rise, this advantage becomes even more pronounced, reinforcing nuclear energy's role as a cost-competitive, low-carbon electricity source.

Nuclear energy programs can also create macroeconomic benefits for an economy, particularly in terms of industrial development, research and development spillovers, and the high level of training and expertise of its workforce. The nuclear power industry encompasses a complex value chain from mining and fuel processing to plant construction, operation, and decommissioning, contributing significantly to regional economic development. Nuclear power creates about 25% more jobs per unit of electricity than wind energy (WNA 2020). This employment advantage spans high-skilled sectors across the supply chain, contributing to long-term economic development.

Energy Security Benefits

Nuclear energy offers significant benefits for enhancing energy security by providing a stable, reliable, and domestic source of low-carbon electricity. Unlike fossil fuels, which are subject to volatile international markets and supply chain disruptions, nuclear fuel is compact, high in energy density, and can be stockpiled for years, insulating countries from geopolitical risks and price shocks. Furthermore, nuclear power plants operate continuously with high-capacity factors—often exceeding 90%—making them a dependable backbone for national electricity grids (IAEA 2023a).

Nuclear power generation is largely unaffected by external environmental conditions and maintains stable output across periodic, regional, and seasonal variations. According to the IAEA (2023a), the impact of weather on global nuclear power output between 1990 and 2020 was less than 0.1%. The energy released from the fission of 1 kilogram (kg) of low-enriched uranium is equivalent to the energy released from burning approximately 2,700 tons of standard coal. Nuclear power features a long fuel replacement cycle, typically 18–24 months, enabling continuous, stable, and secure operation that is largely unaffected by fluctuations in external energy supplies. This characteristic allows nuclear power to function as a reliable local energy source that can partially replace fossil fuel-power and complement intermittent renewables such as wind and solar. The deployment of SMRs in the future, though the majority of the projects are currently at the demonstration stage, can offer enhanced flexibility and grid stability.

China's Nuclear Development and Technology Advantages

Development of China's Nuclear Power Industry

China's nuclear industry began in the 1950s, with the development of civilian nuclear energy in the 1970s. Through coordinated and sustained support from financial, technological, and industrial policies, China has achieved a high degree of self-sufficiency in reactor design, construction, and the manufacturing of key components and equipment. Technological advancement, most notably the development of the Hualong One reactor, and China's strong performance in safety and operational efficiency, has positioned the country as a prominent and increasingly influential player in the global nuclear energy market. In general, the development of China's nuclear power industry can be characterized by three distinct stages, reflecting its progression from technology importation to self-reliance and international leadership.

- Initial Development Stage (1981–1990)

In the 1980s, China established a strategic framework for nuclear power development, opting to pursue pressurized water reactor (PWR) technology as the foundation of its civilian nuclear program. Two landmark projects were launched during this formative period: the Qinshan Nuclear Power Plant and the Daya Bay Nuclear Power Plant. Qinshan Unit 1, based on the domestically designed 300 megawatt (MW) CNP300 PWR, began construction on March 20, 1985, and entered commercial operation on April 1, 1994. In parallel, the Daya Bay Nuclear Power Plant units 1 and 2 introduced the French 1 GW PWR technology. Unit 1 started construction on August 7, 1987, and began commercial operation on February 1, 1994, becoming the first large-scale commercial nuclear power plant in mainland China.

- Scale-up Development Stage (1991–2005)

During this phase, China implemented the policy of moderate nuclear power development and promoted the standardization and series development of indigenous PWR technology. As part of these efforts, China constructed the units 1 to 4 of Qinshan Phase II Nuclear Power Plant, which utilized domestically designed 600 MW PWR (CNP600). Building on the French M310 technology, China constructed the Ling'ao Nuclear Power Plant units 1 to 4 and developed its own design capacity on CPR 1000 technology. China also constructed Qinshan Phase III Nuclear Power Plant units 1 and 2 by using Canada Deuterium Uranium (CANDU) heavy water reactor technology. Tianwan Nuclear Power Plant units 1 and 2 were built using Russian AES-91 PWR technology.

- Advanced Technology Development Stage (2006–2020)

During this phase, China developed the third-generation PWR technology, known as the "Hualong One," and completed two demonstration projects: units 5 and

6 of the Fuqing Nuclear Power Plant and units 3 and 4 of the Fangchenggang Nuclear Power Plant. China advanced nuclear energy innovation by constructing the world's first high-temperature gas-cooled reactor (HTGR) featuring characteristics of fourth-generation nuclear systems. Additionally, construction began on the world's first commercial onshore SMR in Hainan Changjiang.

China extended its collaboration with international partners on new technology development. It constructed units 1 and 2 of the Taishan Nuclear Power Plant through the introduction of French EPR nuclear power technology. It also adopted American AP1000 technology, constructing units 1 and 2 of both the Sanmen and Haiyang Nuclear Power Plants. Building on the AP1000 design, China independently developed the "Guohe One" PWR technology and built a demonstration project.

As of the end of 2024, China had 58 nuclear power units in operation with a total installed capacity of 59.76 GWe, placing it third globally and accounting for 2% of the country's total installed power capacity (CNEA 2025). Most of these plants are located along China's coastline. China also leads the world in nuclear power construction, with 28 units under construction totaling 33.7 GWe, maintaining the top global position for the eighteenth consecutive year. This significantly surpasses India, which ranked second with eight units under construction totaling 6.03 GWe, and Turkey, which ranked third with four units under construction totaling 4.46 GWe (CNEA 2025).

China's Nuclear Power Technology Development

China's nuclear energy technology strategy follows a three-step roadmap proposed in the 1980s, aiming to achieve the gradual upgrade and sustainable development of nuclear energy utilization (CAEA 2023). The first step focuses on the commercialization and standardization of thermal-neutron reactors (particularly for PWRs), resulting in indigenous technologies such as CNP-600, CPR-1000, and later Hualong One. The second step targets the development of fast-neutron breeder reactors, which offer the potential for improved fuel utilization and waste reduction; projects like the China Experimental Fast Reactor (CEFR) and plans for large-scale demonstration fast reactors support this phase. The third step aims to develop nuclear-fusion technology, with active participation in international projects such as the International Thermonuclear Experimental Reactor (ITER) and domestic fusion experiments, including the Experimental Advanced Superconducting Tokamak (EAST).

The country has achieved significant progress in the standardization, localization, and scale-up of nuclear power plant construction, developing a full range of reactor technologies with outputs of 300 megawatts electric (Mwe), 600 MWe, 1000 MWe, 1200 MWe, and 1400 Mwe over the past decades.

- Third-generation reactors

The Hualong One is China's domestically developed third generation PWR technology. It is an evolutionary upgrade of earlier Gen II designs, incorporating post

Fukushima safety enhancements and fully meeting the international safety and performance criteria established for Generation III reactors.

The Hualong One reactor has a design lifespan of 60 years, an 18-month fuel reloading cycle, and is engineered to achieve an availability rate of over 90%. Its key features include a balance between advancement and maturity, safety and economy, and a combination of active and passive safety systems. The design complies with major international standards, including those set by the IAEA, the United Kingdom's (U.K.'s) Generic Design Assessment (GDA), and the European Utility Requirements (EUR).

As of now, seven Hualong One units have been completed and commissioned worldwide, including demonstration projects at Fangchenggang units 3 and 4, Fuqing units 5 and 6, Zhangzhou unit 1, and Karachi units 2 and 3 in Pakistan. In addition, 41 Hualong One units are currently under construction. This makes Hualong One the most widely deployed Generation III nuclear power technology globally, in terms of the combined number of operational and under-construction reactors.

- Small modular reactors

Small modular reactors (SMRs) typically refer to reactors with a modular design and a power capacity of up to 300 MWe per unit. The modular nature of the assembly makes it possible for systems and components to be factory-assembled and transported as a unit to a location for installation. This provides unique advantages for the deployment of SMR in remote areas, islands, offshore platforms, and regions with limited grid capacity. Compared to large reactors, SMRs offer cost advantages through lower initial investment requirements and shorter construction timelines, although first-of-a-kind SMR projects may match—or even exceed—the cost of conventional large reactors before economies of scale are realized. In addition, SMRs feature advanced passive and inherent safety systems, reducing accident risks and enhancing reliability. Beyond serving as power sources, SMRs can be used for a variety of applications, including regional heating and cooling, industrial steam supply, transportation, construction, seawater desalination, and other high-energy-consuming industries.

China is leading the construction of the world's first land-based SMR demonstration project, known as Linglong One. This reactor, with a capacity of 125 MWe, is expected to enter into service around 2026. The country has been actively advancing the research and development (R&D), and commercialization of SMR technology, exploring multiple technical pathways, including land-based SMRs, offshore SMRs, and heating-focused SMRs. These designs adopt advanced concepts such as active and passive safety systems, inherent safety, modular construction, and long-cycle refueling strategies.

- Fourth-generation advanced nuclear energy systems

In 2006, China officially became a member of the Generation IV International Forum (GIF), an international cooperation framework established for the R&D

of next-generation nuclear-energy systems. Since then, the country has actively participated in the collaborative development of six reactor, including the very high temperature reactor (VHTR), the sodium-cooled fast reactor (SFR), the supercritical water-cooled reactor (SCWR), the gas-cooled fast reactor (GFR), the lead-cooled fast reactor (LFR), and the molten salt reactor (MSR). Among these, China has initiated engineering demonstrations for the SFR and the VHTR (GIF 2018).

The China Experimental Fast Reactor (CEFR) is China's first fast neutron reactor and currently serves as the country's only fast neutron irradiation platform. Construction began in 2000, with the reactor achieving first criticality in July 2010 and grid-connected power generation in July 2011. The CEFR has a thermal power output of 65 MW and an electrical power output of 20 MW. The HTGR is one of the key reactor types for expanding the application of nuclear energy beyond electricity generation. It offers unique advantages, including high operating temperatures, advanced thermodynamic parameters, diverse application scenarios, inherent safety features, relatively low single-unit power output, and the potential to form large-capacity power stations through modular standardization.

China has established a solid foundation in HTGR nuclear power technology as well. Research began in the 1970s, and in 2000, Tsinghua University completed the construction of the High-Temperature Gas-Cooled Test Reactor (HTR-10), which achieved full-power operation in 2003. On December 20, 2021, the demonstration project for the fourth-generation modular high-temperature gas-cooled reactor (HTR-PM) successfully achieved grid-connected power generation at Shidao Bay in Shandong Province.

- Nuclear fusion

China regards magnetic confinement fusion as an advanced energy technology and a strategic priority for development. China's roadmap for magnetic confinement fusion research and development is gradually taking shape.

The HL-2A device is China's first tokamak device with a diverted configuration. In 2009, it realized first high-confinement mode plasma operation, and in 2019, it successfully operated in a high-pressure and high-confinement regime. The HL-2A is capable of conducting advanced experiments related to high-confinement and high-pressure plasma conditions, supporting both existing international thermonuclear fusion experimental reactors and future fusion reactors.

The HL-3 device, currently China's most advanced and highest-parameter next-generation "artificial sun", was completed in 2020 and achieved its first plasma discharge. It is now China's premier research platform for core-level plasma operations. In October 2022, the HL-3 device reached a plasma current exceeding 1 million amperes, laying a solid foundation for future core-level plasma experimental research. In August 2023, it achieved high-confinement mode operation at this plasma current for the first time.

Over the years, China has developed a series of conventional tokamak devices, including HT-6B and HT-6M; the country's first circular cross-section superconducting tokamak, the "Hefei Super Ring" (HT-7); and the world's first non-circular cross-section all-superconducting tokamak fusion experimental device, "EAST." In January 2025, EAST maintained stable H-mode plasma for 1,066 seconds, setting a new benchmark for a long-duration high-performance operation (IEA 2025).

China is also actively integrating advanced digital technologies into its nuclear energy sector. By breaking free from traditional frameworks, the country is promoting comprehensive informatization, digitalization, and intelligent systems across the entire lifecycle and all aspects of nuclear power. Initiatives include the construction of a national nuclear industry data center, the implementation of digital and intelligent engineering solutions in nuclear power infrastructure, and the steady advancement of digital transformation in China's nuclear power industry.

GCC's Nuclear Aspirations and Challenges

The momentum may differ across the Gulf Cooperation Council (GCC) nations, but collectively the region is showing growing interest in nuclear power to enhance energy security, reduce reliance on hydrocarbons, and meet long-term climate and sustainability targets. Nuclear power presents a viable low-carbon energy option that can complement renewable energy development and help meet growing demand in sectors such as desalination, hydrogen production, and off-grid applications. This is particularly relevant for Saudi Arabia and the UAE, which are leading the GCC in nuclear energy development (Mansouri 2024; Rogner, Shihab-Eldin, and Mansouri 2024).

The United Arab Emirates

The UAE released its policy on "The Evaluation and Potential Development of Peaceful Nuclear Energy" in April 2008. This policy establishes a new model through which non-nuclear states may explore and potentially develop a peaceful nuclear energy program with the full support and confidence of the international community. In 2009, the UAE issued its nuclear energy law, which commits the nation to the most stringent standards of safety, transparency, and security. In accordance with this law, the UAE's Federal Authority for Nuclear Regulation (FANR) was established, with responsibility for overseeing nuclear safety, security, radiation protection and safeguards, and the enforcement of global agreements entered into by the UAE.

The UAE has emerged as a pioneer in the GCC's nuclear energy trajectory through the successful deployment of the Barakah Nuclear Power Plant, which began operations in 2020. Developed in collaboration with South Korea's KEPCO consortium, Barakah consists of four APR1400 reactors with a total capacity of 5.6 GWe, contributing up to 25% of the UAE's electricity demand (ENEC 2025). To meet longer-term growth, Abu Dhabi has begun feasibility studies for a second plant. These efforts underscore the important role that nuclear power will play in achieving the UAE Energy Strategy 2050, which targets an energy mix of 44% clean energy, 38% gas, 12% clean coal, and 6% nuclear by 2050.

As part of its commitment to nonproliferation, the UAE pledged not to engage in uranium enrichment or the reprocessing of spent nuclear fuel. This commitment culminated in the signing of the Agreement for Peaceful Civilian Nuclear Energy Cooperation with the United States (U.S.) in 2009, commonly referred to as the 123 Agreement. The agreement laid the foundation for U.S. companies to export nuclear technology and fuel to the UAE, facilitating the development of the Barakah Nuclear Power Plant.

To enhance the security of fuel supply to support its nuclear energy development, the UAE has established a diversified portfolio of partnerships with key international suppliers. Contracts for the supply of uranium concentrates have been awarded to Canada-based Uranium One, U.K.-based Rio Tinto, France's Orano (formerly Areva), and Russia's Techsnabexport (Tenex). In addition, agreements with Tenex, Orano, and the U.S.-based ConverDyn have been secured for uranium conversion services, while uranium enrichment services are provided through partnerships with Tenex, Orano, and the Europe-based Urenco (WNA 2024).

In the area of radioactive waste management, Sweden's Svensk Kärnbränslehantering AB (SKB) is currently assisting the UAE in assessing the feasibility of a geological repository for spent nuclear fuel. The UAE has followed a "dual track" strategy for managing radioactive waste, which entails the concurrent development of a national storage and disposal program alongside efforts to explore opportunities for regional cooperation.

In addition, FANR renewed a five-year agreement with the U.S. Nuclear Regulatory Commission (NRC) on exchanging technical information, cooperating on nuclear safety research and enabling training for FANR staff. Similar cooperation agreements were also signed with South Korea, France, Canada, the U.K., and China.

This collaborative approach at different levels has not only facilitated the successful deployment of nuclear infrastructure but has also established the UAE as a regional exemplar in the peaceful and secure use of nuclear energy.

Saudi Arabia

Saudi Arabia's nuclear energy program has evolved through a phased, deliberate process—advancing from scientific research to infrastructure development, regulatory maturity, and strategic fuel cycle ambitions. The foundation was laid with the creation of King Abdulaziz City for Science and Technology (KACST) in 1977, the Kingdom's central scientific body. In 1988, KACST launched the Atomic Energy Research Institute to advance peaceful nuclear science, develop human capital, and explore applications such as radioisotope production and nuclear safety. Today, KACST remains vital through its Low Power Research Reactor, the Nuclear Technologies Institute and centers focused on radiation protection and radioactive waste management—key pillars of nuclear safety and oversight (Government of Saudi Arabia 2025).

A major milestone came in 2010 with the establishment of the King Abdullah City for Atomic and Renewable Energy (K.A.CARE 2025), an institution tasked with developing peaceful nuclear and renewable energy, formulating policy, and coordinating international partnerships. Saudi Arabia's nuclear governance framework has advanced considerably since the approval of its National Policy of the Atomic Energy Program in 2018. This policy laid the foundation for series of legislative developments, including the Law of Nuclear and Radiological Control and the Law of Civil Liability for Nuclear Damage as well as the establishment of the Saudi Nuclear and Radiological Regulatory Commission (NRRC 2024).

Building on these developments, the Saudi Nuclear Energy Holding Company (SNE) was established in 2020, and all nuclear power plant-related activities were transferred from K.A.CARE to SNE. In 2022, the Duwayhin Nuclear Energy Company (DNEC) was established as a subsidiary of SNE to serve as the owner and operator of the planned nuclear power plant planned in Duwayhin, which is expected to have a capacity of 2–3.2 GWe (NRRC 2024).

The Kingdom is also advancing upstream capabilities in nuclear fuel cycle—such as uranium exploration, mining, and yellowcake production—as part of its broader strategy for resource monetization and localization (Asharq Al-Awsat 2025). The Nuclear Energy Agency estimates 77,731 tons of unconventional uranium within Saudi territory (NEA 2023b).

The Kingdom has pursued international partnerships to support peaceful nuclear deployment, signing cooperation agreements with more than a dozen countries, including France, South Korea, China, Russia, Argentina, Jordan, and the United States (Mansouri 2022). In April 2025, Saudi Arabia and the U.S. advanced efforts toward a formal bilateral civilian nuclear cooperation agreement (Al Arabiya 2025). These agreements provide frameworks for knowledge transfer, fuel cycle services, and safety standards harmonization.

In close collaboration with the IAEA, Saudi Arabia has taken significant steps to align with international safety and non-proliferation standards. In September 2024, the Kingdom formally requested the rescission of the Small Quantities Protocol and the adoption of a Comprehensive Safeguards Agreement. The Kingdom signed a Country Programme Framework with the IAEA for 2024–2027, identifying joint priorities including nuclear power, radiation safety, non-electric applications, and training (IAEA 2024b). Saudi Arabia's Energy Minister, HRH Prince Abdulaziz bin Salman, confirmed that the Kingdom had completed all necessary administrative preparations and was actively working with the IAEA to finalize the subsidiary arrangements (Prince Abdulaziz 2024).

With a foundation of research, regulation, and strategic foresight, Saudi Arabia is positioning itself not only as a nuclear energy adopter—but as a regional innovator, technology partner, and responsible steward of peaceful nuclear advancement.

Qatar

Qatar has adopted a cautious approach to nuclear energy development, emphasizing regional stability and non-proliferation. In various international forums, Qatar has voiced its concerns about rising global geostrategic tensions, consistently advocating for the establishment of a nuclear-weapon-free zone in the Middle East

(Middle East Council on Global Affairs 2025). Domestically, Qatar has strengthened its nuclear governance framework by enacting key legislation, including the Radiation Protection Law in 2002 and the National System for the Account and Control of Nuclear Material Law in 2018, to ensure compliance with international safety and non-proliferation standards (IAEA 2024c).

Qatar currently has no plans to construct nuclear power plants. However, it continues to monitor global advancements in nuclear technology with strategic interest. On December 20, 2021, the Qatar Investment Authority, the country's sovereign wealth fund, finalized an agreement to invest \$112 million in the SMR project led by Rolls-Royce and backed by the British government (Reuters 2021). Through this investment, the QIA acquired a 10% equity stake in Rolls-Royce SMR, joining other key investors including Rolls-Royce Group, BNF Resources U.K., and Constellation Energy. This approach can offer Qatar a potential strategic stake in the development of advanced, safer nuclear power and provide an opportunity for it to explore alternative pathways for decarbonizing its own portfolio in the future, particularly for seawater desalination.

Oman

Oman recognizes nuclear energy as a potential long-term option, while its National Energy Master Plan 2040 currently prioritizes expanding its renewable capacity, boosting efficiency, and developing a vibrant green-hydrogen sector (Oman Observer 2024). The country does not have nuclear power plants nor facilities directly or indirectly related to their operation, and it has stated that it "does not intend to embark on a nuclear-power program or construct research reactors in the foreseeable future" (The Sultanate of Oman 2022).

Nevertheless, Oman is strengthening its regulatory framework and technical capabilities for peaceful nuclear applications in non-power sectors. It has developed domestic infrastructure for radiation protection, licensing, and emergency preparedness according to international best practices. The Radiation Protection Department within the Environment Authority licenses radioactive sources, oversees transport, storage, and disposal, and coordinates emergency preparedness (The Sultanate of Oman 2022). In September 2024, Oman signed its third Country Programme Framework (CPF) with the IAEA for 2024–2029, which sets five priority areas including nuclear and radiation safety, food and agriculture, health, water-resource management, and environmental and cultural-heritage protection (IAEA 2024d).

