CLIMATE INVESTMENT IN CHINA AND THE UNITED STATES: A COMPARISON OF MONETARY AND MARKET TECHNOLOGY DRIVERS

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Executive Summary

1. China and the United States, the world's two largest carbon emitters, have seen expeditious investment growth in renewable energy and climate-related industries.

2. However, different monetary and market-based technology conditions have led to varied strengths and weaknesses in promoting climate investment.

3. China's climate-related investment has been largely driven by central authorities' top-down approach to promoting renewable energy and emission cutting technologies.

4. Long-term monetary and economic conditions in the two countries – high savings, low interest rates, inequality and sectoral savings shifts, and growth in money supply – have promoted both highly speculative investments as well as more positive, climate-friendly investments.

5. These conditions provide widely varying but strong opportunities for the two countries to accelerate climate investments to achieve aggressive mitigation targets.

6. In China, a large and competitive manufacturing sector combined with active policymaking has helped ensure a collapse in prices for many kinds of clean energy equipment, helping to foster a renaissance in clean energy in both China and the United States.

7. The rise of renewable energy in the United States came from a roughly constant supply of hydroelectricity, and a rapid increase in wind and solar electrical production due to steeply falling wind and solar costs.

8. Another key, if counterintuitive, transformation in US energy-related emissions has come from the "shale revolution" in Pennsylvania, Ohio, Texas and the sparsely populated "Great Plains" states.

9. The two countries need to continue climate dialogue and energy cooperation to better understand each other's stances and jointly explore pathways to net zero carbon footprints.

CLIMATE INVESTMENT IN CHINA AND THE UNITED STATES: A COMPARISON OF MONETARY AND MARKET TECHNOLOGY DRIVERS

Richard YARROW & CHEN Gang*

Monetary and Financial Drivers in the United States

1.1 Much of the world in the 21st century has experienced the unusual conditions of substantial savings imbalances and persistent growth in money supply relative to economic activity, while developed economies have seen years of low consumer price inflation that, until recently, has often fallen below estimates by major central banks. These trends have been called "secular stagnation", "Japanisation", or a "global savings glut", terms that describe similar underlying phenomena.[1] While each of these circumstances may characterise a particular economy, the trends have impacted every economy including climate investments in China and the United States.

1.2 Long-term monetary and economic conditions in the United States – high savings, low growth, low inflation, low interest rates and investment yields, inequality and sectoral savings shifts, and growth in money supply – have promoted both highly speculative investments and more positive, climate-friendly investments.

1.3 Though US federal debt has served for decades as the world's most important safe investment, yields have fallen extremely low. Inflation-indexed yields on 10-year Treasury securities were negative from 2011 to 2013, remained almost entirely

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1 Lawrence Summers, "Secular Stagnation and Macroeconomic Policy", IMF Economic Review 66 (2018); Ben Bernanke, "Why are interest rates so low, part 3: The Global Savings Glut", Brookings Institution, 1 April 2015; "Yes, We Are Probably All Japanese Now", https://www.europarl.europa.eu/cmsdata/186940/PIIE_FINAL-original.pdf, accessed 24 May 2022.

below 1% from 2013 to 2021 and have been negative since 2020 as of May 2022.[2] Nominal yields on 30-year securities fell below 5% in 2006 and around 2.9% by April 2022, whereas the US urban consumer price index increased by 8.5% in the 12 months up to March 2022.[3] Investors in US debt thus could expect mediocre returns or outright depreciation in the value of their investments.

1.4 Therefore, in the last 20 years the United States has seen a rise in funds held by investment firms searching for higher yields. One outcome has been the dramatic rise in investments in highly speculative cryptocurrencies and non-fungible tokens by investors ranging from large finance firms[4] and nation-states[5] to lower-income private individuals,[6] despite uncertain or unreliable technological infrastructure underlying these investments,[7] significant fraud rates[8] and usually no essential underlying yields to the investments.

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2 "Market Yield on U.S. Treasury Securities at 10-Year Constant Maturity, Inflation-Indexed (DFII10)", https://fred.stlouisfed.org/series/DFII10, accessed 8 May 2022.

3 "H.15 Selected Interest Rates", https://www.federalreserve.gov/releases/h15/, accessed 9 May 2022; "Consumer Price Index - March 2022", https://www.bls.gov/news.release/pdf/cpi.pdf, accessed 24 May 2022.

4 Hugh Son, "JPMorgan, led by bitcoin skeptic Jamie Dimon, quietly unveils access to a half-dozen crypto funds", CNBC, 5 August 2021; Ray Dalio's comment that "I wouldn't mind losing about 80% of" the value of his firm's bitcoin holdings -- conjuring the very image of an enormously speculative investment, in Ray Dalio, "What I Think of Bitcoin", Bridgewater Research & Insights, 28 January 2021.

5 Marc Frank, "Cuba approves cryptocurrency services, requires central bank license", Reuters, 28 April 2022; Alina Carare et al, "El Salvador's Comeback Constrained by Increased Risks", *IMF Country Focus*, 16 February 2022; Ryan Browne, "Central African Republic becomes second country to adopt bitcoin as legal tender", CNBC, 28 April 2022.