Kuwait

Kuwait first explored nuclear power in the early 1970s. In 1977, the country issued a request for proposals for a combined power and water nuclear power plant, in collaboration with the IAEA and the United Kingdom Atomic Energy Authority (UKAEA). However, the project was canceled in 1979 following the Three Mile Island (TMI) nuclear accident and a sharp decline in global oil prices. Kuwait revisited the nuclear energy option in 1986 and again in 2009, but both initiatives were eventually shelved—first due to the Chernobyl disaster in 1986 and later in response to the Fukushima Daiichi nuclear accident in 2011 (IAEA 2018).

In 2009, the government established the Kuwait National Nuclear Energy Committee (KNNEC) to explore the peaceful use of nuclear energy for electricity generation and water desalination. Following the Fukushima incident, the KNNEC's responsibilities were transferred to the Kuwait Institute for Scientific Research (KISR), which redirected its focus toward research into and the development of nuclear science and applications rather than energy production (IAEA 2018).

While Kuwait currently has no plans to develop large-scale nuclear reactors, it continues to monitor advancements in SMR technology as a potential option to complement its existing energy infrastructure and support its ongoing renewable energy initiatives. The country remains engaged with the IAEA, working to draft a national nuclear law aligned with international safety, security, and non-proliferation standards. Current public discourse in Kuwait centers on assessing the societal, environmental, and economic implications of nuclear energy adoption (Damona 2024). This cautious, research-oriented approach reflects Kuwait's aim that any future deployment of nuclear technology adheres to international best practices and meets public expectations for safety and transparency.

Bahrain

Bahrain is considering nuclear energy as part of its long-term strategic solution to address rising energy demand and meet its environmental and climate commitments. It has no nuclear installations and, in its 2016 National Report to the IAEA, reaffirmed a cautious "safety-first" stance (Kingdom of Bahrain 2016).

Bahrain has expressed interest in SMRs as a potential future option, given its limited land area and relatively modest energy requirements. The country is planning to deploy SMRs in the early 2030s to meet growing energy demands (Energy Intelligence 2025). This would make Bahrain the third country in the GCC to adopt this technology.

Bahrain has prioritized strengthening its regulatory and institutional frameworks to ensure any future engagement with nuclear technologies adheres to international safety and non-proliferation standards. In 2008, Bahrain signed a memorandum of understanding (MoU) with the U.S. to cooperate on the peaceful use of nuclear energy, reaffirming its commitment to the NPT. In line with its commitment to international cooperation and capacity building, Bahrain signed its third CPF with the IAEA in September 2023, outlining key areas of focus, including nuclear and radiation safety, human health, and environmental protection (IAEA 2023b).

In July 2025, Bahrain signed a landmark civil nuclear cooperation agreement with the United States, reinforcing its commitment to carbon neutrality by 2060 and energy security through low-carbon technologies. Building on the 2023 Comprehensive Security Integration and Prosperity Agreement (C-SIPA), the agreement reflects Bahrain's cautious, internationally aligned approach to nuclear energy and sustainable development (MOFA 2025).

Regional Coordination and Cooperation on Nuclear Energy Development

As the GCC countries continue to diversify their energy portfolios, nuclear power is gaining recognition as a strategic pillar for achieving sustainable energy security and supporting economic diversification. The UAE and Saudi Arabia have taken the lead, developing national programs that blend ambitious renewable energy targets with the need for low-carbon baseload supply. Regardless of whether nuclear power is currently part of national energy plans, all GCC states are signatories to the Nuclear Non-Proliferation Treaty (NPT) as non-nuclear weapon states and maintain safeguards agreements with the IAEA. They have participated in regional training programs focused on nuclear safety, radiation protection, and emergency preparedness, and worked together to promote regional standards in nuclear waste management, safeguards, and the transportation of radioactive materials. This collective effort demonstrates the region's shared interest in building a safe and secure nuclear landscape.

Existing cooperation among regulatory authorities has laid the foundation for future regional nuclear programs. In 2021, Saudi Arabia's NRRC signed a cooperation agreement with the UAE's FANR, covering all aspects of nuclear and radiation regulation. Similarly, in 2023, Saudi Arabia's NRRC and Oman's Environment Authority signed an MOU to strengthen collaboration in the peaceful use of nuclear technologies. These initiatives signal increasing regulatory convergence and a shared vision of responsible development.

There also remains the potential for the joint development of nuclear energy projects, particularly for electricity generation and water desalination. A regional nuclear project was first formally considered in 2006, when the GCC Supreme Council approved a proposal to explore joint nuclear development in collaboration with the IAEA. The resulting feasibility study concluded that a joint regional nuclear power plant was both technically and economically viable, but it identified several prerequisites for success. These included enhanced regional grid infrastructure, a unified electricity trade framework, harmonized regulatory and safety standards, and consensus on plant siting, ownership, and pricing models (Baker Institute 2024).

Despite these early efforts, the joint initiative was shelved as several member states—particularly the UAE, Saudi Arabia, and Kuwait—chose to pursue national nuclear programs independently. However, the possibility of deep technical integration or joint infrastructure is still on the table (Baker Institute 2024). The evolving energy landscape, growing climate ambitions, and rising concerns about grid reliability offer new incentives to revisit regional nuclear cooperation.

Existing international frameworks offer valuable models for GCC nuclear cooperation. The European Atomic Energy Community (EURATOM) demonstrates how unified regulations and stringent safety standards can create the world's most advanced regional nuclear governance system. The OECD/NEA's Multinational Design Evaluation Program (MDEP) has successfully streamlined licensing processes for advanced reactors while reducing redundant regulatory reviews. In the developing world, the Brazilian-Argentine Agency for Nuclear Materials (ABACC) has established an effective South–South cooperation model that enhances mutual trust and non-proliferation safeguards, while the Central Asian Radiation Safety Network (CARNRN) has improved regional capacity through resource sharing and collaborative training.

The GCC Interconnection Authority (GCCIA), responsible for developing an interconnected regional electricity grid, provides a crucial infrastructure backbone for facilitating future cross-border electricity trade. This grid could eventually facilitate the transmission of electricity generated from shared nuclear facilities. Such a development would be especially significant for Bahrain, whose limited domestic grid capacity could benefit greatly from regional integration if the Kingdom chooses to pursue nuclear power. In parallel, the development of national legal and regulatory frameworks, alongside the operational experience now emerging in countries like the UAE, makes the prospect of a joint GCC nuclear power plant more feasible today than at any time in the past (Baker Institute 2024).

In addition, the UAE's feasibility study for a geological waste repository presents potential for broader regional participation, especially with the support of international organizations. This is attractive for countries in the region with limited volumes of nuclear waste, which may face economic and technical constraints in establishing national repositories (WNA 2024).

The adoption of nuclear power in GCC countries faces unique technical, economic, and institutional challenges. First, the region's workforce expertise remains concentrated in oil and gas, creating significant gaps in nuclear quality assurance, regulatory compliance, and megaproject management. Second, new nuclear plants require substantial capital investments ($5,000–8,000/kW) and extended construction periods (8–10 years), exposing governments to cost overruns amid volatile hydrocarbon revenues. Third, each nation must establish independent safety regulators, radioactive waste management organizations, and legal frameworks compliant with IAEA standards—processes typically requiring a decade or more to implement.

Region-specific challenges further complicate deployment, including water scarcity for cooling, the need for heat- and dust-resistant designs, and persistent public concerns about safety, security, and spent fuel management. Without targeted solutions—such as specialized workforce development, regional regulatory collaboration, and innovative financing mechanisms—nuclear energy expansion in the GCC will likely proceed cautiously and incrementally.

While states have the right to pursue nuclear energy under the NPT, doing so in practice requires adherence to strict international regulations governing the transfer of nuclear technology. These regulations are primarily overseen by the IAEA, while for U.S.-origin technology, export controls are administered by the U.S. NRC and other relevant agencies under the U.S. export control regime. As a result, technology transfers from nuclear supplier states are often slow, politically sensitive, and subject to extensive scrutiny (Ibraheem 2022). This further compounds the already high costs and long timelines associated with developing nuclear infrastructure.

Public perception and acceptance remain critical. Initiatives like community engagement programs and transparent regulatory frameworks can play an important role in improving the public's acceptance of nuclear technology deployment. Additionally, the development of a skilled workforce through regional partnerships and international training programs is pivotal to sustaining nuclear growth across the GCC.

Outlook for China–GCC Collaboration on Nuclear Energy

China's Emerging Role in the Global Nuclear Market

Nuclear energy development in most countries has historically begun with technology imports from a handful of established nuclear vendors. Rising concerns over climate change and energy security have re-sparked international interest in nuclear cooperation. As of 2025, more than 15 countries are actively involved in nuclear technology exports or overseas nuclear power investments, a sharp rise from just six countries in 2000 (Gitnux 2025). Each supplier nation brings distinct comparative advantages: the U.S. leads in safety and non-proliferation governance, Russia in integrated reactor and fuel cycle services, and France in high-performance reactor design and operations (Jewell, Vetier, and Garcia-Cabrera 2019). Japan, facing difficulties in reactor exports post-Fukushima, is refocusing on advanced technologies such as SMRs and nuclear fusion. South Korea, through its successful delivery of four APR-1400 reactors to the UAE, has emerged as a credible new exporter.

China is a relative newcomer to the nuclear power sector compared to established players like the U.S., France, Canada, and Russia. Drawing on imported technologies from these countries, China has steadily advanced the localization of key technologies for nuclear power plants. By 2024, it had achieved full domestic production of major nuclear power equipment and secured independent control over critical component technologies (China Daily 2025). This marks a dramatic shift from 1996, when the localization rate for the Daya Bay Nuclear Power Project was just 1% (The Economist 2020).

China currently leads the world in the number of nuclear reactors under construction and has made significant strides with the launch of its first domestically developed third-generation reactor, the Hualong One, which commenced operation in 2020. The reactor design has been certified as compliant with European safety standards and has received a Design Acceptance Confirmation from the U.K.'s Office for Nuclear Regulation (ONR 2022). In addition, China is increasingly recognized as a frontrunner in the development of next-generation nuclear technologies, including small modular reactors (SMRs) and high-temperature gas-cooled reactors (HTGRs) (Kim 2023).

China's standardized reactor designs, vertically integrated supply chains, and economies of scale provide a substantial cost advantage, positioning its nuclear technology as highly competitive in global markets. A strong emphasis on design optimization has enabled it to control its investment costs and enhance the overall economic viability of its nuclear power industry. The continuous refinement of reactor designs such as the Hualong One—supported by advanced project management tools and insights from earlier projects—has led to highly standardized

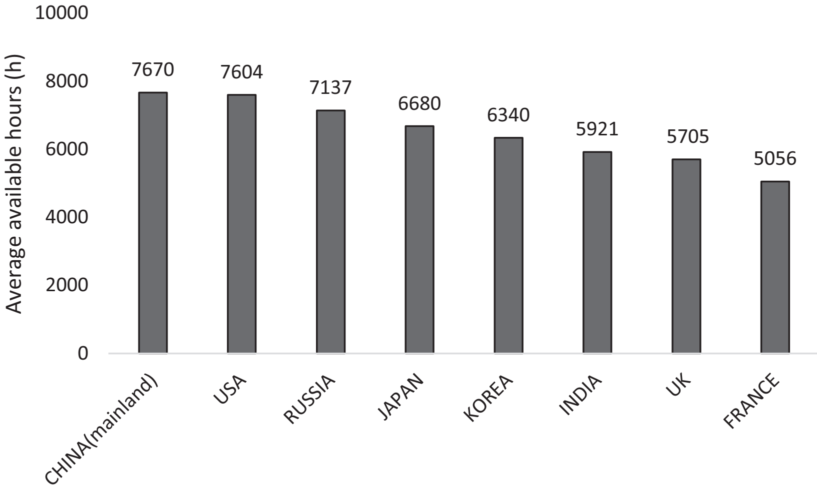

Figure 13.1 Average operating hours of nuclear power by country in the last three years.
Source: CNEA (2024) and IAEA (2023c).

construction practices and efficient execution frameworks, significantly reducing capital expenditure. Additionally, operational enhancements, including proactive maintenance strategies and consistently high-capacity factors, have contributed to lower operating and maintenance costs.

Compared to many international counterparts, China's nuclear power projects demonstrate strong cost competitiveness. Average overnight construction costs in China are estimated at 15,000–20,000 renminbi (RMB) (approximately $2,000–$2,800) per kilowatt (kW), significantly lower than the global average of 42,000–57,000 RMB (about $5,800–$7,900) per kW (GreenPrizm 2024). As a result, Chinese nuclear technologies such as the Hualong One offer substantially lower unit costs than comparable projects in the U.S., France, and Finland. The cost of the Vogtle-3 and -4 reactors in the U.S. rose from an initial estimate of $4,000 to $8,000 per kW, while France's Flamanville-3 increased from around $2,000 to $8,200 per kW; Finland's Olkiluoto-3 experienced similar cost escalations (IEA 2022). Additionally, China's nuclear plants achieve over 7,000 operating hours annually, well above the performance of many international peers, as illustrated in Figure 13.1.

The development of China's nuclear power industry has also facilitated the development of domestic equipment manufacturing and service industries. The construction of the world's first demonstration project using China's Hualong One reactor engaged over 5,000 upstream and downstream enterprises, accelerating the advancement of high-tech industries such as materials, metallurgy, chemicals, machinery, electronics, and instrument manufacturing in the country (CNNC 2024).

China's nuclear technology exports are at an early stage. Since 2000, it has signed more than 50 bilateral cooperation agreements with over 20 countries (Lovering 2022), yet implementation is limited. Pakistan is the only country where Chinese nuclear exports have materialized into operational projects, including four 300 MW CNP units (2000–2017) and two 1,100 MW Hualong One reactor commissioned in 2021–2022.

The appeal of nuclear cooperation lies not only in technology transfer but also in the long-term strategic engagement it entails. Nuclear projects require decades-long commitments, encompassing fuel supply, operations and maintenance, personnel training, and eventually decommissioning. As Lin, Bae, and Bega (2020) note, nuclear partnerships are akin to "hundred-year marriages," creating enduring economic and political linkages. However, nuclear deployment decisions are not based solely on economics. They intersect with national energy strategies, environmental goals, regulatory capacity, public acceptance, non-proliferation obligations, and international diplomacy (U.S. DOE 2022).

Most nuclear newcomers lack the institutional and technical capacity to safely manage nuclear technology. Moreover, nuclear energy is governed by complex multilateral norms, including oversight by the IAEA. Political stability and governance quality in recipient states are therefore critical. Introducing nuclear power in fragile states poses risks that extend beyond the exporter's control; even China's comprehensive supply chain and financing muscle may not offset endogenous governance weaknesses.

Moreover, nuclear energy must be assessed in comparison with alternative options. Although renewables may not yet offer the same level of baseload reliability, they are becoming increasingly cost-competitive and can be deployed much faster. They are also generally less politically sensitive, and advances in battery storage are significantly enhancing their ability to deliver stable power. In many developing countries, solar and wind projects can be completed within two years, compared to a decade or more for nuclear plants. If renewable energy costs continue to decline, the relative competitiveness of nuclear power could erode by the time reactors are commissioned. For countries facing urgent energy shortages, nuclear may not be the most practical short-term solution, especially when renewable alternatives offer more rapid relief.

In sum, China's emergence as a technology supplier marks a significant shift in its role in the global nuclear arena. However, overseas success will hinge on factors that extend well beyond the success of the reactors, including political risk, regulatory maturity, public perception, and the evolving economics of competing low-carbon technologies.

Prospects for China–GCC Collaboration

China has, in recent years, deepened its collaboration with the GCC states on both nuclear energy development and nuclear technology applications. In the nuclear energy sector, China and the UAE signed an intergovernmental cooperation agreement in the peaceful use of nuclear energy, with key areas including reactor operation, fuel supply chains, and personnel training programs (CAEA 2025). In parallel, China and Saudi Arabia have intensified their joint efforts in uranium and thorium exploration, nuclear safety enhancement and public security integration (CAEA 2025).

On the nuclear technology front, China's radiation detection equipment has been widely exported to countries such as Saudi Arabia, the UAE and Qatar. These technologies are crucial to ensure public safety at high-profile international events, including the FIFA World Cup Qatar 2022 and Dubai Expo 2020. Additionally, Chinese firms and academic institutions have established partnerships with Kuwait, Oman and Bahrain, particularly in the fields of nuclear medicine and basic research (CAEA 2025).

A major milestone in this evolving partnership is the first China–GCC Forum on the Peaceful Uses of Nuclear Technology, held in April 2025. This forum underscored both parties' commitment to expanding cooperation and facilitating knowledge exchange across several strategic sectors, including nuclear medicine, water desalination, and the industrial applications of nuclear technology. This forum also marks a new phase in bilateral strategic dialogue, aiming to serve as a long-term platform for sharing opportunities, addressing common challenges, and advancing mutual objectives in nuclear energy and technology development (GCC-SG 2025; CAEA 2025).

This forum represents a direct outcome of the proposal made by Chinese President Xi during the inaugural China–GCC Summit held in Riyadh on December 9, 2022. At the summit, President Xi outlined two initiatives aimed at strengthening nuclear cooperation: the establishment of a China–GCC forum on the peaceful use of nuclear technology and a China–GCC nuclear security demonstration center (Xinhua 2022). He also announced the provision of 300 training opportunities for professionals from GCC countries, focused on the peaceful use of nuclear energy and nuclear technologies.

However, the foundation for China's nuclear engagement with the GCC states was laid much earlier. In 2014, President Xi introduced the "1+2+3" cooperation framework during the sixth ministerial conference of the China-Arab States Cooperation Forum (CASCF). This framework positioned energy cooperation as the core pillar of China-Arab relations. It identified infrastructure construction and trade and investment facilitation as the two essential supporting instruments, while emphasizing three key domains for technological breakthroughs, including nuclear energy, space satellite technology, and new energy sources. This framework was further institutionalized through China's Arab Policy Paper released in 2016, which detailed the "1+2+3" strategy as a comprehensive approach to deepen China's cooperation with Arab countries, including the GCC, across multiple sectors (CGTN 2022).

Sustained dialogue between China and the GCC states is vital for aligning strategic interests, localizing advanced reactor technologies, and building regulatory and human resource capacity. China's nuclear expertise complements the GCC's energy diversification goals, while structured collaboration can address technology adaptation, fuel cycle needs, and long-term regional energy security.

In this context, joint initiatives between China and the GCC states could be further explored in four areas.

- **Building nuclear safety regulations and standards**

There is considerable potential for China–GCC collaboration on nuclear safety regulation and standards, particularly as GCC states expand their still nascent regulatory capacities. China's mature regulatory system, anchored by the National Nuclear Safety Administration (NNSA) and its enforcement of the HAF safety codes (Chinese nuclear safety regulations), offers a valuable reference model for emerging nuclear programs. Both sides can coordinate licensing standards, develop regional emergency-response protocols, and establish a China–GCC nuclear security demonstration center as envisaged by the 2022 China–GCC summit.

Within the newly established China–GCC Forum on the Peaceful Uses of Nuclear Technology, a dedicated nuclear safety regulation track could facilitate structured dialogue and the exchange of best practices. Regulatory convergence may be especially beneficial in scenarios where Chinese-designed reactors, such as the Hualong One, are deployed in the region.

A joint nuclear training center could be established under the China–GCC Forum to provide training for regulatory officials, inspectors, and operators from the GCC countries. Both sides could organize joint workshops focusing on licensing processes, reactor safety evaluation, environmental impact assessments, and cybersecurity frameworks for nuclear systems.

In 2017, the OECD's Nuclear Energy Agency (NEA) established a dedicated working group under the Multinational Design Evaluation Programme (MDEP) to facilitate collaborative safety design reviews of the Hualong One reactor. Known as the HPR1000 Working Group, it currently includes nuclear regulatory authorities from Argentina, China, South Africa, and the U.K. The MDEP framework is open to additional national regulators with an interest in specific reactor designs. GCC states may consider joining the HPR1000 Working Group, particularly if they are evaluating or planning to adopt the Hualong One reactor.

Additionally, both sides could strengthen their cooperation under the IAEA framework by jointly participating in or co-hosting IAEA-led safety review missions. Such collaboration not only promotes regulatory alignment but also contributes to the development of a robust and transparent nuclear safety culture, supporting the safe and sustainable expansion of nuclear energy in the region.

- **Increasing public acceptance**

Public acceptance is an essential pillar for the sustainable development of nuclear energy, particularly in emerging nuclear countries such as the GCC states. As these countries scale up their civilian nuclear programs, cooperation with experienced partners like China can support the development of effective public communication frameworks.

China's Nuclear Safety Law provides a legal foundation for information disclosure and public participation, complemented by institutional mechanisms for science popularization, crisis communication, and stakeholder engagement. Practical initiatives, such as public open days at nuclear facilities, mobile science vans, visitor centers, and multimedia educational materials, form a comprehensive strategy to demystify nuclear technology and build public trust. These practices are reinforced through centralized data platforms that disclose environmental and operational information.

For the GCC states, China's experience offers transferable models to support localized public outreach programs, regulatory transparency, and education campaigns. Joint efforts could include training exchanges, the co-development of communication tools, and collaborative public awareness initiatives under the China–GCC Forum on the Peaceful Uses of Nuclear Technology. By institutionalizing such programs, both sides can promote informed public discourse and embed a shared safety culture—critical to the long-term legitimacy of nuclear power in the Gulf.

- **Improving supply chain security**

China is among the few nations with a fully integrated nuclear industry chain spanning uranium exploration through spent-fuel management. This vertical integration creates multiple entry points for deeper China–GCC collaboration.

Upstream: Cooperation can focus on uranium prospecting, geological survey, and joint-venture mining, an approach already piloted in Saudi Arabia. China can transfer technologies such as satellite remote sensing, advanced drilling, and ore-processing techniques. There may also be potential for joint uranium mining ventures in third countries.

Midstream: Technical collaboration in reactor physics, fuel-behaviour modeling, and safety simulation can elevate regional expertise. China can deliver engineering, procurement, and construction (EPC) packages for Hualong One or SMR projects, paired with workforce training schemes to ensure operational self-reliance.

Downstream: Emerging digital-twin platforms, artificial intelligence (AI)-based diagnostics, and remote-operation tools can be co-developed to boost plant availability. Localizing component manufacture, such as instrumentation and control (I&C) systems and primary coolant pumps, would embed GCC firms in the nuclear supply chain and leverage China's standardized industrial ecosystem.

Fuel cycle: Cooperation could cover low-enriched uranium (LEU) fuel supply contracts and capacity-building in fabrication through simulators and pilot lines. China's experience in wet and dry storage, as well as interim storage facility design, offers valuable references for GCC states. Joint work might include cask design optimization, transport logistics, and waste conditioning technologies.

It is important to note that activities such as enrichment and reprocessing remain proliferation sensitive and subject to strict international oversight. Any collaboration must comply with IAEA safeguards and relevant export control regimes.

- **Expanding nuclear energy adaptability**

While traditionally focused on electricity generation, nuclear energy is increasingly being applied across a broader spectrum of non-electric uses, including industrial heat supply, seawater desalination, hydrogen production, and marine and space exploration. China has actively demonstrated its capabilities in these areas through nuclear heating projects in Liaoning, Shandong, and Zhejiang, with the Haiyan project marking its first industrial-scale application. In parallel, China is advancing the development of SMRs and HTGRs, designed for integration with energy-intensive industrial zones such as petrochemical parks.

In the water-scarce context of the GCC, where cooling water availability is a major constraint, these technological pathways present significant opportunities for bilateral cooperation. China can assist in the design and deployment of dry or hybrid cooling systems suited to arid environments. SMRs and HTGRs, with their lower water demands, offer a more adaptable solution for regional deployment. Furthermore, nuclear-powered desalination using reactor waste heat and joint efforts in marine ecosystem protection and thermal discharge mitigation can address critical sustainability concerns. By leveraging China's experience, GCC countries can accelerate the adoption of advanced nuclear technologies, integrate them into hybrid renewable systems, and align this adoption with their long-term goals for water security and energy diversification.

Conclusion

China has built a nuclear program that supports both domestic energy security and international competitiveness. It illustrates how a coordinated national strategy—backed by strong institutional frameworks, investment in research and development, and international partnerships—can foster a resilient and forward-looking nuclear sector.

For GCC countries that plan to launch or scale up civilian nuclear programs, China's policy and practical experiences may present a pathway to achieve their broader economic and climate goals. Such collaboration could be strategically oriented around four key areas:

- The exchange of technical expertise, regulatory policies, and operational experience would help establish a shared agenda focused on nuclear safety, security, and the peaceful use of nuclear technology.
- The development of culturally tailored communication strategies and co-produced media content, educational campaigns, and community forums could help build public trust and acceptance of nuclear energy development in the region.

- Joint ventures in uranium conversion, enrichment services, and component manufacturing could anchor regional industrial capacity and foster long-term supply chain resilience.
- The co-development and localization of Hualong One and SMR/HTGR technologies could enhance the adaptability of nuclear systems to the GCC countries, especially their integration with renewable energy infrastructure, seawater desalination, and industrial application.

Pursuing these avenues would not only solidify GCC energy security, it would also position the GCC as a hub for next-generation nuclear technology in the Middle East. To ensure the long-term viability of such cooperation between the GCC and China, it is also essential that both parties address broader structural challenges together. These include geopolitical uncertainties, regional security, water resource limitations, and the shifting competitiveness of renewable energy alternatives.

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14 Strategic Partnerships Between China and the GCC States on Geothermal Development

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Introduction

Over the past 20 years, China has increasingly been engaged in trade with the six GCC states. While China's interest in the region may have initially been driven by its energy needs, the relationship is now diversifying beyond oil and gas. The sobering realities of climate change and volatile energy markets have deepened the need for orderly, sustainable, and equitable energy transitions.

Geothermal energy offers a domestically sourced, low-carbon, and reliable base-load energy option that competes favorably with other renewable energy sources. Despite its significant potential and long-standing history, the installed capacity of geothermal energy accounts for only 0.2% of the world's installed power capacity, leaving its share in the energy mix minimal and its growth stalled (Aguilera et al. 2024). Even though there are ongoing geothermal developments in more than 90 countries, consistent geothermal capacity growth has been restricted to just a few nations due to their unique geological characteristics and active utilization of these resources. However, recent developments, including escalating energy security concerns, an increasing awareness of climate change, sustainable investments, and technology spillover from the oil and gas industry, have put geothermal energy back into focus.

China has emerged as a contender in the field of geothermal heating and is harnessing geothermal energy for electricity generation and direct use (Lund, Huttrer, and Toth 2022). The country's geothermal resources constitute 7.9% of the world's total potential for electricity generation and direct use (Wang et al. 2020). In 2017, China adopted its "13th Five-Year Plan for Geothermal Energy Development and Utilization" with the intention of advancing geothermal development to mitigate air pollution and provide a stable supply of base load electricity and heat. The subsequent "14th Five-Year Plan for Renewable Energy," introduced in 2021, continued to emphasize the development and utilization of geothermal energy, focusing on optimizing the deployment of geothermal heating and cooling systems (China National Development and Reform Commission 2021).

GCC member countries, including Saudi Arabia, the UAE, and Oman have launched comprehensive geothermal initiatives to explore the potential for geothermal resources to transform the energy landscape, particularly in electricity

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generation, cooling, and water desalination. Geothermal potential has been identified in the west of Saudi Arabia, characterized by an active tectonic environment with tectonic plates continuously in motion and frequently interacting. These interactions often result in geological phenomena such as earthquakes. The movement and friction of tectonic plates generate significant heat, which is yet to be harnessed. Pilot projects in the west of Saudi Arabia are currently underway to evaluate the geothermal resource base and its possible applications (Al Suwailem, Aldubayan, and Al-Momen 2024).

China and the GCC countries have the opportunity to form a strategic partnership in geothermal energy, driven by their shared commitment to a low-carbon future, energy security, and economic growth. This collaboration could accelerate geothermal development globally, offering sustainable energy solutions for a fossil fuel-reliant world. China, a leader in research and development (R&D), offers expertise in applied geothermal technologies and cost-effective engineering solutions, supporting the GCC's geothermal development. GCC countries have subsurface expertise, existing infrastructure, and financial prudence, and can help expedite geothermal growth. China's developed policy framework for geothermal energy can serve as a benchmark for the GCC states as they develop their regulatory frameworks and risk mitigation schemes to exploit their geothermal resources. It is essential to have continuous policy dialogues, share best practices, and harmonize regulations between both entities. Establishing a connected energy market that incorporates geothermal projects can incentivize investments from China and the GCC.

From the Earth's Core to Comfort: The Journey of Geothermal Energy

Geothermal energy is derived from heat stored in rocks and fluids beneath the Earth's surface. This energy is accessed by drilling into the ground and using carrier fluids to bring the heat to the surface. Once at the surface, the heat is extracted from hot water or steam and converted into electricity or used for various applications, depending on the resource temperature and technology. These applications include electricity generation and direct use for heating and cooling buildings, supporting agriculture (e.g., greenhouse planting and artificial breeding), and industrial uses (e.g., water distillation and chemical extraction). Heat utilization technologies include absorption chillers and ground-source heat pumps (GSHPs).

The Earth's core, with temperatures comparable to the sun, harbors immense thermal energy, shielded by layers of impermeable rock. This energy reserve, amounting to 15 million zettajoules[1] (Tait 2022) far surpasses conventional energy sources like coal and gas. However, only a tiny portion of this potential has been tapped. According to the International Geothermal Association, in 2021, global geothermal operations generated a mere 16.3 gigawatts (GW), accounting for less than 0.5% of all renewable energy. There are several challenges to the widespread adoption of geothermal energy. These include high initial costs, extended periods before revenue generation, technical limitations, and social and administrative hurdles (Al Suwailem et al. 2024).

The methods for exploring and extracting geothermal resources are similar to those used in the oil and gas industry. Current geothermal systems are mainly in tectonically and volcanically active regions, like the Pacific Ring of Fire, mid-oceanic ridges, and rift valleys. These areas offer high-yield, low-risk prospects with high temperatures and shallow depths. Medium-low temperature resources under 90 degrees Celsius (°C) are found in tectonic basins, which are often rich in fossil fuels.

A geothermal (or hydrothermal) system comprises a heat source, a permeable reservoir with a water supply, and a steady recharge mechanism. A lack of one or more of these pillars necessitates technological interventions to harvest the heat. In reservoirs with dwindling or non-existent water supplies, technologies are used to (re-)charge them to ensure sustainable heat supplies. Wastewater or used water is injected into these geothermal reservoirs via designated injection wells to maintain their pressures and arrest the decline in geothermal fluids flowing to the surface.

In the case of very low permeability[2] reservoirs, technologies used in the oil and gas industry can be retrofitted to create artificial pathways for hydrothermal fluids. These cutting-edge technologies will likely be pivotal in unlocking geothermal power in extreme temperatures and in hard, heterogeneous sedimentary rocks.

The economic viability of geothermal resources depends on temperatures, flow rate, and fluid chemistry. High-temperature reservoirs over 90°C are found in volcanic and tectonic regions and are ideal for electricity generation using flash or binary power technologies. These plants offer clean, baseload electricity with capacity factors above 70%, which are not provided by solar power voltage and, to an even lesser extent, wind. Medium-to-high temperature geothermal systems provide a steady supply of clean-based baseload energy unaffected by weather conditions or natural occurrences.

Temperatures below 90°C are suitable for direct-use applications like district heating and industrial use. Very low-temperature resources, under 30°C, are used for small-scale heating.

GSHP systems consist of a heat pump, a ground heat exchanger (GHE), and an air distribution system. They use the ground, the temperature of which remains relatively constant, as a heat source or sink. The GHE design affects heat exchange efficiency. A heating or cooling coil facilitates heat exchange between the heat pump and the space being heated or cooled. GSHP applications have grown, especially in urbanized areas in Europe and China, providing efficient space heating and cooling (Aguilera et al. 2024). GSHPs use low-temperature geothermal energy, at around 18°C, and have a significantly reduced environmental impact compared to coal-based heating.[3] Absorption chillers are technologies capable of producing cooling using medium or low-temperature heat sources. Using absorption chillers for cooling can lead to electricity savings and a reduction in pollutant emissions.

These technologies can be cost-effective options for cooling large buildings and district cooling systems. Ground-source heat pump systems, which utilize geothermal energy, are more energy-efficient than air-source heat pump systems due to the low and stable ground temperature they harness. Thermal energy extracted from geothermal sources can be applied as the heat source for absorption chillers, resulting in cleaner technologies. Geothermal energy sources are mainly employed to supply the thermal energy needed for cooling in air conditioning (AC) systems. It is also possible to integrate other geothermal systems, such as power production units, with absorption chillers to produce cooling (Soltani et al. 2019).

Geothermal Resource Base, Exploration, and Developments in China and GCC States

Geothermal Resources, Developments, and Markets in China

China's strategic location within two significant geothermal belts, the Himalayan geothermal belt and the circum-Pacific geothermal belt contribute to the country's high geothermal potential. Its geothermal resources represent approximately 7.9% of the world's total geothermal resources. This positioning offers China a unique opportunity to harness these resources for sustainable power generation and heating.

The geothermal heat flow (Figure 14.1) shows a zonal distribution for both eastern and southwestern continental China. Over 3,200 geothermal systems have been identified in China, and 255 of them are classified as high-temperature (enthalpy)

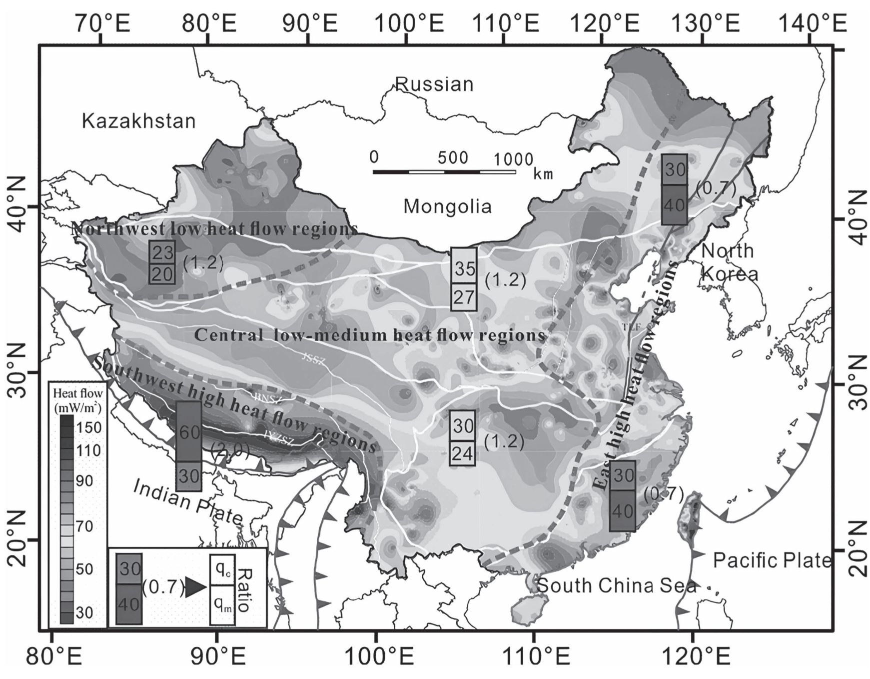

Figure 14.1 China heat flow map (measured in megawatts per square meter).

Source: Jiang et al. (2019).

systems, which have the potential to generate a total of 5,800 gigawatt hours (GWh) of electricity (Ma 2021). They are mainly found in southern Tibet and the western provinces of Yunnan and Sichuan. The Yangbajing geothermal field in Tibet has high-temperature geothermal fluids, with temperatures of around 330°C at a depth of 2,000 meters.

Around 2,900 medium-to-low-temperature geothermal systems were also identified, with a total natural heat discharge equivalent to approximately 29 GWh. These systems are predominantly located in southeastern coastal provinces and inland basins such as the Songliao Basin, the North China Basin, the Jianghan Basin, the Weihe Basin, and various intermontane basins, where geothermal wells at depths of 1,000–3,000 meters typically yield fluids with temperatures between 80°C and 100°C (Figure 14.1). As of year-end 2023, the installed capacity of geothermal for electricity and direct use (predominantly in district heating and bathing) was 34.89 megawatt electrical (MW_e) and 67,060 megawatt thermal (MW_{th}), respectively, according to Rystad Energy.

Various factors have driven China's geothermal development and proliferation in recent years. First, the country's growing energy demand and the need for sustainable energy sources have pushed the government to explore alternative energy options. Being a clean and renewable resource, geothermal energy aligns with China's strategic goals to reduce its carbon emissions and combat air pollution. The Chinese government has implemented supportive policies and incentives to encourage investment in geothermal projects, including subsidies, tax benefits, and research funding. These measures have facilitated the growth of geothermal energy infrastructure and technology development, making it a viable component of China's energy mix.

Technological advancements and increased expertise in geothermal energy extraction and utilization have played a significant role in its development in China. China has invested in R&D to improve the efficiency and cost-effectiveness of geothermal technologies. Collaboration with international experts and organizations has also contributed to enhancing local capabilities. Additionally, the geographical advantage of having abundant geothermal resources in regions such as Tibet, Yunnan, and Sichuan has provided a natural impetus for development. These factors combined have enabled China to harness geothermal energy more effectively, contributing to its proliferation as a sustainable energy source.

Geothermal power generation in China began in the early 1970s, driven by the need for energy security following the Arab oil embargo and the Islamic revolution in Iran. In 1970, China's first geothermal power station (92°C, 300 kilowatts [kW]) was built in Dengwu, Fengshun County, Guangdong Province. The following year, the first worldwide organic medium-to-low-temperature geothermal power station, approximately 67°C, was constructed in Wentang, Yichun County, Jiangxi Province (Tian et al. 2020).

Five low- and medium-temperature geothermal power plants were also built. However, these projects were economically unfeasible. By the end of the 1970s, most low-to-medium-temperature geothermal plants were decommissioned. The ones currently operating are those erected in Dengwu, Wentang, and Huitang cities.

The first high-temperature geothermal power station was built in Yangbajing, Tibet, in 1977 (Zhang, Chen, and Zhang 2019). The initial installed capacity was only 1 MWe in 1981. Eight new units (3 MWe each) were added successively to this plant between 1981 and 1991. In 2009 and 2010, two new sets of screw expansion generators (with an installed capacity of 2 MWe) were added. The total installed capacity of the plant reached 26.18 MW. The plant currently contributes 50% of Lhasa's summer power supply and 60% of its winter power supply.

Direct geothermal use in China has been on the rise in recent years, propelled by state mandates to conserve energy in buildings and reduce greenhouse gas emissions. GSHP installation is a rapidly expanding sector. In 2009, GSHPs constituted 53.5% of installed geothermal capacity and 52% of annual geothermal energy consumption, mainly in residential buildings. Tianjin, located south of Beijing, has China's largest demand for geothermal space heating, covering 25 million m^2 and accounting for 6% of the city's central heating (An 2016). The city extracts 6.4 million cubic meters of geothermal energy annually, and this is projected to expand to 35 million m^2 by 2020.

China has made significant advancements in geothermal energy utilization, with seven geothermal district heating projects and numerous initiatives in greenhouse heating, agricultural drying, industrial processes, and bathing/swimming facilities. Geothermal district heating ranked first for the most utilization with 49.93% of the total capacity. GSHP projects are operational in over eight regions nationwide, which account for 42.23% of the total geothermal energy utilization capacity in 2021. China's direct geothermal utilization capacity is equivalent to 100.2 GWth, with an annual utilization of 828,882 terajoules (TJ) at the end of 2021 (Guo et al. 2023). CThe geothermal market structure in China is segmented into three main areas: upstream, midstream, and downstream. The upstream segment involves geothermal exploration and evaluation, with advanced technologies, geological surveys, and cutting-edge technologies used to identify and assess geothermal resources. This segment is crucial for the entire geothermal value chain, as it determines the feasibility of geothermal energy development. The market in this segment is relatively concentrated, with a few key players holding significant market share due to the high technical demands and the need for specialized equipment and expertise.

Active players in China's geothermal market include both state-owned and private entities and research institutions. The National Geothermal Energy Center and the Chinese Academy of Sciences are pivotal in driving exploration and technological advancements in the sector. Provincial and municipal geological exploration institutes also play a significant role in regional surveys and resource assessments. Universities, including petroleum and geology faculties, contribute to R&D, providing the scientific foundation and skilled professionals the industry needs. These entities collaborate to advance geothermal exploration, drilling technologies, and resource management.

China's geothermal value chain encompasses exploration, borehole drilling, and geothermal energy utilization. Exploration and evaluation are critical in the upstream segment, requiring sophisticated equipment and methods to locate viable geothermal resources. The companies developed in geological universities or institutes, such as Hubei Dida Heat Energy Technology, are market leaders due to their rich resources and experiences. The midstream segment involves borehole drilling, where specialized drilling techniques are employed to access geothermal reservoirs. Equipment manufacturing companies from the oil and gas engineering industry, such as the Jereh Group, are also active in geothermal drilling technologies. Downstream, the market becomes more competitive, with a focus on utilizing geothermal energy, particularly in shallow and hydrothermal applications. This includes heating, cooling, and power generation, with various companies competing to offer innovative solutions. The downstream market is more fragmented, with a broader array of players due to its lower barriers to entry and diverse application possibilities. Apart from the companies targeting specific geothermal utilization technologies, China's three major national oil companies, China National Petroleum Corporation, China Petrochemical Corporation, and China National Offshore Oil Corporation, are also active in geothermal energy applications, especially geothermal heating. These large firms can typically cover the whole industrial chain due to their extensive experience in exploration and drilling technologies. Their projects focus on utilizing disposed oil wells, waste heat in oil fields, and shallow geothermal energy.