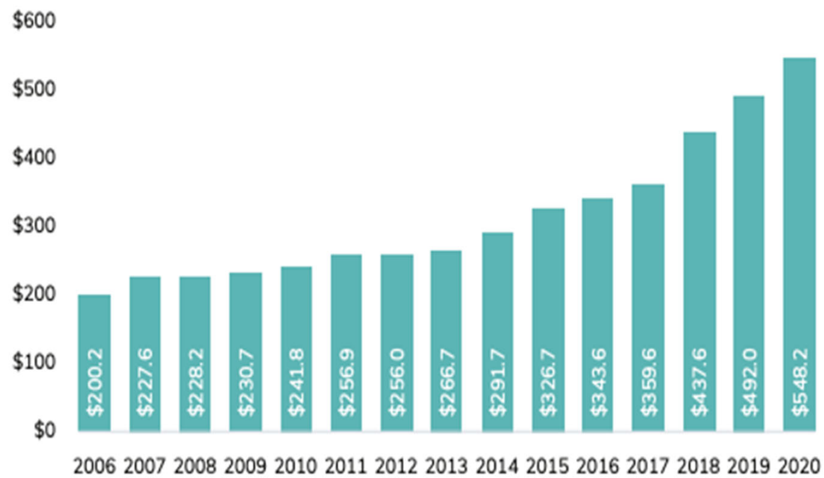
6 Sirin Kale, "'I put my life savings in crypto': how a generation of amateurs got hooked on high-risk trading", *The Guardian*, 19 June 2021; Carol McNaughton Nicholls et al, "Understanding self-directed investors: A summary report of research conducted for The Financial Conduct Authority", BritainThinks, March 2021; Paul Krugman, "How crypto became the new subprime", *New York Times*, 27 January 2022; "More Than One in Ten Americans Surveyed Invest in Cryptocurrencies", NORC at the University of Chicago, 22 July 2021. See also Amanda Hess, "Does a Toddler Need an NFT?" *New York Times*, 27 April 2022.

7 Anna-Cat Brigida and Leo Schwartz, "Six months in, El Salvador's bitcoin gamble is crumbling", *Rest of World*, 15 March 2022; Alexander Osipovich, "Crypto 'Yield Farmers' Chase High Returns, but Risk Losing It All", *Wall Street Journal*, 17 July 2021; Daren Fonda, "Lending Your Crypto Could Generate Attractive Yields. But How Safe Is It?" *Barron's*, 12 December 2021. For a contrasting argument, see Steve Kaczynski and Scott Kominers, "How NFTs Create Value", *Harvard Business Review*, 10 November 2021.

8 MacKenzie Sigalos, "Crypto scammers took a record $14 billion in 2021", CNBC, 6 January 2022; Simon Constable, "U.S. Saw More Than 80,000 Cryptocurrency Frauds In 2020", *Forbes*, 29 June 2021; Khristopher Brooks, "Cryptocurrency scams have soared 1,000% since October", *CBS News*, 17 June 2021.

1.5 A related outcome has been a rise in funds targeting start-up firms. According to the National Venture Capital Association, US venture capital firms more than doubled their funds under management in a few years, from US$256 billion in 2012 to US$548 billion in 2020 (see Figure 1).

FIGURE 1 ESTIMATED ASSETS UNDER MANAGEMENT BY US VENTURE CAPITAL FIRMS



Source: *NCVA 2021 Yearbook*, available at https://nvca.org/wp-content/uploads/2021/08/NVCA-2021-Yearbook.pdf, accessed 24 May 2022.

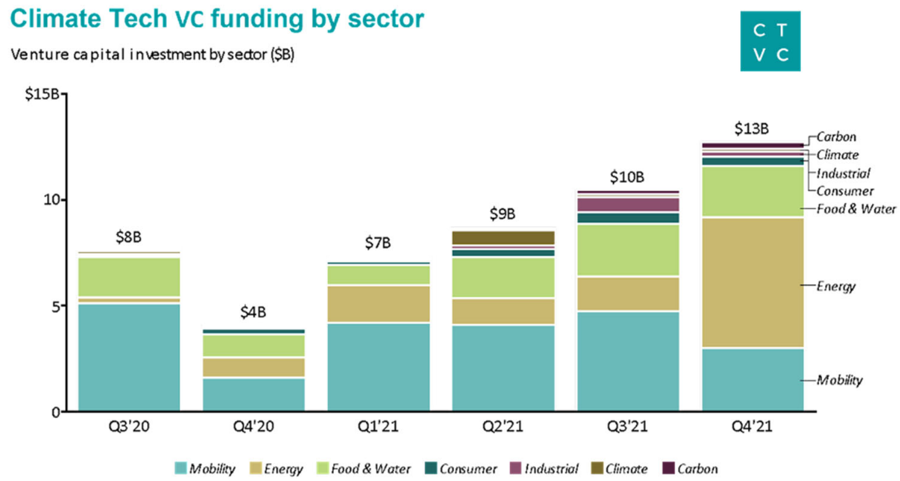
1.6 Alongside the rise in venture capital has been a rise in higher risk, environmentally conscious or climate-friendly investments, including in highly experimental technologies (for instance, see Figure 2). These technology investments can be equally risky for investors. A 2016 MIT study on start-up investments found that clean energy technology investments were exceptionally likely to fail to return capital to investors, with failure rates of "cleantech" start-ups in the study's sample approaching 100% in 2008, 2009 and 2011.[9]

1.7 Nevertheless, many climate-friendly investments now seem to hold better prospects for growing long-term returns[10] when contrasted with sustained low rates of return for more traditional investments.

[9] Benjamin Gaddy, Varun Sivaram and Francis O'Sullivan, "Venture Capital and Cleantech: The Wrong Model for Clean Energy Innovation", MIT Energy Initiative Working Paper, July 2016.

[10] William Mathis, "Renewable Returns Tripled Versus Fossil Fuels in Last Decade", *Bloomberg*, 18 March 2021.

FIGURE 2 ESTIMATES OF CLIMATE TECH VENTURE CAPITAL FUNDING BY SECTOR FROM *CLIMATE TECH VC*.



Source: Sophie Purdom and Kim Zou, "$40B 2021 climate venture recap", available at https://climatetechvc.substack.com/p/40b-2021-climate-venture-recap, accessed 24 May 2022.

1.8 An International Energy Agency study found that average rates of return on total assets for renewable energy companies in advanced economies were negative in 2011-15 and were 1% in 2016-20.[11] Despite these low rates, the study found that an equity portfolio of the same renewable energy companies generated 727% returns over from 2011 to 2021. New climate investment funds such as the MSCI Global Alternative Energy index, MSCI ACWI IMI Clean Energy Infrastructure index and iShares Global Clean Energy ETF have each reported relatively high price to earnings ratios (from 25.6 to 49.4) and low dividend yields (around 1%), but still significantly increased their assets and trading volumes, especially from 2019 to end-2021.[12] A Silicon Valley Bank report estimated that US venture capital funding in climate technology had increased by 80% from 2020 to 2021 alone.[13]

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11 "Clean Energy Investing: Global Comparison of Investment Returns - A Joint Report by the International Energy Agency and the Centre for Climate Finance & Investment", Imperial College Business School, March 2021.