Geothermal Resource Regime and Ongoing Exploration Activities in GCC countries

Geothermal energy has not been widely developed in GCC countries, primarily due to the member states' abundant and relatively inexpensive fossil fuel resources. With vast oil and natural gas reserves, they have traditionally relied on these energy sources for domestic consumption and export revenues. This abundance has made developing alternative energy sources like geothermal less economically attractive. The capital-intensive nature of geothermal projects, requiring significant upfront investment in exploration, drilling, and infrastructure, further diminishes their attractiveness when cheaper energy options are available. Additionally, the GCC has historically lacked expertise and research in geothermal energy, with a stronger focus on optimizing hydrocarbon extraction. These factors, combined with the slow pace of energy diversification initiatives, have limited the scale of geothermal energy development in the GCC.

In the energy strategies of GCC states, geothermal energy has generally been overlooked in favor of other renewable and clean energy sources like solar, wind, hydrogen, and nuclear power. These alternatives align more closely with the region's technological capabilities and the availability of these scalable renewable resources.

Conventional hydrothermal systems in GCC countries are chiefly located in the western and southwestern regions of Saudi Arabia. These regions exhibit prominent surface-level geological characteristics that suggest the presence of geothermal resources. These areas are also associated with tectonic and volcanic activities, comprising several volcanic terrains, as illustrated in Figure 14.2. Known

Figure 14.2 Geothermal features in Saudi Arabia: volcanic fields (black-filled polygons), hot springs (filled red triangles), and heat flow measurements.

Source: Map reconfigured based on Lashin et al. (2015).

as "harrats," these terrains contain over 2,500 dormant volcanoes and many hot springs (Al Suwailem et al. 2024). Some hot springs in this region have recorded temperatures of up to 80°C, with flow rates varying seasonally (Jiang et al. 2016). Geothermal resources in this area of the Kingdom generally exhibit low-to-medium temperature gradients, with exceptions in the Wadi Al-Lith and Jizan areas, where the surface temperatures of hot springs range from 46°C to 95°C.

Initial exploration near Harrat Rahat, east of Medina, has identified potential sweet spots for geothermal energy production. In February, the King Abdullah University of Science and Technology drilled a second observatory well. This pilot project aims to harness geothermal heat for district cooling through absorption chilling and water desalination. It also aims to explore the potential for lithium extraction and carbon dioxide (CO_2) or flue gas sequestration. Geothermal exploration is gaining momentum, with Saudi Aramco and other companies conducting pilot projects to explore the potential of geothermal energy for district cooling, deep geothermal cooling applications, and power generation (Al Suwailem et al. 2024).

The terrain in the eastern part of Saudi Arabia and the other GCC countries comprises sedimentary formations, referred to as the Arabian Platform (see Figure 14.2). The Sultanate of Oman, famous for tourism and natural therapies, has roughly 23 hot springs. However, they have low geothermal temperature gradients, estimated at an average of 25°C per kilometer.

The Arabian Platform also contains significant hydrocarbon deposits, with some reservoirs located at depths of 2 km or more. Depleted and abandoned oil and gas wells in these areas could have temperatures sufficient for geothermal applications. They could also synergize with other energy transition technologies, such as hydrogen production and carbon capture and storage (Al Suwailem et al. 2024). SLB, a leading service provider, is collaborating with Oman's Ministry of Energy and Minerals and the Oman Investment Authority to develop a national geothermal strategy. After mapping geothermal prospects using data from 7,000 oil, gas, and water wells, the company is now assessing the economic viability of these resources (SLB 2023).

The UAE has successfully launched and piloted a geothermal-based district cooling initiative. Two wells in Masdar City were drilled approximately 12 years ago to a depth of ~2.6 km to capture ~90ºC water. Facilities have recently been installed to channel the captured water through an absorption cooling system that produces chilled water. With a $15 billion endowment for low-carbon technologies, this pilot project, led by the Abu Dhabi National Oil Company (ADNOC) and Tabreed, a district cooling utility company in the UAE, aims to tap into geothermal heat for district cooling. This will reduce electricity demand for cooling from the grid and help decarbonize one of the most energy-intensive sectors (Al Shehri et al. 2020).

The limited availability of public data makes a robust assessment of geothermal resources and the development of rigorous heat flow maps and associated drilling prognoses impossible. To date, there are no publicly available heat flow maps for Saudi Arabia and other GCC countries that would aid in assessing their resource potential.

The Role of Policies and Regulations in Derisking Geothermal Development

Geothermal Energy Promotion Measures in China

Since the turn of this century, China has set targets and policies for geothermal energy applications to help achieve its carbon peaking and carbon neutrality goals (State Council of the People's Republic of China 2021) (Table 14.1). The Chinese National Energy Administration proposed increasing the geothermal heating–cooling area by 50% by 2025, as well as doubling the country's geothermal power generation capacity (National Energy Administration 2021).

Geothermal energy is listed as one of the five non-carbon-based energies in the "Roadmap for Carbon Neutrality in China's Energy System." To achieve carbon peaking and carbon neutrality, China's energy structure needs to be optimized, and energy efficiency needs to be improved. The contribution of solar thermal and geothermal energy is projected to increase significantly, with their combined share of China's end-user energy consumption reaching around 15% by 2060, almost

Table 14.1 Geothermal energy promotion measures in China

No.	*Year*	*Name*	*Issuing agency*	*Issue No.*
1	22021	Notice of the State Council on issuing an action plan for carbon peaking before 2030	The State Council	000014349/ 2021-00098
2	22021	"14th five-year plan" renewable energy development plan	National Development and Reform Commission, National Energy Administration, Ministry of Finance, Department of Natural Resources, Ministry of Ecology and Environment, Ministry of Housing and Urban-Rural Development, Ministry of Agriculture and Rural Affairs, China Meteorological Administration, State Forestry and Grassland Administration	1445
3	22021	Several opinions on promoting the development and utilization of geothermal energy	National Development and Reform Commission, National Energy Administration, Exchequer, Department of Natural Resources, Ministry of Ecology and Environment, Ministry of Housing and Urban-Rural Development, Ministry of Water Resources, National Bureau of Statistics	000019705/ 2021-00121
4	22021	Notice of the National Energy Administration on Renewable Energy Heating	National Energy Administration	3
5	22022	14th Five-Year Plan for Modern Energy System	National Development and Reform Commission, National Energy Administration	000019705/ 2022-00027
6	22023	National Carbon Peak Pilot Construction Program	National Development and Reform Commission	1409

Analysis based on: State Council of the People's Republic of China 2021; China National Development and Reform Commission 2021; China National Energy Administration 2021b; China National Energy Administration 2021a; China National Energy Administration 2022; National Development and Reform Commission 2023

double its 2020 level. The direct use of fossil fuels in the buildings sector will be reduced after 2025 and completely phased out by 2060, with the use of low-carbon natural gas decreasing to only 4% by 2060.

The International Energy Agency's "Roadmap for Carbon Neutrality in China's Energy System" illustrates how energy used for heating could be decarbonized through a shift to low-carbon fuels and energy efficiency improvements

(International Energy Agency 2022). By 2035, coal- and oil-burning boilers and incompatible gas-burning equipment will be banned in buildings and district heating systems in China. Electric heat pumps will increasingly replace fossil fuel boilers, meeting 14% of heating demand by 2060. The share of heating demand met by renewable energy, including solar thermal and geothermal power, is expected to rise from 20% today to nearly 50% by 2060. Additionally, the share of electricity in building energy use will approach 60% by 2060, with significant growth in electric cooking (Amran et al. 2020).

The "14th Five-Year Plan for Modern Energy System" (China National Energy Administration 2022) and "14th Five-Year Renewable Energy Development Plan" (China National Development and Reform Commission 2021) focus on accelerating the electrification and low carbonization of energy used in buildings. China aims to boost non-fossil energy production by over 150 million tons of standard coal equivalent annually. The plans promote deep geothermal energy for heating and cooling, especially in northern China, using technologies that minimize the environmental impact. The integration of geothermal energy with tourism, industry, and other energy sources is encouraged, along with the development of medium and deep geothermal energy for refrigeration on the southeast coast and heating in alpine regions like Yunnan and Guizhou.

In regions rich in geothermal resources, such as Tibet, Qinghai, and Sichuan, geothermal power generation will be developed, supporting advanced technologies like dry-hot rock and enhanced geothermal systems. Large-scale geothermal heating projects are planned for areas like the North China Plain, with Henan province spearheading demonstration projects. Shallow geothermal energy will be promoted in areas with significant heating and cooling demand through the use of ground-coupled heat pumps and water-source heat pumps.

Regions such as the North China Plain, the Fen-Wei Plain, the Songliao Plain, and the Ordos Basin can adopt hydrothermal geothermal for heating on a large scale. Henan province, in particular, can promote 10 million m^2 of demonstration projects for the large-scale utilization of medium and deep geothermal energy for heating. Special attention should be given to geothermal energy utilization in Yunnan–Guizhou alpine areas. In Beijing, Tianjin, Hebei, Shanxi, Shandong, and Henan provinces, as well as the Yangtze River region, shallow geothermal energy should be developed due to the local geological conditions and heating/cooling demands, and further demonstrations of the clustered utilization of shallow geothermal energy should be encouraged.

The "Notice of the National Energy Administration for Renewable Energy Heating" encourages using oilfield-produced water and geothermal energy for heating, emphasizing balanced mining and water management. It promotes medium and deep geothermal heating through zoning and combining centralized and decentralized approaches. The notice also advocates for adopting "underground heat transfer" technology, developing shallow geothermal energy, and replacing loose coal heating with surface, soil, and underground water-source heating where applicable (China National Energy Administration 2021a).

The National Energy Administration's notice emphasizes the use of geothermal energy for heating, particularly in conjunction with oilfield-produced water and groundwater resources. Balanced mining and irrigation principles will guide the development of medium and deep geothermal energy, focusing on sustainable resource management. The "National Carbon Peak Pilot Construction Program" supports local efforts to achieve carbon peaking, with 100 cities and parks selected for pilot projects (China National Development and Reform Commission 2023). The program promotes clean heating, emphasizing renewable energy and waste heat in cold regions and efficient heat pumps and geothermal energy in hot summer and cold winter areas.

Prospects for Geothermal Energy in the GCC States

The application of geothermal energy is very limited in the countries surrounding the Arabian Gulf, except for Iran, which currently has an operational geothermal power plant with an installed capacity of 5 MWe (Richter 2011). No geothermal power plants have been erected in the GCC.

GCC countries have predominantly desert climates and frequently experience sweltering days with temperatures often surpassing 40ºC. A significant portion of energy demand in buildings is attributable to cooling. Research suggests that in Saudi Arabia, electricity used for cooling represents 101 TWh in residences and 70 TWh in commercial establishments. This consumption equates to approximately 50% of the total yearly electricity use in buildings, increasing to as much as 70% during periods of peak cooling demand. Consequently, the government has earmarked district cooling and urban planning as two important components of its strategic planning (Aboud et al. 2021). Cooling using GSHPs for residential and large-scale districts will likely yield energy efficiencies. Despite their potential, GSHPs have limited application in the Middle East and North African countries (Al Suwailem, Aldubayan, and Al-Momen 2024).

GCC states face significant water limitations and are among the largest producers of desalinated water globally. The primary method employed for freshwater production is reverse osmosis, a technology known for being carbon intensive and dependent on oil- and gas-fired facilities. Conventional desalination methods use 10 kilowatt hours (kWh) to 15 kWh to generate one cubic meter of fresh water. Transitioning to geothermal energy to power some desalination plants could offer the GCC countries a more environmentally friendly and cost-effective approach to freshwater production.

Research suggests that geothermal binary power plants are the most suitable technology for generating electricity (Lashin 2020). The ideal locations for these plants are in western Saudi Arabia. Based on recent studies, several areas, such as Jizan, Arar, Wadi Al-Lith, and Tabuk, have geothermal source temperatures between 150°C and 300°C, making them sufficient for the insulation of geothermal energy plants (Demirbas et al. 2016).

GCC countries increasingly incorporate alternative energy, such as renewable and nuclear power, into their energy mix. This strategic shift toward renewables enhances their energy security by reducing their dependence on fossil fuels, which are subject to market volatility and geopolitical risks. Moreover, incorporating alternative energy supports economic diversification by creating new industries and job opportunities, crucial for long-term economic stability in the Gulf region.

The technologies used for the exploration, development, and utilization of geothermal energy significantly overlap with those of oil and gas. The wealth of geological, drilling, logging, and geophysical data accumulated during oil and gas exploration and production can be directly applied to developing and utilizing geothermal resources. The GCC therefore could repurpose many idle oil and gas wells for geothermal energy.

Using shallow geothermal heat pumps could save massive amounts of energy and reduce electricity costs. Geothermal desalination and electricity production can operate entirely without oil and gas, particularly if the facilities and pipelines needed are electrified by geothermal energy. As a dependable energy source that can work 24 hours a day regardless of the weather, geothermal energy can help enhance energy diversification, reliability, resilience, and security.

China–GCC Alliances: Sustainable Investments and Technological Exchange in Geothermal Energy

Since the China–GCC Summit on December 9, 2022, cooperation between the two parties in energy trade and investment has seen notable developments. The joint statement from the summit underscored a mutual commitment to advancing energy and climate cooperation. It emphasized the vital importance of energy security and the necessity of bolstering cooperation in developing clean energy sources and technologies (Saudi Press Agency 09).

The collaboration between China and the GCC states in geothermal energy represents a mutually beneficial partnership, leveraging both parties' strengths and needs. China has substantial experience in geothermal power generation and direct use. Chinese energy firms, the services sector, and research institutes can collaborate on assessing the resource regime potential, pilot testing geothermal wells, and designing and building geothermal power plants. Key technologies to focus on include electric power generation, geothermal cooling, and the use of geothermal power in distillation or oil production processes.

During its 12th Five-Year Plan in the 2010s aimed at accelerating renewable technology development and utilization, China also made considerable progress in the direct use of GSHP systems. This was primarily due to government incentives, including risk mitigation schemes, with the Chinese government investing approximately \$12–\$18 billion to support the GSHP industry. GCC countries could benefit from adopting similar incentives to accelerate the deployment of geothermal energy. Given their expertise in borehole drilling and the presence of abandoned oil fields or boreholes, GCC countries could repurpose these resources to foster collaboration in the oil and gas sector, thereby stimulating geothermal development and attracting new entrants. GCC countries could also invest in geothermal projects in China and acquire stakes in Chinese companies specializing in geothermal energy. This approach mirrors their strategy in mineral projects, where they have sought to secure resources and diversify their economic interests. For instance, Saudi Arabia's Public Investment Fund (PIF) and the Saudi Mining Company have invested in mining ventures, focusing on strategic minerals and technology transfer (Reuters 2023). Similar investments in the geothermal energy sector could help foster partnerships, drive innovation, and contribute to the global transition toward renewable energy sources.

Technology transfer and project development are enabled by fit-for-purpose policies and regulatory frameworks. Such policies and regulations should be established to promote China–GCC cooperation, including green financing and public funding for geothermal energy projects. Investing in geothermal energy will help GCC countries diversify their energy portfolios and create a more stable and resilient energy system.

Furthermore, geothermal projects can stimulate local economies by developing new technologies and generating skilled jobs. Therefore, geothermal energy should be a vital component of the GCC countries' strategy to meet their future energy demands sustainably and securely. The prospects for GCC and China cooperation in R&D and technology are promising, driven by their mutual interests and complementary strengths. Both entities are keen on diversifying their renewable energy portfolios and enhancing their technological capabilities.

Universities, government agencies, and research institutions in the GCC and China can partner to construct a centralized repository of subsurface data for geothermal reservoirs in the Arabian Peninsula. Comprehensive database and heat flow maps will help prospective developers understand the potential of geothermal energy, select sites for the exploration and deployment of geothermal projects, and assist in creating suitable regulations, incentives, and market models that cater to the development of the geothermal sector. Such partnerships can also play a pivotal role in developing and customizing fit-for-purpose technologies, such as cooling and water desalination, and generating electricity for the GCC's arid climate and existing infrastructure. The potential areas of cooperation are given below:

Electric Power Generation

China can assist GCC members in geothermal electric power generation through several avenues, leveraging its expertise and technological advancements in renewable energy.

It is envisaged that Organic Rankine Cycle (ORC) technology will play a pivotal role in generating electricity from medium- to low-temperature geothermal sources in GCC countries. Power plants utilizing this technology aim to serve residential and commercial sectors as well as the oil and gas industry. The world's second oilfield-associated geothermal power station (400 kWe) was constructed in 2011 in the Huabei Oilfield in China (Aboud et al. 2021). The expected power generation capacity of this power station is 1.5 GWh per year, with an average annual oil production increase of 120,000 tons. It saves 4,100 tons of fuel annually and reduces CO_2 emissions by 26,000 tons annually.

Space Cooling

The demand for cooling in GCC countries has been rising, driven by their economic growth and elevated temperatures. Research suggests that 101 TWh of electricity is utilized for cooling in residences and 70 TWh in commercial establishments (Almasri, Rami, and Narayan 2021). This consumption equates to approximately 50% of the total yearly electricity usage in buildings, increasing to as much as 70% during periods of peak cooling demand. Consequently, in its strategic planning, district cooling and urban planning have been earmarked as two important facilitators (Aldubayan and Alsuwailem 2025). Cooling can be provided by GSHP systems or by using absorption chillers. GSHP systems are more suitable and efficient for districts with demand for both heating and cooling because low-temperature geothermal energy is easily obtainable. Absorption chillers are ideal for harnessing geothermal energy in districts with cooling demand, but only if medium-to-high geothermal energy can be accessed.

China has rapidly developed GSHP systems, most of which are for both cooling and heating, with the market growing at an average annual rate of over 20%. By the end of 2021, over 530 million m^2 were serviced by GSHP systems in China. GSHP systems provide heating and cooling to an area of 2.57 million square meter at Beijing's Daxing International Airport, and a sub-center of Beijing City has installations that offer heating and cooling to 3 million m^2 of floor space. Cooling utilizing medium-deep geothermal systems has been applied in southern China, where cooling demand dominates (Tian et al. 2020). The absorption chillers utilized the 70°C geothermal water to generate 9°C colder water for the AC cooling system in Guangdong Province.

Water Desalination

Geothermal energy can play an integral role in water desalination. When the low-temperature multiple-effect distillation method[4] is combined with geothermal energy, geothermal water can be heated by a heat exchanger to reach the required temperature for desalination. Using geothermal energy as the heat source for seawater desalination can provide constant heating to ensure the stability of thermal desalination and reverse osmosis processes.

Geothermal energy can also meet the continuous electricity demand of desalination plants. Geothermal energy is less affected by seasonal weather variations than other forms of renewable energy. For example, the typical temperature of the ground heat source in China's Hainan province ranges from 70°C to 90°C, which is ideal for low-temperature multiple-effect distillation. Ground heat sources with temperatures higher than 100°C can supply power for reverse osmosis. The mature technology for geothermal production, which involves extracting hot water from underground aquifers, can produce electricity and water economically. Its self-sufficiency in providing heat and, potentially, electricity makes it superior to other desalination methods.

Harnessing Geothermal Energy From Oil and Gas Assets

Geothermal energy can be generated alongside oil production by harvesting the heat from the large amount of water produced in the oil recovery process. For example, within the 4,000 m depth of China's petroleum mineral rights area, the estimated shallow geothermal energy is equivalent to 108 trillion tons of standard coal. In addition, 15 oil fields produce over 1 billion cubic meters of water annually, and their waste heat resources are estimated at nearly 1.8 million tons of standard coal equivalent. It is estimated that the primary heat storage and power generation power of China's Daqing, Liaohe, North China, Shengli, Zhongyuan, and Henan oilfields could reach 3,000 MW, and the geothermal resources within 10 km of major oil-producing regions in China are equivalent to 1.8 trillion tons of oil. Utilizing waste heat is essential to reduce costs and increase the efficiency of oil fields. In 2018, China produced approximately 190 million tons of crude oil. Because the water cut—the proportion of water in the total liquid extracted from oil wells—was around 90%, the total volume of water produced was about 1.7 billion tons. We argue that even if a modest temperature difference of 10°C is captured from this produced water, the recoverable waste heat could be equivalent to 2.4 million tons of standard coal. Redirecting this energy—such as for oil processing, trading operations, or transportation—could significantly reduce the reliance on natural gas, while lowering oil field emissions and overall costs.

On the other hand, many abandoned oil wells can also be reused and transformed into geothermal wells, reducing the risks and costs of geothermal energy development. Geothermal power can be generated from abandoned oil fields through nano-catalytic cracking technologies Geothermal power can be generated from abandoned oil fields by leveraging nano-catalytic cracking, which reduces the viscosity of the remaining crude oil and raises its temperature to enhance heat extraction. When combined with advanced thermal power generation technologies and integrated oil—geothermal cogeneration methods, these approaches offer new potential for energy recovery from depleted fields. Medium and deep geothermal energy can also be directly used for heating through hydrothermal geothermal heating technology.

Since China's National Energy Administration began promoting the use of produced water from oil fields for geothermal heating, major national oil companies have adopted this method. For example, CNPC has used geothermal energy to heat office buildings and support heat tracing for heavy oil production at the Liaohe Oilfield. Similarly, SINOPEC has utilized waste heat from produced water for heating purposes at the Shengli Oilfield.

Notes

1 1 zetta = 10^{21} or 1,000,000,000,000,000,000,000.
2 Permeability refers to the pathways used to move hydrothermal fluids through the rocks.
3 Coal-based heating is a conventional heating approach commonly used in northern China.

4 Multiple-effect distillation (MED) is the low-temperature thermal process of obtaining freshwater by recovering the vapor of boiling seawater in a progression of vessels (also called effects).

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15 Potential for China–GCC Collaboration on Critical Minerals

Dongmei Chen and Jianping Ge

Introduction

Critical minerals are essential inputs for clean energy technologies such as renewable power, nuclear power, electricity networks, electric vehicles, battery storage, and hydrogen. A typical electric vehicle requires six times the mineral input of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired plant of the same capacity (IEA 2021). Growing electrification in transportation, building, and industrial sectors is also shaping the infrastructure that the world economy has relied on. The energy transition from fossil fuels to clean energy is actually a shift from a fuel-intensive to a material-intensive economy (IEA 2021; IRENA 2023).

The concentration of mineral production in a small number of countries makes the supply chains relying on those minerals vulnerable not only to market power and logistical risks but also to geopolitically induced disruptions. Resource-rich countries are increasingly implementing state control policies to enhance the benefits of extraction and processing industries, while also taking steps to develop downstream sectors. Numerous mineral-consuming nations have prioritized supply chain diversification and friend-sharing options in their critical mineral strategies, along with measures to incentivize investment in local production, technology innovation, and material recycling. The differing strategies between major suppliers and major consumers have increased the complexities of the market. Moreover, heightening geopolitical tensions between the United States and China, and the rise of de-risking strategies in Western economies, have added uncertainties to the already tight market supply.

As the energy transition gathers pace in the Gulf Cooperation Council (GCC) countries and China, developing reliable, diversified, sustainable, and responsible supply chains for critical minerals and clean energy manufacturing becomes crucial for both sides. Overseas resource exploration and global market participation remain important for China, even though it boasts rich mineral resources and well-established manufacturing bases for clean energy technologies. The GCC states have recently started generating economic growth from mineral resource exploration and downstream product manufacturing. Enhancing China–GCC

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collaboration on mineral supply chains can help achieve the economic transition goals of both sides.

Minerals and Metals: State of Development in GCC and China

Mineral Resource Reserves

Historically the GCC has focused more on oil and gas resource extraction than metals and minerals. Only over 3% of the world's global mineral reserves are found in the GCC and less than 1% of the total global mineral exploration and extraction budget is invested in GCC countries (USGS 2019). The GCC has significant untapped potential for nonfuel mineral resource exploration, extraction, and processing.

Saudi Arabia's western Arabian Shield contains substantial precious and base minerals, such as gold, silver, aluminum, iron, copper, zinc, manganese, and chromium. The Arabian Shield also holds valuable minerals, such as tantalum and niobium. To date, over 48 minerals have been identified in the Kingdom, with at least 15 deemed commercially viable (Alqarout 2023). Following a reassessment in 2024, Saudi Arabia revised up its estimate of the value of the country's potential mineral reserves to $2.5 trillion, almost double the previous estimate made in 2016 (CNBC 2024).

Oman is well-endowed with natural mineral resources, concentrated mainly in its 700 kilometer (km) by 150 km mountain range, which offers an exposed ophiolite geological outcrop containing minerals such as copper, gold, silver, chromite, lead, nickel, manganese, and zinc. Other regions in the sultanate are blessed with deposits of dolomite, limestone, gypsum, silica, cobalt, marble, and iron. The country's main copper reserves, estimated at around 54.5 million tons, are located in the Sohar area of the Al Batinah region (Oxford Business Group 2020).

Large areas of the United Arab Emirates (UAE) are covered in Quaternary sediments, and the bedrock geology is well exposed in the Hajar mountains, the Musandam Peninsula of the eastern UAE, and along the southern side of the Arabian Gulf west of Abu Dhabi (Saibi et al. 2021). The country holds deposits of valuable metallic minerals including copper and gold, along with substantial bauxite reserves essential for aluminum production. Recent exploration efforts have also uncovered potential reserves of rare earth elements.

There is limited information on the reserves of minerals and metals in other GCC states. Given the size of their landmass, it is reasonable to assume Qatar, Bahrain, and Kuwait have small potential reserves.

In contrast with the GCC's early stage of mining exploration, China has matured into a major supplier of minerals and metals over the last decade. By 2022, the country had discovered 59 kinds of metallic minerals and 95 kinds of nonmetallic mineral reserves (China Ministry of Natural Resources 2022). China has the world's largest reserves of antimony, bauxite, molybdenum, rare earths, strontium, tin, titanium, and tungsten, as shown in Table 15.1. Recently, China has seen substantial growth in its production of lead, zinc, nickel, cobalt, lithium, beryllium, gallium, germanium, fluorite, and crystalline graphite.

Table 15.1 China's nonfuel minerals reserves

	Minerals	*Unit*	*China's Reserves*
1	Antimony	Million tons	0.64
2	Bauxite	Million tons	711
3	Chromite	Million tons	3.09
4	Cobalt	Million tons	0.14
5	Copper	Million tons	41
6	Gold	Thousand tons	2.964
7	Iron ore	Billion tons	16.12
8	Lead	Million tons	20.41
9	Lithium	Million tons	4.05
10	Manganese ore	Million tons	281.69
11	Molybdenum	Million tons	5.85
12	Nickel	Million tons	4.22
13	Platinum	Tons	87.69
14	Rare earths	Million tons	44
15	Silver	Thousand tons	71.783
16	Strontium	Million tons	24.64
17	Tin	Thousand tons	1,130
18	Titanium	Million tons	223.83
19	Tungsten	Million tons	2.95
20	Vanadium	Million tons	7.87
21	Zinc	Million tons	44.23

Source: China Ministry of Natural Resources (2023)

Mineral Production and Trade Flow

Low energy costs and industrial incentives have given the GCC's aluminum industry a strategic advantage. Five of the six GCC countries produce aluminum in smelters, but Saudi Arabia is the only GCC country to have the full value chain from bauxite mining to alumina refining and aluminum production. In 2022, the GCC's total aluminum production reached 6.13 million tons per annum, accounting for 4.35% of total global production. The UAE was the world's fifth largest producer of aluminum. It was also the first country to produce aluminum using solar power.

The GCC countries' significant infrastructure development and industrial growth over recent years has driven their demand for iron and steel. Saudi Arabia is the largest market and also the largest GCC producer of iron and steel, accounting for around 40% of the GCC's market share and 50% of its total production.

The GCC's copper production is distributed unevenly among the member states. Saudi Arabia's copper reserves in the Arabian Shield have a confirmed value of \$7 billion, and its estimated potential reserves of 26 million tons of copper could be worth up to \$222 billion (MIMR 2022). This resource potential has positioned Saudi Arabia as the GCC's largest producer of copper concentrate. It currently produces copper from mines at Jabal Sayid, Al Masana, and Al Amar, totaling 340 thousand tons per annum (ktpa). Its production output has increased steadily in recent years, rising from 36 ktpa (copper [Cu] content) in 2017 to 75 ktpa (Cu content) in 2022 (BGS 2024). The UAE has the strongest capacity for copper product manufacturing in the GCC. It has a continuous cast copper rod plant at the Fujairah Free Zone, with a capacity of 100 ktpa (USGS 2024). This made the UAE the world's largest exporter of copper wires (HS code 740811) in 2022, accounting for 15% of global total exports (World Bank 2023). It is also the GCC's largest exporter of copper and related articles.

In contrast to the GCC states, China has been a major player in the global critical minerals market for decades. China is one of the few countries in the world with diverse and abundant natural resources. China accounts for nearly 70% of global graphite extraction and 68% of all rare earths (IEA 2023a). It is also the world's largest producer of zinc, lead, and gold. However, many of its mineral resources have become depleted due to continued exploration and extraction over decades. Between 1998 and 2021, the reserve-production ratios of China's copper, tin, nickel, and rare earth fell by 64.69%, 61.43%, 74.77%, and 69.55%, respectively (Jin, Yu, and Wang 2022). China possesses significant mineral reserves; however, many are low-grade, which presents challenges due to their complex mineral compositions. An additional challenge is that the mineral deposits are scattered geographically. For example, China has 4.5 million tons of lithium reserves, or an estimated 14% of total global lithium reserves. The largest granitic pegmatite-type lithium deposit is located in Aba and Ganzi prefectures, Sichuan Province (Liu et al. 2017). However, poor transportation and geological constraints hinder the development of lithium resources in this area. The lepidolite content in lithium-rich Jiangxi and Qinghai provinces is quite low, leading to very high extraction costs. In the case of iron ore, only about 30% of China's resources meet the average grade quality. As a result, the industry faces challenges related to the complex processing of low-grade ore and the management of tailings generated during the process (Zhu et al. 2022).

China dominates the global refining capacity for critical minerals, controlling nearly 100% of graphite refining, 90% of rare earths, 74% of cobalt, 65% of lithium, 42% of copper, and 43% of nickel (IEA 2023a). Despite increased global efforts to diversify supply chains and advance minerals exploration, China will continue to be an important player in refined minerals. By 2030, China is expected to still be the foremost refiner of most metals globally, with a 46% share of copper refining, 57% of lithium, 74% of cobalt, 93% of graphite, and 77% of rare earths (IEA 2024a).

China's dominant role in global minerals processing and rising demand for minerals from its industrial manufacturing base has increased its reliance on mineral imports from overseas markets. China relies almost entirely on the Democratic Republic of Congo (DRC) for cobalt imports, over 80% of its nickel is imported from the Philippines, over 60% of its lithium is imported from Australia, and nearly 50% of its manganese is imported from South Africa (IEA 2023a). China produces half of the world's steel but heavily relies on imported ore, importing more than 80% of its total demand between 2015 and 2020, of which around three-fifths come from Australia and one-fifth from Brazil. While China is the world's largest producer of aluminum, its use of aluminum in electrical appliances, heat dissipation materials, and aviation also makes it the world's largest aluminum consumer. Over the past decade, it had an aluminum import dependence of around 50%, climbing as high as 60% in 2023 (World Bank 2023). Major sources of its bauxite imports include Guinea, Australia, and Indonesia. China has been the world's largest importer of copper ore since 2009, with over 50% of its imports coming from Chile and Peru.

Securing mineral supplies is no less important for China than it is for the GCC countries. Improving resource productivity and material recycling, increasing investment in domestic exploration, and diversifying global supplies of critical minerals are realistic strategies for both the GCC states and China.

Assessing Demand for Minerals and Metals in the Renewable Energy Transition

In this chapter, we use Saudi Arabia as a case study to illustrate the growth potential of mineral demand in the GCC to support the manufacture of renewable energy technologies. Compared to other GCC states, Saudi Arabia has the most developed policy frameworks to encourage renewable energy installation and local manufacturing. In 2019, it announced a target to install 58.7 gigawatts (GW) of renewable energy by 2030, comprising 40 GW of solar photovoltaics (PV) and 16 GW of wind. In 2021, it committed to producing 50% of its power from renewables by 2030 as part of its Nationally Determined Contribution to the Paris Agreement on climate change. More recently, Saudi Arabia's minister of energy announced plans to add 20 GW of renewables annually to reach 130 GW by 2030 (Saudi Gazette 2023). Accordingly, Saudi Arabia has developed policy roadmaps and identified key segments for the local manufacture of renewable technologies in the near, medium, and long term, to maximize the benefit from their deployment. We assume the new 130 GW target by 2030 will follow the same ratio of wind and solar PV deployment as the previous target announced in 2019. This would result in 35 GW of wind power, 89 GW of solar PV, and the remainder comprising other renewable technologies. By the end of 2023, Saudi Arabia installed 2.5 GW of solar PV and 400 megawatts (MW) of wind power (IRENA 2024).

China has achieved stunning growth in renewable energy development in the last two decades. By the end of 2023, its total installation of renewables reached more than 1.5 terawatts (TW), comprising 609 GW of solar and 441 GW of wind. China will likely achieve its 2030 national target for wind and solar (1,200 GW) six years ahead of schedule. In our assessment of mineral demand, we adopt the International Energy Agency's (IEA's) forecast from its World Energy Outlook (IEA 2023b) as a reference for China's wind and solar development. Under the IEA's Announced Pledges Scenario (APS), China's total installed capacity is estimated to be 946 GW of wind and 2,558 GW of solar PV by 2030.

In 2023, there were 8.1 million new electric vehicles (EVs) registered in China, representing a 35% increase relative to 2022 (IEA 2024b). The Chinese government has announced targets to achieve a 50% share of electric vehicle sales in key air pollution control regions and a 40% sales share nationwide by 2030. This would drive the stock of EVs[1] to 113 million by 2030 under the IEA's APS scenario (IEA 2024b). By the end of 2023, China had almost 22 million EVs on its roads.

Each renewable energy technology has different sub-technologies. To simplify the estimation of the demand for minerals and metals, this chapter adopted the assumptions and hypothesis of the sub-technology types, their market shares and mineral intensities from Valero et al. (2018). In the case of wind power, two types of wind turbines are considered, gearbox and direct drive, with market shares of 75% and 25%, respectively. In the case of solar PV, 85% of the market is dominated by crystalline technologies, with the rest comprising thin-film technologies, each sub-technology (copper indium gallium selenide [CIGS], cadmium telluride [CdTe], and amorphous silicon [a-Si]) having a 5% market share. The mineral intensity for light-duty EVs is directly obtained from Liang et al. (2022).

This chapter limits itself to providing an understanding of the magnitude of minerals and metals demand for manufacturing key clean energy products and identifies major gaps between local supply and estimated demand. Due to the constraints of research resources, we do not consider the expansion of electricity infrastructure required to support a low-carbon transition and the competing demand from other sectors such as construction and digital technologies.

Our assessment reveals that iron and steel, aluminum, silicon, copper, and silver are highly in demand in both China and Saudi Arabia. The copper demand for solar PV manufacturing is more than two times that needed for wind turbine manufacturing, while the majority of iron and steel demand is for wind turbine manufacturing.

Saudi Arabia wishes to become the region's manufacturing hub for clean energy products. Our preliminary assessment shows challenges in securing the minerals needed for wind turbine and solar product manufacturing if it relies on current local capacity. As discussed in the earlier section, in 2021, the production capacity of iron and steel in Saudi Arabia was more than 9.8 million tons per annum. This can satisfy the annual demand for wind turbine and solar PV manufacturing, which is expected to be 700 ktpa from 2024 to 2030 (Figure 15.1). However, the outlook is not so positive for other minerals and metals. Saudi Arabia has substantial reserves of around 26 million tons of copper, per the latest estimate made in 2023. From 2017 to 2021, it doubled its copper production from 36 ktpa to 76 ktpa. If Saudi Arabia's installation of renewables from 2024 to 2030 is as forecast, 75,000 tons of copper will be needed annually for wind turbine and solar PV products (Figure 15.1). The market would be more or less balanced if current copper production only serves the demand for wind turbine and solar PV products. However, given the wide use of copper in many other sectors involved in industrialization and urbanization, such as industrial equipment, machinery, electric systems, railways, ships, and building construction, the copper supply could become significantly constrained. Other minerals required for wind and solar PV, such as nickel, magnesium, cadmium, gallium, indium, and rare earths are rarely produced in Saudi Arabia.

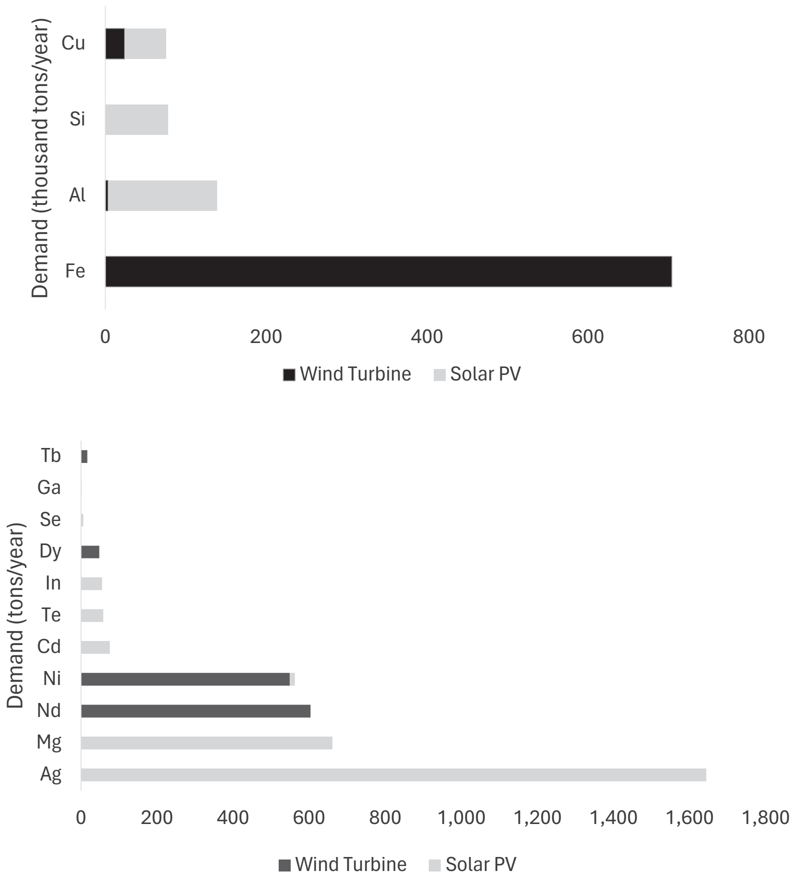

Figure 15.1 Annual estimated mineral demand for wind turbine and solar PV in Saudi Arabia from 2023 to 2030.

Source: Authors' calculation.

To meet its ambition for the integration of wind and solar power, and EVs by 2030, China's demand for minerals would increase nearly fourfold for copper, 4.5-fold for aluminum, and around threefold for iron and steel from their 2023 levels. In addition to basic metals, China's demand for nickel, cobalt, and lithium would also increase more than fourfold from today's level, as shown in Figure 15.2. While China's demand for these minerals has increased, their domestic supply is declining.

This chapter only considers the clean energy products that would be used in China's domestic market. If we include clean energy products made in China but

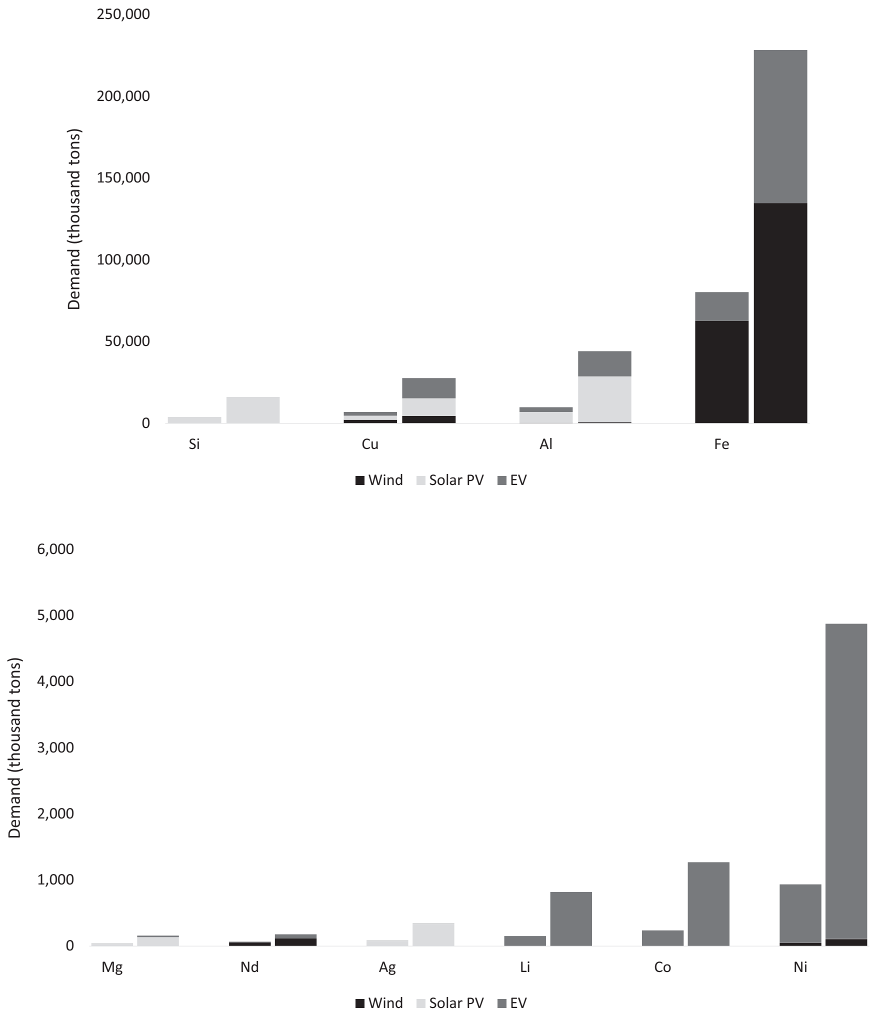

Figure 15.2 Cumulative mineral demand for wind turbine, solar PV, and EVs in China.