12 Ibid.; "MSCI Global Alternative Energy Index (USD)", https://www.msci.com/documents/10199/40bd4fec-eaf0-4a1b-bfc3-8ed5c154fe3c, accessed 9 May 2022; "MSCI ACWI IMI Clean Energy Infrastructure Index (USD)", https://www.msci.com/documents/10199/411e3490-6a19-76ec-d4ac-b393152bc04e, accessed 9 May 2022.

13 "The Future of Climate Tech", https://www.svb.com/trends-insights/reports/future-of-climate-tech, accessed 24 May 2022.

1.9 With the growing appetite for riskier investments, especially for climate investments, the number of climate-oriented start-ups in the United States has risen significantly. In 2019, venture capital firms made over 600 deals, worth over US$15 billion, with climate technology start-ups.[14] New climate-friendly US "unicorn" firms, valued at over US$1 billion, include Silicon Valley-based UPSIDE Foods (developing lab-grown meats) and Sila Nanotechnologies (silicon-based batteries), Virginia-based Fluence Energy (electricity storage), Nevada-based Redwood Materials (recycling capabilities) and Massachusetts-based Commonwealth Fusion Systems (fusion energy).

1.10 Despite risks to the broader economy and financial system from a prolonged period of very low interest rates, such firms' success at quickly raising billions in funding and valuations appears linked to the broader monetary environment of high savings, low yields and unusually low costs of financing.

1.11 Huge flow of funds into financial markets has created an environment where large and small companies may be suddenly rewarded with high valuations for pivoting to cleaner technologies or industrial processes. Stock prices and valuations of several large and small US automakers – notably, General Motors, Ford, Tesla, Nikola and Rivian – have surged since 2019 following announcements on electric vehicles, batteries, or other climate-related plans.

1.12 These valuations do not imply substantive profitability and production: in June 2020, hydrogen-powered and electric vehicle start-up Nikola reached a market valuation of over US$28 billion without having significant production capabilities, while registering losses into 2022. Such valuations are not likely to last, and have brought risks of broader societal harm from misallocated capital. Indeed, in spring and summer of 2022 many of these firms faced sharply falling equity values. Yet such high valuations from a historically unusual monetary context at least provided some incentives for business leaders to pursue climate-friendly programmes.

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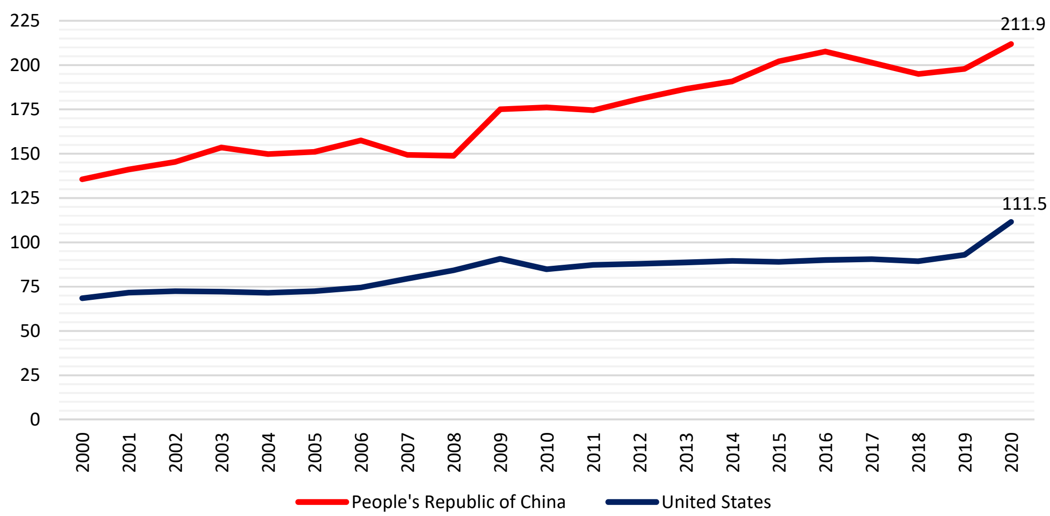
14 Henry Sanderson, "Clean tech 2.0: Silicon Valley's new bet on start-ups fighting climate change", *Financial Times*, 25 March 2021.

Monetary and Financial Drivers in China

2.1 In some ways, monetary and financial trends in China appear more extreme than those in the United States. Broad money as a share of gross domestic product (GDP) in the United States rose suddenly during the pandemic, but the same measure in China grew by a much larger 80 percentage points of GDP from 2000 to early 2022 (see Figure 3). China's broad money supply is now exceptionally high by world standards – among middle and high-income countries, China's officially reported figure is only matched by those of Japan and the two Chinese special administrative regions with their own currencies, Hong Kong and Macau.