Source: Authors' calculation

Note: The left-hand-side bars show demand in 2023; the right-hand-side bars show demand by 2030.

exported to overseas markets, the demand for minerals could be much higher. Given its high dependence on mineral imports, as discussed in the earlier section, any interruptions to this supply would have a negative impact on China's progress in its energy transition and its role in the global market for clean energy products.

Great Game Change in the GCC

New Mining Strategy and Market Reforms

Saudi Arabia has undertaken a number of structural reforms in its mining sector. It updated and approved a new Mining Investment Law in 2020 to encourage foreign investment and international collaboration. Saudi Arabia launched a $182 million mineral exploration incentive program in 2024 to reduce investment risk in green field projects and junior miners. The Saudi Industrial Development Fund complements this initiative by providing up to 75% of capital expenditure (CAPEX) for mining ventures (MIMR 2022). All these efforts have helped incentivize mining activities in Saudi Arabia. The number of building material quarry licenses rose from 158 in 2021 to 538 in 2023, and exploration licenses jumped from 58 to 258 during the same period (Arab News 2024).

Similar to Saudi Arabia, Oman has also updated its policy and regulatory frameworks to drive new economic growth from its mining sector. It adopted a new Mineral Wealth Law in 2019. The law strengthened the responsibility of the Public Authority for Mining and established specific regulations for bidding, bid evaluation, awarding, and contracting. To support and leverage private investment in the mining sector, Oman established Minerals Development Oman (MDO), a partnership between the State General Reserve Fund (50%), Oman Investment Fund (25%), and Oman National Investments Development Company (25%). As of 2019, MDO had invested in six major projects, including joint ventures with Mawarid Mining and state-owned Oman Mining Company (Oxford Business Group 2020).

The UAE aims to increase its mining sector's contribution to its non-oil GDP to 5% by 2030. In its first mineral wealth strategy launched in 2023, detailed targets included increasing the number of companies in its mining and manufacturing industries, boosting the mining sector's added value, increasing relevant exports, substituting mining extraction industry imports valued at $558 million with local products, and declaring six geological reserves (Arabian Business 2023). The UAE does not have a unified law regulating mining activities. With the new Commercial Companies Law of 2022, foreign investors and entrepreneurs are permitted to have up to 100% ownership in almost all sectors except activities deemed to be strategic (UNCTAD 2022). This marks a positive step forward for the UAE mining sector's growth.

Compared with these three big players, the rest of the GCC states have made relatively slow progress on policy and project development. Qatar enacted a new foreign investment law in 2019 to ease restrictions on foreign investment in most sectors. Its Natural Resource Law established a licensing system governing all upstream activities, including natural gas, petroleum, and mineral resources. Neither Bahrain nor Kuwait has legislation nor policy incentives to encourage mining investment. The mining activities are regulated through laws established for general business, for example, the Commercial Companies Law in Bahrain and the Environment Law in Kuwait.

A Regional Approach to Integrated Value Chains

Given their unique strategic locations for international trade and logistics, low-cost advantages for manufacturing, and ambitious plans for clean energy transitions, the GCC countries led by Saudi Arabia and the UAE aim to build a mining, processing, and manufacturing hub in the region for low-carbon technologies. This presents an opportunity for the GCC member states to align their resources, plans, and policies to enable integrated mining value chains.

The GCC Mineral Resources Committee (MRC) was recently established to enhance cooperation and streamline operations among the GCC countries. The committee has started to play a role in coordinating the mining strategies and sharing best practices among the member states. It has also explored creating a regional map highlighting mineral investment potential (OneArabia 2024).

In parallel with the GCC's MRC, a supra-regional partnership encompassing Africa, Western Asia, and Central Asia has been under development since 2022, when Saudi Arabia started organizing and promoting the Future Minerals Forum (FMF) in Riyadh. Several initiatives have been identified and discussed in the annual FMF gatherings. These include developing regional strategies for critical minerals to meet the rising demand for minerals used in the manufacture of low-carbon technologies; developing a regional sustainability framework for better deployment of environmental, social, and governance (ESG) standards; developing regional centers of excellence for knowledge sharing, data transparency, and technology transfer; and establishing regional integrated value chains for green metals that could build on local mining and processing advantages.

Cooperation between the GCC states and countries in Africa and Asia has grown, with the aim of facilitating investment in resources-rich countries and establishing a regional hub for mineral supply chains. In 2024, Saudi Arabia signed memorandums of understanding (MOUs) with Egypt, Russia, Morocco, and the DRC for the exploration and processing of mineral resources under supra-regional partnership. It partnered with Japan on investments in Africa and other resource-rich nations, with a focus on securing nickel, lithium, and other minerals for the production of EV batteries. The UAE has long been a major investor in infrastructure and logistics in Africa. Its shift to mining investment has been swift. In December 2023, Zambia's government announced that Abu Dhabi-based International Resources Holding (IRH) had bought a 51% stake in Mopani Copper Mines for $1.1 billion. Shortly after this deal, IRH announced its interest in Lubambe Mine and other mining projects in Zambia, and concluded a $1.9 billion mining partnership in the DRC.

Rising Influence on the Global Market

The GCC has the desire and potential to play a vital role in the global minerals market, given its success in building influence in the global oil and gas market. This has motivated countries like Saudi Arabia, the UAE, and Oman to actively engage with international investors and mining majors.

The primary interest of the GCC countries is to seek international funding, technologies, and experiences that are most needed at the early stage of mining development. With capacity established at home, from upstream exploration and extraction to downstream product manufacturing, the GCC countries can grow their weight in the global minerals market.

Diversifying the supply chain for critical minerals is a critical strategy for the GCC, as it has been for major economies like the United States (U.S.) and the European Union (EU). For example, to support the acquisition of international mining assets, Saudi Arabia launched a mining fund, Manara Minerals. It is a joint venture, with 51% owned by Ma'aden and 49% owned by the Public Investment Fund. This fund is prepared to deploy more than $15 billion of capital for investments over the coming years as suitable opportunities emerge in the international market (Arab News 2023a).

In addition, the Gulf States have shown strong interest in establishing exchange platforms for mineral and metal commodities. Saudi Arabia is exploring the launch of a new commodities trading platform for battery materials, including graphite and rare earths (Arab News 2023b). The UAE announced the launch of its Critical Minerals Trade Finance Fund and the new TradeFlow Metals digital platform in a joint effort with the Singapore-based Fintech-powered fund management firm TradeFlow Capital Management (Open Mineral 2023). However, due to the limited volume of minerals trading in the Gulf and the dominance of the London Metal Exchange and Chicago Mercantile Exchange in lithium and cobalt trading, there are still many uncertainties surrounding the development of the Gulf States' plans.

Global Mineral Geopolitics and China's Strategies

Minerals in the Context of Geopolitical Risks

Minerals and metals are vulnerable to supply disruptions due to their heavy geographical concentration both at the mining and processing stages. Scaling up production requires large investments, environmental permitting and community consultations that can delay a supply response to price changes. Meanwhile, setting up processing capacity comes with challenges such as regulation restrictions, infrastructure investment, and access to minerals and technology. As a result, about 45% of global mineral production is dedicated to trade, and roughly half of the world's countries rely on three or fewer exporting countries for their imports of minerals (IMF 2023).

On the supply side, resource nationalism has been on the rise and numerous governments have increased their control over national mineral resources to enhance the benefits they derive from the extracting and processing industries. In 2021, the risk index of resource nationalism increased significantly for 34 countries, covering most resource-rich countries in Africa, Latin America, and Asia (Verisk Maplecroft 2021). The policies being pursued by these countries include strengthening their tax regimes, increasing royalty rates, renegotiating existing contracts, and placing restrictions on foreign investments and exports. Mineral producers are increasingly taking steps to build downstream sectors to maximize the benefits of their mineral resources. Countries endowed with critical mineral resources, such as cobalt-rich DRC, nickel major Indonesia, and the lithium triangle which includes Chile, Argentina, and Bolivia, are now geopolitical hotspots. They find themselves at the forefront of a global contest for resource access and control as these minerals are not evenly distributed across the globe.

A case in point is Indonesia. It is the world's largest producer of nickel, the eighth-largest producer of copper, and it also has significant reserves of bauxite, cobalt, and tin. The country has placed progressively stringent restrictions on the export of mineral ores to promote domestic processing, including in January 2020 announcing a ban on all nickel ore exports. To complement these defensive policies, Indonesia is also developing special economic zones and providing tax holidays for investors in onshore processing facilities to encourage the development of downstream industries such as battery manufacturing (Gupta 2023). This strategy has brought significant investment to nickel mining and smelter operations in Indonesia. Unsurprisingly, the surge in the country's nickel production has boosted the global supply and intensified competition in the global nickel market.

On the demand side, ensuring security of supply and gaining competitive advantages in clean energy industries have become key priorities for major consumer countries. They have started to diversify their supply chains as part of their critical mineral strategies, along with measures to incentivize investment in local production, technology innovation, and material recycling. For example, the EU's Critical Raw Materials Act targets 10 % domestic mineral extraction and 40% local processing by 2030, and the U.S. Inflation Reduction Act provides tax credits for critical mineral production, mandating the domestic sourcing, or "friend-shoring," of the critical minerals used in EV batteries as a condition for subsidies.

The divergent strategies and outlooks of major supplier and consumer countries have added complexity to international relations. Resource-rich nations are increasingly diversifying their partnerships with major consumer economies to secure more favorable terms for resource extraction, technology transfer, infrastructure investment, and the development of domestic mining and downstream industries (Abrar 2024). For instance, several African countries have established successful collaborations with China, the U.S., the EU, Australia, and Japan across the value chains of cobalt, lithium, nickel, rare earth elements, and other base metals.

Meanwhile, major consumer countries are establishing new frameworks and alliances to safeguard access to these vital resources. The Minerals Security Partnership (MSP), comprising Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, Norway, Sweden, South Korea, the EU, the United Kingdom, and the United States, seeks to reduce reliance on geographically concentrated supply chains and diversify access to responsibly sourced critical minerals. Additionally, the Group of Seven (G7) is developing a "buyers' club" to enhance coordination on mineral procurement (IRENA 2023).

These developments could accelerate regional cooperation and economic integration. However, growing competition among global powers for influence over strategic mineral resources also risks intensifying geopolitical tensions and introducing new layers of complexity to international economic relations.

With geopolitical tensions on the rise, especially since Russia's invasion of Ukraine and the escalating economic rivalry between the U.S. and China, the global economy is at risk of splitting into different blocs. Restrictions are increasingly being placed on the flow of trade, capital, technology, and workers to safeguard national interests. The International Monetary Fund's World Economy Outlook (IMF 2023) notes that if there is no trade between two hypothetical blocs (China–Russia+ and U.S.–Europe+), the minerals and metals market would experience higher volatility and uncertainty. In the China–Russia+ bloc, the price of mined minerals, including cobalt, lithium, copper, and nickel, would rise substantially. At the same time, the U.S.–Europe+ bloc could experience similar increases in the prices of refined minerals. Moreover, commodity producers would have powerful incentives to switch allegiances, given the potentially significant differences in commodity prices among blocs. This would induce more supply shocks, volatility, and uncertainty in commodity markets, challenging fiscal, monetary, and financial stability (IMF 2023).

China's Strategies for Mineral Resources

China is and will continue to be a key player in global critical mineral production, processing, and supply chains. Supportive policy frameworks, established production networks, proximity to suppliers, and a large pool of skilled labor have established the fundamentals for the cost competitiveness of Chinese minerals industries. Open access and international trade integration are also essential for its growth. China has gradually developed its technologies and expertise in mining, processing, and refining by participating in the global trade system. Being the global manufacturing hub, China has also benefited from importing mineral resources and exporting downstream industrial products.

China began to formalize the institutional administration of its mineral resources in 1982, with the establishment of the Ministry of Geology and Mineral Resources. In 1986, China released its first Mineral Resources Law, which established the exploration and mining permits system and defined the major role of state-owned enterprises (SOEs) in mining activities. China established the Ministry of Land and Resources in 1998 to ensure better resource allocation, address the environmental issues stemming from resource exploitation, and reduce the gap between supply and demand. A series of new policies and guidelines were formulated during this period, with a focus on improving the recovery rate of mining and processing. The new Ministry of Natural Resources, established in 2018, holds the most consolidated authority over all types of natural resources. It has deepened the reform of the mining rights transfer system, significantly decentralized the mining rights approval authority, and established a national royalty system for mineral resources.

Over the past decades, China's strategic focus on mineral resources has become more balanced, expanding higher value-added downstream sectors while ensuring supply security and environmental protection. This is very different from its earlier strategies focused on boosting mine production and encouraging material exports.

In its first minerals strategy, known as the National Plan for Mineral Resources (2008–2015), the Chinese government focused on increasing its domestic reserves and output of coal, oil, natural gas, and coalbed methane. It prioritized increasing the domestic supply of minerals while improving geological environment protection and land reclamation. The strategy mentioned international cooperation, but it mainly focused on increasing foreign investment utilization and introducing advanced foreign mining technology and management experience.

Due to concerns about potential shortages and supply chain risks, in its second minerals strategy, the National Plan for Mineral Resources (2016–2020), China increased the state's control over critical minerals. For the first time, the Chinese government released a catalog of 24 strategic minerals, which were selected for their perceived importance to China's economy, defense, and the advancement of its high-tech industries. The minerals essential for major green technologies, such as lithium, copper, nickel, cobalt, graphite, zinc, chromium, and rare earths, are all included in the list (NDRC 2016). The plan continues China's robust industrial policy, with even stronger commitments to promoting the development of strategic and emerging industries.

Domestic supply is fundamental to China's minerals security. The National Plan for Mineral Resources (2016–2020) aims to increase its reserves and output of strategic minerals by enhancing the financial support of geological prospecting and prioritizing exploration activities in 297 key mining areas. Preferential policies are provided to projects with the potential to improve the efficient use and preservation of minerals, upgrade industrial structures, advance technology innovation, and promote green transition. Further efforts are needed to build a risk warning and reporting system and stimulate China's mining rights trading market.

International cooperation is also an integral element of China's minerals security strategy. The government expects to retain its participation of foreign capital and expertise in domestic mineral resources exploration. However, its move toward protecting and optimizing domestic critical minerals has limited foreign participation in some strategically sensitive sectors. For example, in 2021, the government announced that foreign entities were prohibited from investing in exploration, mining, and the beneficiation of rare earths, radioactive minerals, and tungsten. Meanwhile, overseas resource exploration and market participation have become increasingly important in China's mineral strategy. The country has a desire to build a joint investment model under the Belt and Road Initiative that promotes full supply chain cooperation from exploration to extraction, refining, processing, and manufacturing. This cooperation targets not only mining activities but also essential infrastructure, including electricity, waterways, and ports. China also aims to build international forums, promote policy dialogue, and strengthen technological cooperation in the field of geosciences.

Given the complexity of geopolitical rivalry and developed economies' increasing concerns about China's influence on critical minerals, it becomes harder for

Chinese companies to invest and get involved in developed economies' mining activities. Three Chinese companies, Sinomine (Hong Kong) Rare Metals Resources, Chengze Lithium International, and Zangge Mining Investment (Chengdu), were ordered to sell their holdings in three Canadian mining companies in November 2022 after the Canadian government tightened its rules on foreign investments in the critical minerals sector (The Guardian 2022). Five international companies linked to China, including the Yuxiao Fund, were ordered to offload shares in Australian rare earth mines in June 2024, per the advice from the Foreign Investment Review Board of Australia (Australian Broadcasting Corporation 2024). Moreover, the final U.S. regulations on clean vehicle credits, released in May 2024, stipulate that manufacturers need to demonstrate compliance with the Foreign Entity of Concern (FEOC) restriction for access to subsidies and tax breaks provided by the U.S. Inflation Reduction Act (IRA). A business will be classified as an FEOC if it is incorporated, headquartered, or performs relevant activities in China, Russia, North Korea or Iran. The regulations also classify a business as an FEOC if 25% or more of its board seats, voting rights, or equity interests are cumulatively held by the governments of any of these countries (CRS 2024).

Consequently, more Chinese firms are looking for critical minerals' development opportunities in emerging markets. In 2023, Chinese overseas investment in mining and metals under the BRI framework reached $19.4 billion, the highest level in a decade and a remarkable 160% increase from 2022 (Nedopil 2024). Chinese companies have been strongly engaged in Africa, Bolivia and Chile in Latin America, and Indonesia. Chinese battery players such as CATL, Sunwoda Electronic and EVE Energy have formed joint ventures with nickel miners and refinery businesses in Indonesia (S&P Global 2023). In Argentina, Ganfeng Lithium has invested in five lithium projects in the Salta and Jujuy provinces (Ganfeng 2023), and Zijin Mining is developing the Tres Quebradas lithium project (Zijin Mining 2022). In Africa, Chinese companies have been more actively investing in the mining sector. Some $7.8 billion of Chinese investment has gone into a copper mine project in Botswana, cobalt and lithium mines in Namibia, Zambia, and Zimbabwe, and copper and cobalt projects in the DRC (Reuters 2024). However, it is worth noting that while Chinese investments in Africa are significant, Chinese mining companies represent only 8% of Africa's total mining output (Egyin 2024).

Prospects of a China–GCC Collaboration

China's leading position in new energy product manufacturing and mineral supply chains faces growing risks from escalating geopolitical tensions and increasing trade barriers in the U.S. and EU. To navigate this shifting global landscape, China must adapt its trade and investment strategies by diversifying overseas investments and aligning more closely with local market demands and production capacities. Meanwhile, to achieve a robust and extensive economic transition, the GCC states need to increase their efforts to develop investor-focused legislation and regulatory frameworks. This may include ensuring the fiscal sustainability of public spending, strengthening private-sector participation, developing backward and forward linkages across sectors, and implementing comprehensive labor market reforms. In addition, to support export diversification, GCC countries should work to expand their regional and global influence by leveraging and scaling their domestic industrial infrastructure.

Looking to the future, China and the GCC states can benefit from jointly advancing theoretical and technological innovation in mineral resource exploration, assessing the criticality of mineral resources amid shifting market and technological dynamics, and promoting material recycling and substitution. More strategically, China and the GCC can enhance their collaboration on supra-regional partnership initiatives, coordinate financial and technical resources, and stimulate supportive trade and investment regimes for mineral exploration, extraction, processing, and downstream production. The unlocked resource and investment potential in Africa, Western Asia, and Central Asia could be critical for both China and the GCC to realize their economic transition, national security, and climate action ambitions.

Promoting Technology Development and Knowledge Sharing

Strengthening knowledge exchange between China and the GCC states could help to improve intermediate processing and manufacturing capabilities, promote material recycling and substitutions, and advance technology development related to the processing of low-grade ores, residual mineral deposits, by-product elements, and tailings. Through joint research programs focusing on deep exploration and new technologies, China and the GCC can benefit from an improved understanding of the formation, distribution, and evolution of mineral deposits. The development of geochemical exploration methods could improve the analysis of micro-scale element concentrations and states, even at the nanometer or molecular scale. The use of new technologies such as big data and artificial intelligence could lead to a scientific and technological revolution in mineral resource science. Advancing theoretical and technological innovation in mineral resource exploration can give decision makers the latest assessment of the criticality of mineral resources.

Integrating Mineral Supply Chains

Over the recent years, China–GCC collaboration in strengthening supply chains for clean energy product manufacturing has gained significant momentum. To build on this progress, GCC states should implement targeted policies and regulatory frameworks that incentivize business investment, boost labor productivity, and support the development of competitive local suppliers. At the same time, Chinese companies can enhance their engagement by deepening technological partnerships with GCC counterparts, establishing local industrial presence, and prioritizing strategic investments across the mineral supply chain. By fostering localized industry collaboration, both Chinese and GCC firms can better position themselves to meet regional and global clean energy market demands.

Enhancing Regional Cooperation Platforms

Based on the supra-regional partnership proposed by Saudi Arabia at the FMF of 2022, along with regional collaboration forums such as the China–Arab Forum and GCC–China Summit, China and the GCC states can deepen the coordination of their financial and technical resources. Sustained collaboration can foster enabling trade and investment environment for minerals exploration, extraction, processing, and downstream production across Africa, Western Asia, and Central Asia. A structured regional cooperation framework would facilitate data sharing, policy dialogue and joint initiatives. Such a framework could include: (i) the collection and exchange of data on critical mineral production and markets; (ii) enhanced understanding of supply-demand dynamics and identification of supply chain opportunities; (iii) mapping of key critical minerals and downstream producers; (iv) promotion of knowledge transfer and capacity building; and (v) joint efforts to shape global regulatory standards and advance best practices in safety, stakeholder engagement, and environmental sustainability.

Note

1 Electric vehicles here include battery electric and plug-in hybrid electric passenger light-duty vehicles but exclude two or three wheelers.

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16 Innovative Digital Energy Trajectories and Benefits

China–GCC Partnership for a Sustainable Future

Sulayman Al-Qudsi, Shaikha Al-Fulaij, and Weiquan Wang

Introduction

Since the late twentieth century, digitalization has driven global technological transformation, reshaping economies and industries. The rise of the internet, big data, artificial intelligence (AI), and blockchain has revolutionized productivity and efficiency. Rapid advancements in computing power, particularly in AI and deep learning, now enable the efficient processing of vast datasets, generating actionable insights across industries (Hilbert 2020).

In the energy sector, digitalization[1] refers to the integration of digital technologies across generation, distribution, storage, and consumption to optimize efficiency and promote sustainability through data analytics and smart technology (Alturki et al. 2022). This transformation began in the 1960s with analog control systems for power plant supervision. The twenty-first century introduced the "smart grid," an advanced electrical system that integrates automation, real-time monitoring, and digital communication to enhance efficiency, reliability, and renewable energy integration (IEA 2020).

Since 2022, AI and machine learning have accelerated the transformation of the energy sector. Smart meters now provide real-time consumption data, enabling dynamic grid management to balance supply and demand while minimizing outages. Additionally, distributed energy resources (DERs)—such as renewables, battery storage, and electric vehicles—are becoming increasingly integrated into the grid, enhancing flexibility and sustainability (Paige 2024).

This chapter is organized into seven sections. Following this introduction, the first section provides an economic overview of the GCC and China, comparing their economic structures, labor skills, and capital wealth to contextualize their distinct development paths and their implications for digital energy collaboration. The authors, then, explore GCC–China digital energy cooperation, reviewing the GCC's digital energy adoption, key policy initiatives, and strategic investments, including sovereign wealth fund allocations in China. After that, the authors examine China's digital energy landscape, highlighting advancements in AI-driven energy efficiency, renewable integration, digital twins, grid reliability, and robotics. The authors then assess current and future collaboration opportunities, offering quantitative insights into potential synergies. Finally, the chapter culminates by

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summarizing the key findings and outlining the implications for future GCC–China digital energy cooperation.

China–GCC Digital Trade, Infrastructure, and Capital Wealth

This section reviews recent trends in commodity and digital trade, as well as infrastructural developments in China and the GCC, comparing their sources of capital wealth.

China–GCC Digital Trade and Infrastructure

International trade has long been a driver of economic growth, and China's rise as a global manufacturing leader exemplifies this principle. However, trade dynamics are rapidly shifting toward digital trade, which is experiencing exponential growth and redefining global commerce.

In 2023, China recorded an 8.5% year-on-year increase in digitally delivered services trade, reaching 2.72 trillion yuan (387.5 billion United States dollars [US$]). Additionally, cross-border e-commerce surged by 15.3%, amounting to 2.37 trillion yuan (Feifei 2024). These figures highlight China's strategic pivot toward digital trade, complementing its traditional manufacturing dominance.

This expansion in e-commerce has had a ripple effect on the GCC economies. Historically reliant on hydrocarbon exports, the GCC is now actively expanding its digital trade footprint by investing in logistics, emerging technologies, and non-resource-based sectors. The GCC e-commerce market size reached USD 507.2 billion in 2024. Looking forward, IMARC Group expects the market to reach USD 2,020.6 billion by 2033, exhibiting a growth rate (CAGR) of 15.3% during 2025–2033 (IMARC, 2025).

To strengthen its digital infrastructure, Saudi Arabia is integrating smart living hubs with logistics centers as part of its $500 billion Neom project designed to foster international trade in information and communications technology (ICT). Meanwhile, the UAE dominates the regional e-commerce market, generating $60 billion annually through platforms like Noon and Amazon. The UAE's digital trade is projected to grow by 12.3% between 2023 and 2028, positioning it as the fastest-growing digital trade hub in the GCC (Arab News 2024).

The GCC's digital transformation is evident in its increasing participation in high-value services such as cloud computing, fintech, and AI-driven logistics, aligning with its economic diversification goals. The UAE's Digital Economy Strategy aims to double the contribution of digital trade to its gross domestic product (GDP) by 2031, emphasizing innovation and global connectivity. Similarly, Qatar's National Vision 2030 seeks to establish the country as a leading hub for digital services and global trade integration.

Globally, digital trade is expanding far faster than traditional trade. According to the OECD (2023), digital trade accounts for $5 trillion, or 25%, of global trade. This rapid expansion has led to digital trade regulations being incorporated into 50% of all regional trade agreements (OECD 2023). Unlike the European Union (EU) and the United States (U.S.), China maintains an open trade policy on high-tech exports, reinforcing its role as a dominant player in the digital trade ecosystem.

The China–GCC digital trade relationship was formalized with the China–GCC Free Trade Agreement (FTA) in 2004 and strengthened through the Bilateral Economic Relations Forum in 2010 (Shidhani and Baig 2024). These agreements have since evolved into strategic alliances encompassing trade, technology, and infrastructure development.

Strategic Collaboration in Digital Trade and Infrastructure

China's engagement with the GCC extends beyond bilateral trade, fostering strategic collaboration in technology, digital trade, and infrastructure. China's open trade policies on high-tech goods provide a distinct advantage for GCC nations. For instance, despite geopolitical tensions, most GCC countries have partnered with Huawei to develop 5G network infrastructure, underscoring China's central role in the GCC's digital transformation (Zweiri, Al Qawasmi, and James 2023).

China's growing influence in the GCC digital economy is closely tied to its Belt and Road Initiative (BRI), which seeks to strengthen cross-border connectivity and enhance economic integration along major trade corridors. This initiative aligns with the GCC's national development strategies, including Saudi Vision 2030, UAE Centennial 2071, and Qatar National Vision 2030, which emphasize economic diversification through trade, logistics, and industrial growth.

Key Examples of China–GCC Collaboration

Infrastructure development is a cornerstone of China–GCC collaboration. For instance, Chinese firms are playing a significant role in the construction of Neom, Saudi Arabia's $500 billion futuristic city powered by renewable energy and equipped with advanced digital infrastructure (NEOM 2024). In the UAE, the Smart Dubai initiative leverages Chinese expertise in AI, the Internet of Things (IoT), and blockchain technologies to enhance urban governance and citizen services.

The Digital Silk Road (DSR) forms a pivotal component of the BRI, integrating AI and other advanced technologies to strengthen digital infrastructure and foster innovation. Aligned with the GCC's vision of economic diversification, the DSR further supports innovation and smart city development, positioning the bloc as a strategic hub for digital transformation and commerce, capitalizing on its prime geographic location (Zheng 2024).

Capital Wealth Comparison Between China and the GCC

There are notable differences between China and the GCC in terms of their economic structures, governance models, and resource bases. Demographically, China's population is 20 times that of the GCC. Additionally, China's GDP is 12 times the combined GDP of the GCC economies. More subtle differences arise in the composition of capital wealth. According to the World Bank, an economy's overall capital wealth consists of four components: (1) natural capital (oil, gas reserves, forests, scenery, etc.); (2) human capital (a highly skilled, productive, and efficient labor force); (3) produced physical capital, such as machinery, buildings, office or warehouse supplies, vehicles, and computers; and (4) net foreign assets (World Bank 2021).

In 2018, human capital accounted for about 73% of China's capital wealth. In contrast, the GCC lags significantly behind in this regard: human capital represents 23% of all capital wealth in Saudi Arabia, 14% in Kuwait, 22% in Qatar, and between 39% and 43% in the UAE, Bahrain, and 45% in Oman. The most significant contributors to the GCC economies are natural resources (natural capital), which account for 46% in Kuwait, 47% in Saudi Arabia, 34% in Qatar, 31% in Oman, and 27% in the UAE. By contrast, the contribution of natural capital is only 4% in China (World Bank 2021). These differences lead to variations in worker productivity, innovation, and output diversity.

Disparities in capital wealth are further exacerbated by differences in digital workforce skills, presenting challenges for GCC economies while also creating opportunities for collaboration with China. It is estimated that 45% of jobs in the Middle East and North Africa (MENA) region could be automated, which is close to the global average of 50%. This reality has prompted GCC nations to revamp their education systems, aiming for global competitiveness through digital learning and upskilling programs. An example is Kuwait's Abdullah Al Salem University (ASU), which emphasizes AI and robotics research to meet the evolving job market's needs and acknowledges international competition among universities in swiftly adopting a skills-first approach (Al-Qudsi et al. 2023; Katz, Madgavkar, and Schaninger 2022).

China maintains its position as a global leader in digital skills, as shown in Figure 16.1. Collaboration between the GCC and China therefore holds significant potential to accelerate the upskilling of the GCC's labor forces, enabling them to meet the demands of enhanced energy sector efficiency (Al-Qudsi et al. forthcoming).

The GCC–China Digital Energy Sector

This section reviews the evolution of the digital economy, focusing on the digital energy sector in the GCC and China.

GCC Digital Economy Size and Penetration

The GCC countries have experienced substantial economic growth in recent years, with the collective economic output projected to reach approximately $1.5 trillion by 2024. Digital growth, averaging 12–15% annually, is driven by GCC governments' efforts to diversify their economies away from fossil fuel dependence toward digital innovation. Currently, the digital economy is estimated at $300 billion, representing about 20% of the combined GDP of the GCC countries (TRENDS 2023). This shift toward digitalization aligns with global trends and addresses the region's

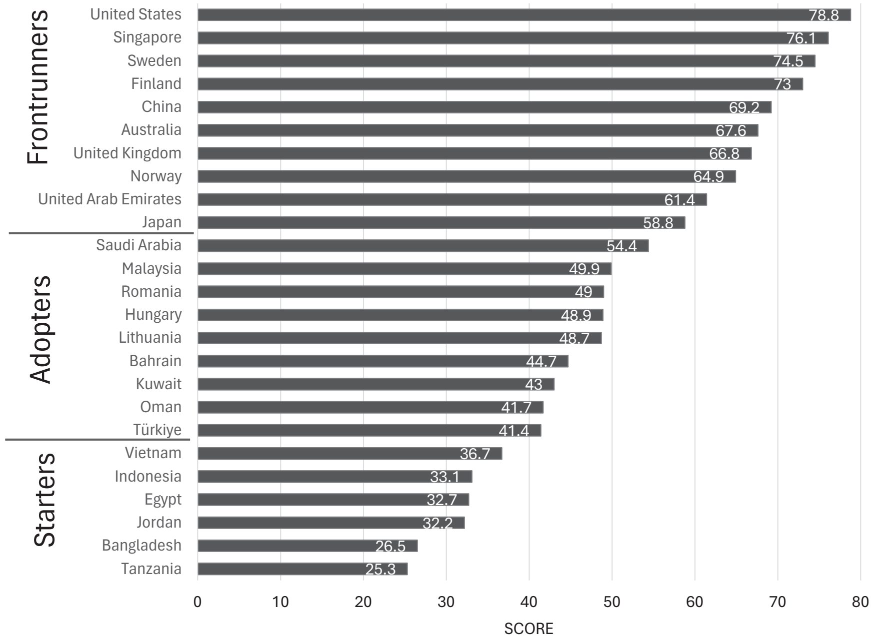

Figure 16.1 Global Digital Index 2024 for the GCC, China, and selected countries.

Source: HUAWEI and IDC 2024.

need to create jobs for a growing, highly educated population (CAICT 2024). The digitalization agenda is firmly embedded in national development strategies, including Saudi Arabia's Vision 2030, the UAE's Digital Strategy 2021, Qatar's National Vision 2030, and Kuwait's Vision 2035.

Key drivers of the GCC's economic growth include the e-commerce sector, which contributes roughly $60 billion annually, led by platforms such as Amazon.ae, Noon, and Souq.com (now Amazon.sa). These platforms have revolutionized online retail and cross-border e-commerce across the GCC.

Digital twins are among the most recent technological breakthroughs gaining popularity in the GCC, transforming various sectors, particularly energy. This technology enables the creation of virtual replicas of physical entities, facilitating real-time monitoring, operations, and optimization of assets. For example, digital twins can monitor pipeline integrity, estimate the duration until equipment failure, duration, and refine maintenance schedules, all of which help minimize costs and enhance managerial decision-making. Companies like Aramco have adopted this technology to maximize efficiency while minimizing downtime, giving them a competitive advantage in the global energy market (McKinsey & Company 2022).

E-commerce revenues alone reached $30 billion in 2023, reflecting an annual growth rate of 12% since 2018. However, comprehensive data on the GCC digital economy from 2005 to 2023 remains limited. Over the past 15 years, the GCC's digital infrastructure and technology sectors have experienced transformative growth through substantial investments.

Digital services increasingly contribute to the GCC's digital economy, adding approximately $50 billion. Key areas include cloud computing, digital marketing, online education, and healthcare services. The fintech sector, valued at $40 billion, has also seen robust growth, driven by innovations in mobile payments (e.g., STC Pay and Beam Wallet), digital banking, blockchain technology, and online lending platforms. Furthermore, investments in digital infrastructure, including the rollout of 5G networks, have accelerated the GCC's digital transformation (Al-Qudsi et al. 2022; Saxena 2023).

Saudi Arabia's cloud computing market is projected to reach $2.5 billion by 2026, reflecting a CAGR of 25%. Initiatives like Saudi Arabia's Neom project leverage artificial intelligence and machine learning to optimize energy systems, exemplifying the GCC countries' commitment to integrating advanced technologies into infrastructure development (MIT Sloan Management 2024). Blockchain technology facilitates the verification of the origin and sustainability of hydrocarbon exports, addressing the increasing demand for environmentally responsible products in global markets. In the energy transition, technologies like digital twins and blockchain are instrumental in integrating renewable energy sources. Digital twins enable the simulation of energy production, optimizing efficiency, while blockchain supports energy credit trading, promoting accountability and transparency. These advancements align with the GCC's goals of economic growth and environmental sustainability (Almutairi et al. 2022).

Corporate adoption of technological innovation is a critical driver of digital technology diffusion in the GCC. Leading companies like SABIC and RasGas have embraced robotics, automation, and AI-driven analytics to improve efficiency and reduce costs. SABIC's five-year digital transformation strategy aims to modernize core business areas, including manufacturing and finance (SABIC 2024; Saxena 2023).

GCC Digital Economy: Growth, Innovation, and Digital Energy Transformation

The GCC economies are undergoing a major digital transformation, with collective economic output projected to reach $1.5 trillion by 2024. This shift is driven by government-led diversification efforts, moving away from hydrocarbon dependency and toward technology-driven economies. In 2020, the GCC digital economy contributed nearly 12.2% of its GDP (El-Darwiche et al. 2021). By 2024, the GCC's digital economy increased to approximately $300 billion, accounting for 20% of its GDP (TRENDS 2023). Digital energy is a critical pillar of this transformation, as discussed below.

Saudi Arabia is at the forefront of digital energy transformation, integrating AI and big data analytics into energy management. The Saudi Electricity Company (SEC) has implemented AI-enhanced energy storage, using machine learning models to predict energy demand fluctuations, ensuring efficient grid management and reducing reliance on fossil fuels. The rollout of nine million smart meters in Saudi Arabia has enabled real-time energy tracking, demand response, and dynamic pricing models. Additionally, the Sakaka Solar Power Plant utilizes AI-based solar forecasting systems to optimize energy output and enhance grid reliability (Ben Youssef 2024).

The UAE has made significant strides in blockchain-based energy trading and IoT-driven energy efficiency projects. Dubai and Abu Dhabi are pioneering smart grid innovations by integrating digital energy storage and decentralized energy generation. The Dubai Electricity and Water Authority (DEWA) has launched a peer-to-peer energy trading platform that allows businesses and households to sell excess solar energy through blockchain smart contracts. Meanwhile, the Abu Dhabi National Oil Company (ADNOC) has incorporated real-time IoT sensors into its power infrastructure to enhance efficiency in energy production and grid monitoring. The UAE's AI-driven demand response system helps optimize electricity distribution, reducing energy waste in high-consumption areas (Reuters 2024).

Bahrain's Electricity and Water Authority (EWA) employs machine learning algorithms to predict peak demand and dynamically allocate power supply, thereby improving grid stability. Bahrain has also initiated pilot projects utilizing blockchain for peer-to-peer renewable energy trading, enabling consumers to securely trade excess solar power. The national rollout of advanced metering infrastructure (AMI) allows for real-time tracking of energy consumption, enhancing energy efficiency for both industrial and residential sectors (Ben Youssef 2024; Lea 2024). Oman is advancing its renewable energy expansion by integrating digital technologies, leveraging AI, IoT, and digital twins to optimize solar and wind energy production. Petroleum Development Oman (PDO) is using AI-powered digital twin models to simulate and improve solar energy generation efficiency. The Dhofar Wind Farm, developed in partnership with Masdar, employs real-time IoT sensors to monitor turbine performance and optimize wind energy capture. The Oman Power and Water Procurement Company (OPWP) is investing in AI-driven battery storage management to stabilize intermittent renewable energy supply (Moore 2025).

Kuwait is significantly investing in smart energy infrastructure, AI-driven load forecasting, and blockchain-enabled energy transactions. The Ministry of Electricity, Water, and Renewable Energy is deploying machine learning algorithms to predict energy demand, ensuring efficient grid operations. Kuwait is also implementing automated grid control systems that allow for real-time adjustments in energy distribution based on demand fluctuations. The integration of solar farms and energy storage solutions into its power grid is supported by IoT-enabled monitoring systems (Moore 2025).

Qatar is modernizing its liquefied natural gas (LNG) sector through AI-driven efficiency analytics and smart power management. QatarEnergy is utilizing AI-powered digital twins to monitor LNG processing and optimize fuel efficiency, reducing energy costs. Msheireb Downtown Doha, one of the world's first fully smart city districts, incorporates AI and blockchain for sustainable energy optimization. Additionally, Qatar's energy grid has been upgraded with 5G-connected sensors, improving real-time energy tracking and predictive maintenance (El-Darwiche et al. 2021).

Blockchain technology plays a crucial role in securing energy transactions, ensuring supply chain transparency, and facilitating renewable energy trading. Saudi Arabia's Blockchain-Based Renewable Energy Registry ensures the authenticity of green energy credits for investors (IMARC 2024).

Infrastructure Investments and Collaboration With China

The collaboration between China and the GCC is underscored by strategic infrastructure investments, particularly in digital technologies. A notable example is Huawei's pivotal role in deploying 5G technology across the GCC, enabling high-speed digital services and fostering the growth of e-commerce and other digital industries. China's Digital Silk Road also complements the GCC's broader objectives by enhancing trade route connectivity and integrating GCC economies into global digital trade ecosystems.

GCC Digital Energy Sector Transformation

The GCC's oil and gas sector is rapidly integrating AI, automation, blockchain, and IoT to enhance efficiency, reduce costs, and optimize production. Key players—including Saudi Aramco, RasGas, KPC, Taqa, Bapco, and Borouge—are at the forefront of this digital shift. Aramco's digital twin technology enables real-time monitoring and predictive maintenance of oil rigs and refineries, reducing downtime by 20% and improving resource recovery. Its Fourth Industrial Revolution Center in Dhahran integrates machine learning and IoT sensors to enhance safety and efficiency (Aramco 2022). In RasGas, automated LNG control systems have boosted operational efficiency by 15% (Tawteen n.d.).

Kuwait Petroleum Corporation (KPC) has invested $2 billion over five years in local manufacturing and technology transfer, thereby reducing its reliance on imports (Alanba 2025). Kuwait National Petroleum Company (KNPC) utilizes Digital Operator Rounds (DOR) and the Maximo Oil and Gas Enterprise Solution for real-time data analysis, fault detection, and integrated operations, enhancing efficiency and lowering maintenance costs (AIU 2024; KNPC 2019). Oman's Taqa digital platform streamlines bidding, inspections, and license management, attracting investors and optimizing investment cycles, particularly in gypsum mining (Global Gypsum Staff 2024). In Bahrain, Bapco employs data analytics, IoT, and blockchain to optimize oil extraction, refining, and distribution, while the EWA's smart grids and advanced metering infrastructure enhance renewable energy integration (Borealis and Borouge 2022).

SABIC uses robotics to improve hazardous material handling, increasing production efficiency by 15%, while smart sensors reduce its costs by 10% (SABIC 2024). In the UAE, collaborative robots in packaging lines have reduced cycle times by 25%, optimizing operations (Borealis and Borouge 2022). Furthermore, the integration of machine learning in ethylene and polyethylene plants has led to a 12% annual reduction in their energy consumption (Rupa et al. 2024).

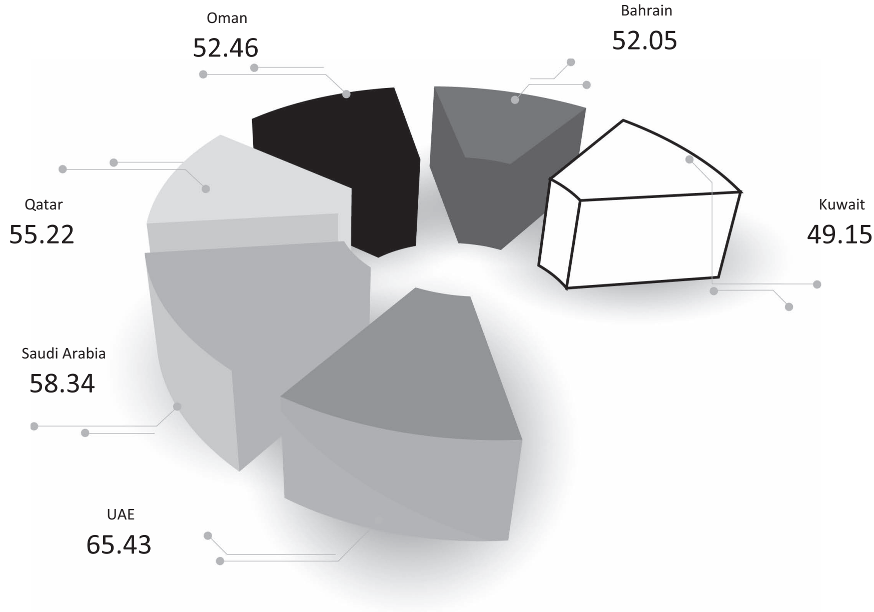

Figure 16.2 GCC E-Performance Index 2023.