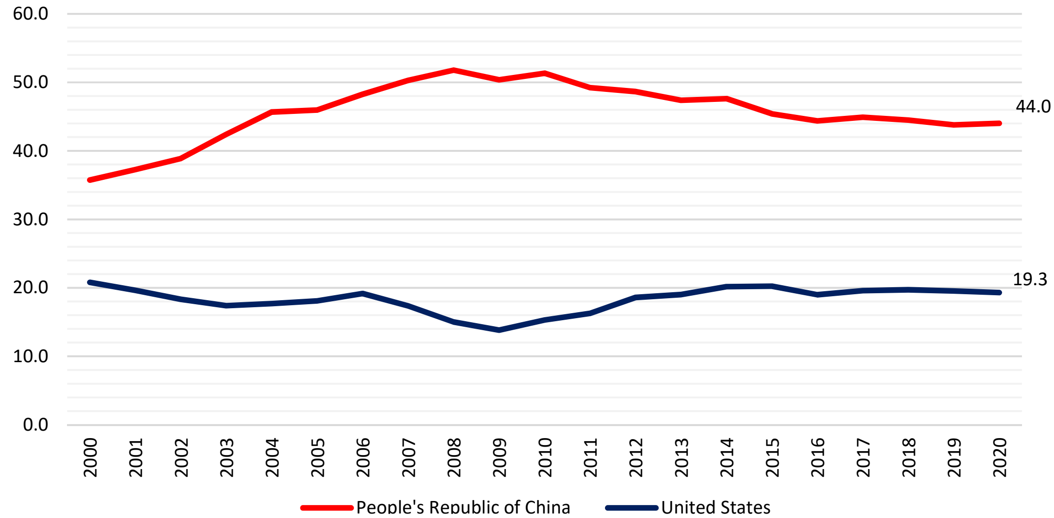
2.2 While China's national savings rate declined modestly in the 2010s, the rate remains unusually high by current world standards (see Figure 4) and by historical standards. The officially reported household consumption shares of GDP for the United States and United Kingdom at the 1944 peak of World War II industrial mobilisation only fell to around 50% of GDP, while that in wartime Japan only fell below 40% of GDP in one year, at the peak of mobilisation in 1944. By contrast, China's official household consumption share has not surpassed 40% of GDP since 2005.

FIGURE 3 BROAD MONEY SUPPLY AS PER CENT OF US/CHINA GDP (World Bank estimate)



Source: World Bank data.

FIGURE 4 GROSS SAVINGS AS PER CENT OF GDP (World Bank estimate)



Source: World Bank data.

2.3 As in the United States, the growth in money supply and savings in China has influenced equity markets, but the rise of Chinese equities has been more prone to sharp corrections and the overall equity market remains small relative to China's economic size. In early 2021, the market capitalisation of companies on the Shanghai stock exchange reached RMB45.7 trillion or US$6.9 trillion. Meanwhile, the Tokyo exchange held a market capitalisation of around JPY695 trillion or US$6.6 trillion, though in nominal US dollar terms China's GDP was nearing three times that of Japan.

2.4 Similarly, venture capital and private equity have increased in China, but remain relatively small compared to funds in other economies. ChinaVenture Group data show that Chinese venture capital investments rose from US$9 billion in 2010 to US$73 billion in 2015 before plateauing towards US$61.6 billion in 2020.[15] The annual number of VC investments likewise veered from nearly 2,000 in 2011, to over 12,000 in 2015, to just over 5,000 in 2019. Private equity investments in China grew rapidly after 2012, rising from US$38 billion to US$109 billion in 2015, but also subsequently plateaued at US$115 billion in 2020. Private equity firms made

[15] However, GaveKal and Preqin report that venture capital investments by *US dollar funds* in China had held at around US$90-100 billion from 2017 to 2021. See Dan Wang, "Venture Capital After the Tech Route", Gavekal, 28 October 2021.

moderate commitments to industries that may be adjacent to climate goals: 7% of 2019 private equity investments were in the transportation sector and 5% in "energy and mining" (not all of these in "green" firms), versus nearly 20% in internet and IT investments.[16]

2.5 While the savings imbalance and money supply growth appear to be greater in China than in the United States, these trends in China do not appear to have fostered many of the US phenomena — from the rapid rise in cryptocurrencies to the emergence of a growing variety of climate start-ups and unicorn firms developing highly experimental new technologies.

2.6 Instead of monetary easing ultimately providing purchasing power to small-scale innovative firms, loose monetary policy in China's more state-guided economy has contributed to investments in the real estate sector and in government-adjacent sides of the economy, which benefit from low rates offered by state-guided or state-controlled financial institutions. These sectors have scaled up investments in key existing renewable energy technologies, thanks to easy money access from state-led financial institutions. This framework has fostered less of an effective innovation framework and a much greater focus on sectors like real estate.

2.7 In the United States, the Federal Reserve is seen as the decisive actor independently guiding monetary policy, with US money supply propelled by the Fed's quantitative easing policies. US state and local governments generally must adhere to harder, often constitutionally imposed budget and debt constraints. While the People's Bank of China (PBoC) has a vital role in establishing China's monetary policy, China's local and regional jurisdictions have operated within looser budget constraints, as government-related agencies and banks support or issue extensive debt for numerous infrastructure projects, sometimes with semi-public financing vehicles that mask local or regional authorities' new debt obligations. This structure facilitates an expanding money supply that circulates within state-guided or state-led firms and institutions, rather than among smaller venture capital and private equity firms that follow political or profit-seeking desires of many autonomous private investors.

16 Investment data from ChinaVenture via CEIC.

2.8 In the United States, some legislators and central bank officials have suggested using the Fed's monetary policy powers to actively and directly promote a "green" transformation of the economy. These ideas have proven controversial among economists and politicians associated with the major US political parties, particularly given the Fed's distance from electoral accountability. The Fed's climate activity is mostly limited to a research role, though the Fed will likely begin climate stress testing in 2022-2023.[17]

2.9 In China, the PBoC adopted directly climate-conscious monetary policies in what might be called "green quantitative easing", alongside climate standards and public statements.

2.10 In November 2021, the PBoC announced the launch of the "carbon emission reduction facility" (CERF), which supports national-level financial institutions to give loans for emission reduction schemes. Institutions can receive PBoC funds of up to 60% of the principal of eligible loans at an interest rate of 1.75% for one year. Recipient institutions must report on climate-related effects of their investments.[18] Officially, institutions must also carry the risks of their climate investments, but it is still unclear what would happen if firms fail to repay CERF funds or if investments are fraudulently characterised as "green". CERF took effect in December 2021 with RMB85.5 billion in new funds for green loans, covering over 2,800 borrowers.[19]

2.11 For years, the PBoC had quietly used window guidance to steer financial institutions towards climate-friendly lending. In 2018, the PBoC began accepting "green bonds" as collateral for its medium-term lending facility and tightening standards for green bonds in 2021 to exclude fossil fuel investments. Such bonds often fund clean

17 Mychael Schnell, "Powell says climate stress tests will 'very likely' be a 'key tool going forward'", *The Hill*, 11 January 2022.