Source: Authors' analysis based on ZAWYA (2024).

GCC Digitalization Progress and Challenges

Progress in Digital Economy Development

The GCC countries have made good progress in digitalization, as evidenced by the E-Performance Index. This index evaluates various dimensions of digital performance, including digital infrastructure, e-governance, economic diversification through technology, and digital inclusion, reflecting the GCC's commitment to advancing its digital economy (Figure 16.2).

Challenges in Digital Transformation

Initiatives such as Alibaba Cloud's Riyadh project emphasize advanced cloud services and security features to enhance Saudi Arabia's competitiveness in digital services (Alwetaid 2023; Center3 2012; Alibaba Cloud n.d.).

Initiatives to Address Digital Skills Gaps

To combat labor skill shortages and prepare for future demand, GCC countries have implemented various programs. These include the Saudi National Program for Coders, which aims to train 100,000 coders by 2028. In workforce training, the Saudi Technical and Vocational Training Corporation offers e-training and

English programs to develop the practical and technical skills necessary for the digital economy. The UAE has launched the ambitious One Million Arab Coders Program to expand digital literacy, alongside the National Program for Artificial Intelligence, which focuses on preparing the workforce for AI integration. Additionally, the UAE Centennial Plan 2071 is a long-term initiative aimed at equipping future generations with the skills and knowledge needed for sustainability and global competitiveness (UAE Government Portal n.d.; IMF 2024b). Qatar promotes science, technology, engineering and mathematics (STEM) education and skills training to cultivate a digitally proficient workforce and has established technology clusters to attract and retain tech talent. Other GCC countries, including Kuwait, Oman, and Bahrain, have introduced similar digital training programs to align with broader economic diversification goals (Alwetaid 2023; Center3 2012; Alibaba Cloud n.d.; Digital Dialogue 2024; El Zein 2022).

- ***Stimulating GCC–China Digital Energy Cooperation***

China–GCC digital energy collaboration aims to access new markets and promote trade in digital energy technologies, thereby enhancing mutual economic growth. This collaboration will likely attract investment through joint venture capital, foreign direct investment (FDI), the establishment of local digital industries, and the diversification of local economies (IRENA 2023; IEA 2017). Moreover, the China–GCC partnership is likely to accelerate innovation and research and development (R&D) while fostering the adoption of AI, the IoT, and blockchain technology applications. Specifically, this collaboration will create joint R&D initiatives and promote rapid innovation in renewable energy, storage, and grid technologies, benefiting all participating nations (Global Smart Buildings News 2023; Kavanaugh, Ramachandran, and Mosier 2024).

- ***Advancing Digital Energy Technologies and Economic Reforms in the GCC***

GCC reform policies emphasize fiscal prudence, structural transformation, and an expanded role for the private sector. For instance, Aramco has implemented advanced digital twins and AI systems to predict its maintenance needs and enhance the efficiency of its oil and gas operations. Furthermore, Saudi Arabia's liberalization of foreign ownership rules has attracted global investors, spurring innovation in energy derivatives and smart grid technologies.

Likewise, the UAE has implemented significant innovation-driven reforms to attract foreign investment and foster innovation, particularly in the digital and clean energy sectors. Amendments allowing 100% foreign business ownership outside of free zones have bolstered investor confidence and participation.

- ***Digital Energy Partnerships and Flows of Fresh Investments***

Chinese and GCC companies have formed joint ventures and partnerships that leverage the strengths and resources of both entities, enhancing their pursuit of mutual interests and capitalizing on emerging opportunities in the energy sector (Wyman 2021). From 2020 to Q3 2023, the GCC has cumulatively invested over $800 billion in industrial, energy, and resource sectors, with a clear focus on fostering innovation, complex product development, and climate and economic sustainability (Burrell and Jahani 2024).

China has committed to reaching a carbon peak by 2030 and carbon neutrality by 2060. In 2023, it added as much solar photovoltaic (PV) capacity as the world did in 2022, while its wind energy capacity grew by 66%. China also leads globally in nuclear power additions, further solidifying its position as a clean energy leader. To support these efforts, China has developed various green financial instruments, including green loans, bonds, and equity funds, to dynamically channel capital into clean energy projects (IEA 2024; He 2024).

, The GCC's sovereign wealth funds (SWFs) are also increasingly investing in technology and digital energy projects. For instance, the Oman Investment Authority (OIA) committed $150 million to ewpartners, a Saudi- and China-based investment firm, to stimulate the local and regional economy. The OIA's involvement in ewpartners' Technology Innovation Fund II, a $1 billion private equity fund, underscores the region's focus on advancing technology investments. The increased use of the U.S. dollar as a geopolitical tool, combined with potential sanctions and asset freezes, has prompted GCC countries to de-risk their exposure to Western financial systems. The risks associated with the SWIFT payment system have also encouraged these countries to seek alternative multilateral payment platforms, potentially emerging through collaborations between BRICS+ and the GCC (Saidi 2024).

The Saudi Public Investment Fund (PIF) invested in the Telecommunication Towers Company, acquiring 51% of its shares and forming one of the largest telecom tower companies globally. PIF is also developing a tech firm, projected to be worth $40 billion with assistance from Andreessen Horowitz, aimed at positioning Saudi Arabia to be at the forefront of AI development. PIF also started Alat, a firm that plans to transform Saudi Arabia into a capital for electronics and advanced industries, partnering with SoftBank and Dahua Technology to create AI manufacturing-based industries. In 2023, the fund concluded six memorandum of understanding (MOUs) totaling $50 billion with leading Chinese financial institutions such as the Agricultural Bank of China, Bank of China, and China Construction Bank. Such collaborations between the GCC and China focus on enhancing infrastructure and developing technological capabilities. Similarly, the OIA has committed $150 million to a technology innovation fund with Chinese partners to foster economic diversification (Creative Mind Management Consultancy 2024).

- **Green Energy and Research-Educational Partnerships**

China's expertise in green financial instruments, such as green loans and bonds, supports clean energy investments. The GCC benefits from partnerships like ADNOC's $15 billion low-carbon initiatives and the UAE's Barakah nuclear facility, which reduces CO_2 emissions by 22 million tons annually (IEA 2024).

China–GCC collaboration extends to the education and research sectors, including university partnerships. These include projects with Peking University and King Abdulaziz University focused on joint research, particularly in renewable energy, artificial intelligence, and environmental sustainability. Moreover, Tsinghua University, renowned for its engineering and technology programs, has partnered with Qatar University to foster research in energy systems, smart grid technology, and AI. Shanghai Jiao Tong University has collaborated with Kuwait University to establish *engineering*, *digital* transformation, and *urban planning* programs. The Beijing Institute of Technology and UAE University have developed joint initiatives in robotics, *machine* learning, and *cybersecurity* (Arab News 2022; Burrell and Jahani 2024). These partnerships enhance the collaboration between China and the GCC.

Digital Energy in China

In China, key trends and measures standardized in the 14th Five-Year Plan aim to further improve energy resource consumption (ERC) metrics. Consumption is targeted to decrease by an impressive 13.4% to 14.2%, which would be a remarkable achievement for the economy. Opportunities are arising for even more significant improvements in energy intensity reduction, which is currently three times that of other OECD countries and 1.5 times greater than the world average (Liu, Liu, and You 2021; Energy Foundation 2022).

According to the International Monetary Fund (IMF), China is “on track to peak carbon emissions before 2030,” with renewable energy developments significantly contributing to the containment of emissions growth (International Monetary Fund 2024a, 36).

Climate targets are being formulated at all levels of government, including state-owned enterprises (SOEs). As the world’s largest deployer of renewable energy, China accounts for over half of all new renewable capacity globally, consistently surpassing its renewable capacity targets set in recent five-year plans (IEA 2023). Given the success of renewable deployment, authorities have appropriately shifted toward a focus on electricity consumption targets.

Table 16.1 China’s digital economy growth (2005–2023)

Year	*Digital economy size (trillion yuan)*	*Exchange rate*	*Digital economy size (billion dollars)*	*Share of GDP (%)*
2005	1.0	0.12202	122.02	5.5
2010	4.0	0.14770	590.79	10.0
2015	18.6	0.15916	2960.34	21.6
2020	39.2	0.14490	5679.96	38.6
2021	45.5	0.15501	7052.86	39.8
2022	50.2	0.14855	7457.32	41.5
2023	54.0	0.14126	7628.29	43.0

Sources: Huaxia (2022); Xinhua (2023); Thomala (2024); Macrotrends (2024)

As noted by Thomala (2024), the Chinese digital economy continues to experience robust growth, expanding annually at a rate of 10%–12%. A significant driver of this expansion is the e-commerce sector, valued at over $2.5 trillion. This boom is attributed to a confluence of factors, including government policy and support, infrastructure investments, innovation and technology adoption, and consumer market dynamics (Sources: Huaxia (2022); Xinhua (2023); Thomala (2024); Macrotrends (2024)).

- **Government Policy and Support**

The Chinese government is accelerating the digital economy through strategic policies and investments. Initiatives such as “Internet Plus,” “Made in China 2025,” and “Digital China” promote digital transformation, particularly in the energy sector. These frameworks support advancements in AI, quantum computing, and biotechnology. China fosters research, development, and innovation by aligning policy with investment and expanding globally. Educational and vocational reforms are preparing a digitally skilled workforce, further driving the digitalization of the energy sector. Simultaneously, Chinese tech giants are expanding internationally, enhancing innovation and growth through global partnerships and investments (The National Energy Administration 2023).

- **Digital Adoption, Innovation, and Digital Infrastructure**

The telecommunications and IT industries play a crucial role, adding approximately $1.5 trillion to the economy through advancements in 5G, the IoT, and investments in digital infrastructure. The fintech sector, valued at $1.2 trillion, is driven by digital banking and mobile payment platforms like Alipay and WeChat Pay, alongside innovations in blockchain technology. Investments in 5G and data centers further reinforce this vibrant digital economy.

The WEF estimates that China’s artificial intelligence (AI) industry is large and growing fast: it now exceeds $70 billion and has cultivated over 4,300 companies that have contributed to a continuous stream of breakthroughs. As well, WEF explicates that China aims to boost related sectors to $1.4 trillion in value by 2030 and the core AI industry to $140 billion by 2030 (Word Economic Forum 2025).

- **Consumer Behavior and Readiness**

High internet penetration and a growing middle class have accelerated the adoption of digital commerce, social media, and online services. The digital entertainment sector, valued at $20 billion, exemplifies this growth with advancements in online streaming, gaming, and virtual reality (VR). Platforms like Alibaba and JD.com are pivotal in digital commerce, supported by widespread digital payment systems. Additionally, digital services valued at $1.8 trillion—including cloud computing and software development—are crucial to China’s dynamic digital economy landscape (Banerjee 2024).

Policy Frameworks for Digital Advancement in China's Energy and Industrial Sectors

Chinese digital policies aim to extend energy data sharing throughout the industry for data that does not require high security. This will be achieved through a rights regime regulating data ownership, exchange, marketing, and distribution. These activities aim to harness advanced technologies to improve resource allocation within the economy and enhance the efficiency of renewable energy resources, promoting a regime with unimpeded access to energy information to achieve the structural and functional transformation of the energy sector (Energy Foundation 2022).

China's green manufacturing industries are supported by the Made in China 2025 policy, which aims to promote green technology and establish China as a powerhouse of high-tech production. Enabled by digitalization, the 14th Five-Year Plan (2021–2025) goes even further by calling for the establishment of ultramodern green industries, with a vision of achieving an energy intensity reduction of about 20% and a carbon intensity of economic output ratio of approximately 13.5% by 2025 ("BloombergNEF" n.d.; Yan 2024; Woetzel and Kejun 2017; Statista 2024).

China's development of electric cars, electric batteries, and other components is another promising path in the digital energy economy. Total vehicle production is expected to reach 26 million units by 2030, slightly higher than in 2023, with 60% being new energy vehicles, aligning with the target penetration rate set by Chinese authorities. The installed capacity of wind and solar energy increased from 3.1% of the total generating capacity in 2010 to 36% in 2023. The 2030 target of 1,200 gigawatts (GW) of wind and solar capacity set out in the 14th Five-Year Plan is likely to be achieved by the end of 2024. It is anticipated that a total of 1,800 GW of wind and solar capacity will be installed by 2030, making up about 45% of total generation capacity (IMF 2024a).

Quantifying the Collaboration Benefits: Baseline Rudimentary Estimates

This section quantifies the potential benefits of GCC–China digital energy collaboration. Following the literature, we estimate the benefits and dividends of digital energy collaboration between the GCC and China, involving both tangible and intangible metrics. These metrics capture economic, technological, environmental, and strategic benefits derived from joint projects and technological integration (Williams et al. 2012; Zusman et al. 2021; Quitzow et al. 2019).

Rudimentary Estimates of the Digital Energy Collaboration Benefits

Table 16.2, column 4, and the interpretation given in column 5 offer ballpark estimates of the expected benefits from China–GCC digital energy collaboration based on the aforementioned assumptions and quantifiable components.

The estimated benefits shown in Table 16.2 indicate that the GCC–China digital energy partnership is set to enhance efficiency, investment, and job creation,

Table 16.2 Types of digital energy collaboration and associated benefits

Collaboration area	*Impact measure*	*Quantification method*	*Estimated impact*	*Interpretation*
Energy efficiency gains	15% reduction in energy consumption	Baseline GCC energy consumption: 1,000 TWh	savings of 150 TWh annually; $12 billion in direct savings Multiplier: $18 billion added value	Efficiency improvements enable significant cost reductions and enhance energy security, creating 120,000 jobs.
Renewable energy deployment	20 GW additional renewable capacity	Capital investment: $2 million per MW	$40 billion investment; 80% growth in capacity Multiplier: $60 billion added value	Increased renewable capacity aligns with sustainability goals and creates 180,000 jobs.
FDI in digital energy	$10 billion in new investments	20% growth from $50 billion baseline	$10 billion direct investment Multiplier: $20 billion added value	FDI fosters innovation, capacity building, and job creation, generating 100,000 jobs.
Grid reliability improvement	10% reduction in grid downtime	Current downtime costs: $15 billion annually	$1.5 billion in savings Multiplier: $3 billion added value	Reduced downtime enhances reliability and creates 30,000 jobs in grid management and cybersecurity.
Digital energy services growth	25% market growth	Baseline market value: $20 billion	$5 billion growth in market size Multiplier: $10 billion added value	Expanding markets for AI and blockchain applications create 80,000 jobs in digital services.
Adoption of digital twins and AI	15% operational savings	Baseline operational cost: $50 billion	$7.5 billion in cost savings Multiplier: $11.25 billion added value	Digital twins and AI optimize operations, unlocking 50,000 jobs in advanced technology roles.
Total economic impact	Direct and multiplier-driven impacts	Aggregating all components	Direct Economic Value: $76 billion Total Value: $198 billion	Collaboration boosts economic growth, fosters innovation, and strengthens competitiveness across sectors.
Jobs created	Across all sectors	Calculated from energy efficiency, renewables, etc.	Estimated 560,000 jobs created	Employment spans diverse sectors, supporting skills development and long-term economic sustainability.

Sources: Authors' estimations based on the literature and digital GCC–China energy projects.

driving $198 billion in economic impact while reinforcing the GCC's leadership in sustainable energy. The derived benefits are anchored on the following approach:

A 15% reduction in energy consumption (150 TWh) results in $12 billion in direct savings, along with an $18 billion multiplier effect. This efficiency boost is expected to create 120,000 jobs in energy auditing, advanced manufacturing, and infrastructure optimization, thereby strengthening energy security and economic resilience (IMF 2024a).

- The GCC's renewable capacity is expected to increase by 20 GW, an 80% rise from the current 25 GW, driving $40 billion in capital investment. With a 1.5x multiplier effect, the sector would generate an additional $60 billion, creating 180,000 jobs in construction, operations, and maintenance (IEA 2023).
- An anticipated $10 billion increase in FDI, a 20% rise from the $50 billion baseline, would accelerate technology transfer and innovation. With a 2x multiplier, this would contribute an additional $20 billion in added value, generating 100,000 jobs in clean energy, AI, and digital manufacturing (Alhmoud et al. 2024).
- GCC grid downtime costs are expected to decline by 10%, resulting in annual savings of $1.5 billion. A 2x economic multiplier would raise the total impact to $3 billion, adding 30,000 jobs in grid management, cybersecurity, and smart energy solutions (IMF 2024a; Ran Bi et al. 2025).
- The digital energy services sector is expected to expand by 25%, adding $5 billion to its $20 billion baseline. AI-driven energy management and blockchain-based trading platforms are expected to fuel this growth, with a 2x multiplier boosting the economic impact to $10 billion and creating 80,000 jobs in technology and digital infrastructure (IEA 2023).
- The adoption of AI and digital twin technologies is expected to reduce operational costs by 15%, saving $7.5 billion. A 1.5x multiplier effect would elevate the impact to $11.25 billion, generating 50,000 jobs in data science, AI development, and operational efficiency (Alhmoud et al. 2024).
- The total potential economic impact is as follows: direct value, $76 billion; multiplier-driven value, $122 billion. This would make the total impact $198 billion, with approximately 560,000 jobs created. Therefore, digital energy collaboration would solidify the GCC's role as a global hub for digital energy transformation and sustainability.

Conclusion

China is a global leader in digital energy research, programs, investments, and policy applications. Its digital economy represents approximately 43% of its overall economy and continues to grow rapidly. It is a contender in digital trade, with imports and exports of digitally delivered services rising 8.5% year on year to 2.72 trillion yuan (roughly $387.5 billion) in 2023.

The digital economy in the GCC is also expanding, currently estimated at 20% of the bloc's GDP, with Saudi Arabia leading in digitalized sectors. Breakthrough technologies, such as digital twins, have been widely adopted, enabling the real-time monitoring, simulation, and optimization of assets and processes, particularly in the energy sector. The region's ambitions for infrastructure modernization align well with China's expertise in large-scale construction and technology integration. Smart cities like Neom, a $500 billion renewable energy-powered city, and Smart Dubai exemplify key areas of GCC–China collaboration.

Potential collaboration areas between the GCC and China include smart grid technologies, renewable energy projects, and joint ventures in green hydrogen and battery storage. Infrastructure collaboration is another promising avenue, exemplified by projects like the GCC Railway, a 2,177-kilometer network linking GCC countries. Based on estimates, the collective impact of GCC–China digital energy collaboration could be significant, with a direct economic value of $76 billion, a multiplier-driven added value of $122 billion, and a total economic impact of $198 billion. Additionally, approximately 560,000 jobs could be created across multiple sectors.

Digital trade between China and the GCC has also thrived, with initiatives such as Riyadh's Alibaba Cloud project boosting competitiveness in digital services. Chinese companies like JinkoSolar and LONGi Green Energy contribute to GCC projects, including Dubai's Mohammed bin Rashid Al Maktoum Solar Park. University partnerships further foster energy research and patent collaboration, as exemplified by Peking University's collaboration with King Abdulaziz University on renewable energy and AI projects.

Despite these opportunities, the collaboration faces challenges, including resistance from the U.S. and the West, which introduces geopolitical and economic uncertainties. Financial sanctions and the monopolistic power of the SWIFT system hinder smooth international capital transfers. Institutional issues, such as inclusivity and resource allocation, also play a role in determining the success of collaboration efforts. Strengthening inclusive institutions focused on education, productivity, and technological advances will enhance the mutual benefits, while extractive institutions may hinder progress.

Strategic initiatives should be considered to further solidify collaboration. Developing a joint digital industrial park modeled after the China-Singapore Suzhou Industrial Park could serve as a hub for innovation and cooperation. Establishing energy research and patent-sharing mechanisms, such as joint R&D initiatives in renewable energy and AI, would accelerate technological advancements. Strengthening cultural and technological exchanges will also be crucial in building resilient partnerships and mitigating external pressures. By implementing these strategic proposals, GCC–China collaboration can continue to expand and generate long-term economic and technological benefits.

Note

1 It is crucial to distinguish between digitization and digitalization. Digitization refers to converting information from physical or analog form into digital format (e.g., turning a Word document into a PDF). Digitalization, on the other hand, builds on digitization by using digital data and technologies to improve operations, innovate business models, and enhance customer engagement (Alsuwailem and Henni 2022).

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Index

Pages in *italics* refer to figures and pages in **bold** refer to tables.