18 "The People's Bank of China Launches the Carbon Emission Reduction Facility", http://www.pbc.gov.cn/en/3688110/3688172/4157443/4385345/index.html, accessed 24 May 2021; "PBoC Officials Answer Press Questions on the Launch of Carbon Emission Reduction Facility", http://www.pbc.gov.cn/en/3688110/3688172/4157443/4385447/index.html, accessed 24 May 2022; "PBoC launches carbon-reduction monetary policy facility", https://www.centralbanking.com/central-banks/monetary-policy/7895581/pboc-launches-carbon-reduction-monetary-policy-facility, accessed 24 May 2022.

19 "Central Banking and Climate Action – China Steers Credit to Decarbonize", https://ieefa.org/wp-content/uploads/2022/03/Central-Banking-and-Climate-Action_China-Steers-Credit-to-Decarbonize_March-2022.pdf, accessed 24 May 2022.

energy and transit investments, though as recently as 2018 a sizeable share of Chinese green bonds supported modifications at fossil fuel plants. In the second half of 2021, the PBoC began tracking and scoring banks' green investments and evaluating banks for climate-related risks.[20]

2.12 Throughout these years, China's central bank leaders have persistently warned of financial market dangers from climate change and the need for finance to "take climate into account".[21] Central bank policies and guidance have helped propel China's green credit environment, with green loans and bonds amounting to RMB12 trillion and RMB800 billion, respectively, at the start of 2021.[22]

Market Technology Drivers in China

3.1 Technology facilitating emissions reduction has improved worldwide. With improving technologies, markets with the aid of government policies have reduced costs for more efficient, "greener" consumer activity.

3.2 In China, a large and competitive manufacturing sector combined with active policymaking has helped ensure a collapse in prices for many kinds of clean energy equipment, fostering a renaissance in clean energy in both China and the United States. In China, central planners have arranged for dramatic increases in clean energy production and substantial investments in "next generation" clean infrastructure, such as for hydrogen fuel cells. In the United States, a large consumer economy and more limited or indirect federal policymaking activity have spawned many "organic" climate-friendly changes that vary substantially across the country, brought about by diverse private businesses, utilities and households.

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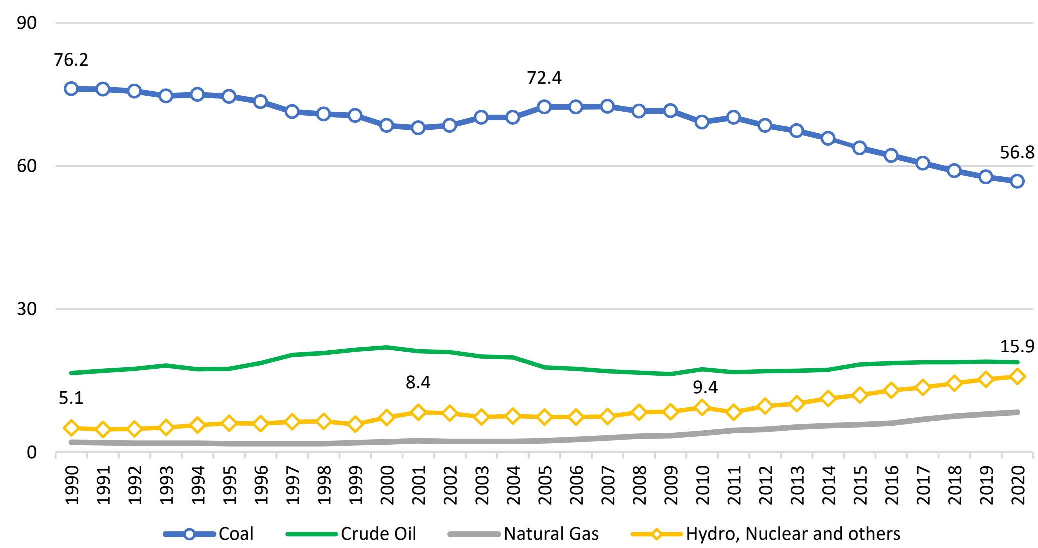
[20] Ibid.; "Yi Gang attended the 2021 Boao Forum annual conference and delivered keynote speech" (in Chinese), http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/4235939/index.html, accessed 24 May 2022; "Chinese Banks Pass First Round of Climate Risk Stress Testing by PBOC", https://www.chinabankingnews.com/2022/02/21/chinese-banks-pass-first-round-of-climate-risk-stress-testing-by-pboc/, accessed 24 May 2022.

[21] "Liu Guiping: Efforts to improve climate risk management in the financial system" (in Chinese) https://www.financialnews.com.cn/jg/ld/202202/t20220218_239704.html, accessed 24 May 2022.

[22] "Make Full Use of China's Monetary Policy Space and Promote Green Finance", http://www.pbc.gov.cn/en/3688110/3688172/4157443/4211225/index.html, accessed 24 May 2022.

3.3 China aims to raise the share of non-fossil fuels in its primary energy consumption to 25% by 2030, higher than previous pledges of 20%. Non-fossil fuels, including hydro, nuclear, wind and solar power, have expanded rapidly for over two decades, helping to mitigate China's energy shortage and reach China's green development targets. From 1990 to 2020, the proportion of non-fossil fuels in China's total energy consumption rose from 5.1% to 15.9%, while the proportion of coal dropped from 76.2% to 56.8% (see Figure 5).

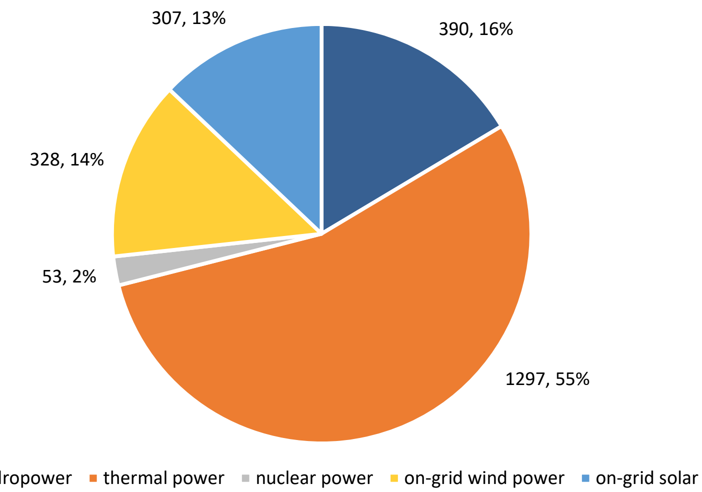
FIGURE 5 CHINA'S ENERGY CONSUMPTION (1990-2020)



Source: CEIC data.

3.4 Meanwhile, the shares of wind and solar in total installed capacity have witnessed substantial growth, mainly at the cost of hydro and thermal-based power. At the end of 2012, China's installed capacity of on-grid wind power reached 60.8 gigawatts (GW) or only 5% of the total, while solar power was merely 3.3 GW, or 0.3%. At the end of 2017, China's on-grid wind power capacity reached 163.7 GW, or 9% of total, and solar power surged to 130.3 GW, about 8% of total installed capacity. By end-2021, China's on-grid wind power capacity reached 328 GW, or 14%, and solar reached 307 GW, or about 13% (see Figure 6).

FIGURE 6 EXISTING INSTALLED CAPACITY OF VARIOUS ELECTRICITY SECTORS IN CHINA BY 2021 (in GW and %)



Source: National Energy Administration of China (2022).

3.5 China has gradually taken the lead in renewable energy-related manufacturing. China's share of global wind turbine production and solar panel manufacturing has risen to 45% and 72%, respectively. From 2010 to 2020, China's installed wind capacity increased nine-fold, from 31 to 280 GW, while from 2015 to 2020, installed solar capacity expanded six-fold, from 42 to 250 GW. Costs for solar and wind energy have fallen markedly since 2010, a downward trend that is likely to continue in the near future. Compared with the levelised cost of electricity from renewable energy in 2010, the costs of solar photovoltaics (PV), concentrated solar power, and both onshore and offshore wind had fallen by more than half by 2020.

3.6 As the world's largest wind turbine manufacturing base, China claims seven spots among the world's top 10 wind turbine manufacturers. The growth of China's wind turbine manufacturers relates to the country's strong growth in wind power investments and installed capacity. The costs of operating and maintaining wind plants fell thanks to increased competition and improved turbine performance. China's manufacturing boom has reinforced the government's approach to promoting wind power, which has become cost-competitive with fossil fuels and requires fewer subsidies.

3.7 China has bet on offshore wind projects next to its coastal industrial bases. The 12th five-year special plan for wind power technology development, formulated by the Ministry of Science and Technology, featured research and development on high power turbines, such as "10 megawatt (MW) wind turbine overall design technology", "3–5 MW permanent magnet direct drive (PMDD) wind turbine industrialisation technology" and "7 MW-class wind turbine development and industrialisation technology". China is now capable of designing and manufacturing large-scale offshore wind turbines, having completed the hoisting and trial operation for 6 MW offshore wind turbines. Nevertheless, developing offshore wind power still faces challenges around constructing power transmission lines and withstanding harsh offshore environments.

3.8 China is the dominant player in the production of solar equipment. About 80% of global solar manufacturing supply chains run through China.[23] China produces as much as 97% of the world's silicon wafers.[24] Many of those wafers are then exported and made into solar cells. Chinese subsidiaries in Vietnam, Malaysia and Thailand assemble an estimated 75% of the silicon solar cells ultimately installed in the United States.[25] China's swelling production capacity has helped bring down the international price of solar panels by more than 80% since 2009.

3.9 New energy vehicles (NEVs) in China include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hydrogen fuel cell electric vehicles (FCEVs) and other vehicles driven by non-traditional fuels. As the world's largest NEV market, China has been promoting production and sales of NEVs, chiefly electric vehicles (EVs), to reduce urban air pollution, greenhouse gas emissions and dependence on oil imports.

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[23] "China dominates the solar energy industry. Can the U.S. catch up?" https://www.marketplace.org/2021/07/07/china-dominates-solar-energy-industry-can-us-catch-up/, accessed 18 January 2022.

[24] As a US Department of Energy report explains, the solar panel supply chain "starts with the refining of high-purity polycrystalline silicon (polysilicon)… Polysilicon is melted to grow monocrystalline silicon ingots, which are sliced into thin silicon wafers. Silicon wafers are processed to make the solar cells that are interconnected and sandwiched between glass and plastic sheets to make [crystalline silicon] modules". In "Solar Photovoltaics Supply Chain Deep Dive Assessment", https://www.energy.gov/sites/default/files/2022-02/Solar%20Energy%20Supply%20Chain%20Report%20-%20Final.pdf, accessed 3 April 2022.

[25] Ibid.

3.10 China is both the largest manufacturer and buyer of EVs in the world. It is a major EV exporter in the world, shipping over 1.36 million vehicles overseas in the first three quarters of 2021, a year-on-year increase of around 120%.[26] China has become a major producer of Tesla vehicle models for global markets, with over 100,000 exported during the period. Leading Chinese EV manufacturers, including BYD, SAIC Motor Corp, Nio and Xpeng, have entered European markets. Meanwhile, China's EV market is also growing fast, driving the growth of plug-in EVs globally. Sales of EV and plug-in hybrid vehicles in China more than doubled to 2.99 million units in 2021, accounting for 15% of total passenger car sales.[27]

3.11 In October 2020, the State Council released China's New Energy Vehicle Industrial Development Plan, 2021-2035.[28] The target is for NEVs to comprise 20% of auto sales by 2025, lower than the 25% target in a proposal by China's Ministry of Industry and Information Technology in 2019. The 2021 plan aimed to form a globally competitive auto sector with advanced NEV technologies and high-quality brands, build extensive battery charging networks, improve national energy security while reducing air pollution and emissions, and stimulate automobile, energy, transportation and information and communications industries.

3.12 China's government intensely monitors developments in hydrogen fuel technology, a nascent sector, for clean energy. China's 13th Five-Year Plan (FYP) and "Made in China 2025" initiative, issued by the State Council in 2015, display ambition in manufacturing and deploying hydrogen fuel cell technologies. The 13th FYP's guideline on strategic emerging sectors aimed to promote R&D on fuel cells, build hydrogen refuelling stations and achieve mass production of FCEVs by 2020.[29]

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26 "Electric vehicles power China's auto exports", https://www.chinadaily.com.cn/a/202110/26/WS61775cd4a310cdd39bc714ae.html, accessed 17 January 2022.

27 Yoko Kubota, "Electric Vehicles Drive Growth for China Car Sales", *Wall Street Journal*, 11 January 2022.

28 "New energy car industry development plan (2021-2035)" (in Chinese) http://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm, last accessed 20 January 2022.

29 "Project launched to develop hydrogen fuel cells in E China", http://www.chinadaily.com.cn/a/201808/30/WS5b873f25a310add14f3888b1.html, last accessed 6 March 2020.

3.13 The "Fuel Cell Technology Roadmap" in the 13th FYP envisioned over 1,000 hydrogen refuelling stations operating by 2030, with at least 50% of hydrogen fuel coming from renewable resources, and over one million FCEVs in service by 2030.[30] In 2018, China began investing heavily in hydrogen fuel cell technology to better use the country's enormous yet inefficient renewable energy capacity in the long run.

3.14 In the 14th FYP, China pledged support for hydrogen and energy storage sectors as "new strategic industries". Notably, provincial governments in Beijing, Shanghai, Shandong, Hebei and Jilin are strongly driving the move towards hydrogen, as regional development plans for 2021-2025 indicate.[31] According to the Beijing municipality's FYP, the city aims to have 37 hydrogen refuelling stations and 3,000 hydrogen fuel cell vehicles operating by 2023, and over 10,000 hydrogen-based vehicles operating by 2025.[32]

3.15 According to the Hydrogen Industrial Technology Innovation Alliance of China, China might use 60 million tons of hydrogen gas by 2050, with hydrogen comprising a tenth of China's energy use.

Market Technology Drivers in the United States

4.1 Despite inconsistent federal policies on renewable energy, the United States has made substantial progress in reducing carbon emissions from electrical power generation. Part of that progress has come from the recent accelerating growth in generation from renewable energy sources. In 2010, US electrical generation from renewable sources represented less than 23% of the electricity derived from burning coal and roughly half of the electricity derived from nuclear fission. In 2021, renewable sources (including biomass) produced more electricity than nuclear

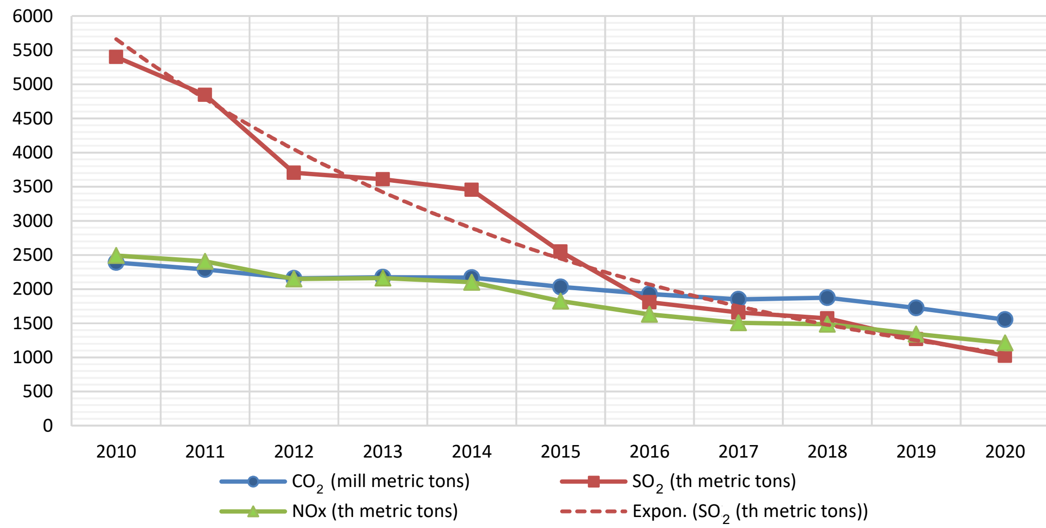
[30] "Chinese Fuel Cell Industry Developments", http://www.fchea.org/in-transition/2019/2/4/chinese-fuel-cell-industry-developments, accessed 9 December 2020.

[31] "China's Hydrogen Market in 14th Five-Year Plan: Provincial Strategy Breakdown", https://energyiceberg.com/hydrogen-14th-fyp-provincial-strategy/, accessed 20 January 2022.

[32] "Beijing releases new hydrogen industry five-year plan", http://www.china.org.cn/business/2021-08/17/content_77698504.htm, accessed 20 January 2022.

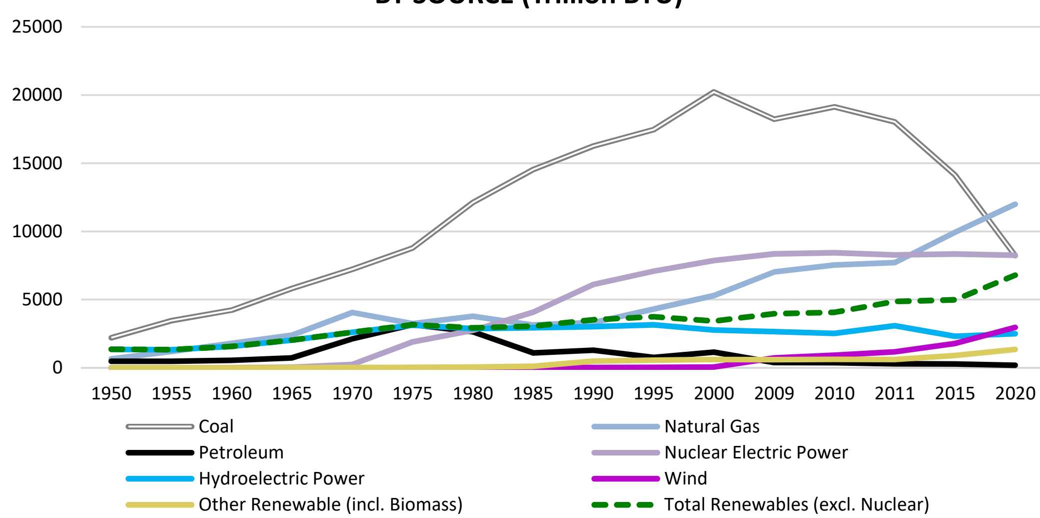
plants and came within 10% of surpassing once-dominant coal (see Figures 7 and 8).

FIGURE 7 US ELECTRICITY-RELATED EMISSIONS



Source: "Table 9.1. Emissions from Energy Consumption at Conventional Power Plants and Combined-Heat-and-Power Plants 2010 through 2020 (Thousand Metric Tons)", available at https//www.eia.gov/elecricity/annual/pdf/epa.pdf, accessed 24 May 2022.

FIGURE 8 US ELECTRIC POWER SECTOR ENERGY CONSUMPTION BY SOURCE (Trillion BTU)



Source: "Table 2.6. Electric Power Sector Energy Consumption (Trillion BTU)", available at https://www.eia.gov/totalenergy/data/monthly/pdf/sec2_15.pdf, accessed 18 July 2022.

4.2 The rise of US renewable energy is thanks to a roughly constant supply of hydroelectricity despite significant droughts in western states, and a rapid increase in wind and solar electrical production. Since 2010, electricity produced from wind in the United States has nearly doubled every five years, with solar energy following a similar pattern from a smaller base.

4.3 Another central, if counterintuitive, transformation in the United States' energy-related emissions has come from the "shale revolution" in Pennsylvania, Ohio, Texas and the sparsely populated "Great Plains" states. Previously, US natural gas production hit relative peaks in 1970 and 2001. New fracking procedures implemented in the mid-2000s suddenly and dramatically revolutionised US gas markets. US natural gas production fully doubled from 2007 to 2020, at a time when US electric utility sales fell by 173 million megawatt hours, or by 4.4%.[33]

4.4 The rise of natural gas led to a fall in consumption of other fossil fuels of unprecedented proportions. Electricity generation from coal fell over 50% in only 13 years, from a historical peak of 2,016 million megawatt hours in 2007 to 773 million megawatt hours in 2020, meeting or surpassing some of the coal substitution scenarios advocated at the time of the Kyoto Protocol.[34] The coronavirus pandemic further accelerated the trend. From 2019 to 2020, coal-based generation declined in every US state except Alaska, California, Virginia and Mississippi, falling by 20% nationwide in a single year before increasing slightly in 2021.[35]

4.5 Natural gas still creates carbon emissions, but at a smaller carbon intensity per unit of energy than either coal or petroleum. As a result, the rise in CO_2 emissions from burning natural gas was outweighed by the collapse in emissions from coal electrical generation (see Figure 9). In 2017, not long after US withdrawal from Paris climate accords, the International Energy Agency reported that US CO_2 emissions from energy had fallen slightly since 2016, compared with an increase of 1% in the European Union, 3% in China and nearly 5% in the world overall.[36] As coal

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33 "Electric Power Annual 2010", http://large.stanford.edu/courses/2012/ph240/nam2/docs/epa.pdf, accessed 24 May 2022; "Electric Power Annual 2020", https://www.eia.gov/electricity/annual/pdf/epa.pdf, last accessed 24 May 2022.

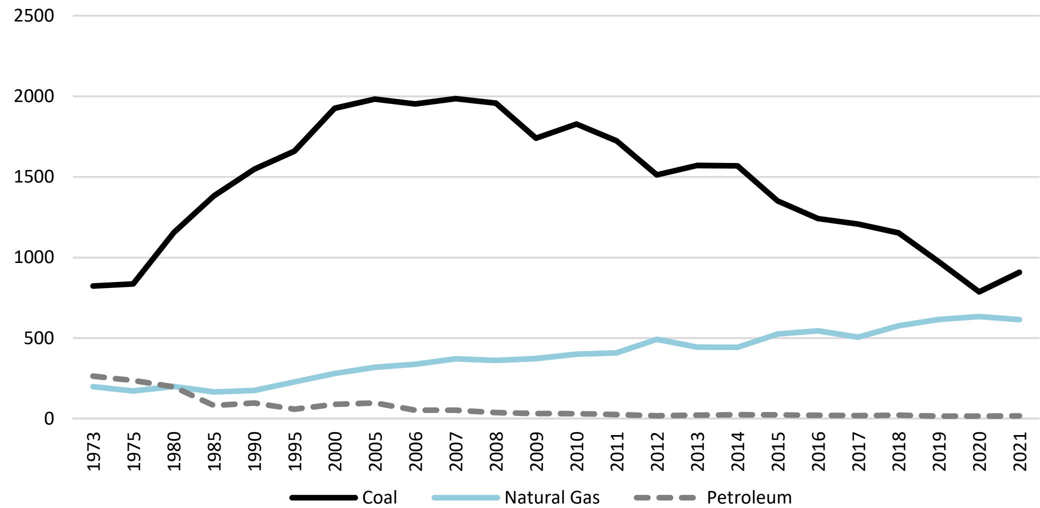
34 "What Does the Kyoto Protocol Mean to U.S. Energy Markets and the U.S. Economy?" https://www.eia.gov/analysis/requests/archive/1998/kyoto/pdf/oiaf9803s.pdf, last accessed 24 May 2022.

35 "Electric Power Annual 2020", table 3.8.

36 "Global Energy & CO2 Status Report: The latest trends in energy and emissions in 2017", https://www.iea.org/reports/global-energy-co2-status-report-2017, last accessed 24 May 2022.

combustion historically produced most US sulphur dioxide (SO_2) emissions, the steep reduction in coal also led to electricity-related SO_2 emissions falling over 80% since 2010 (see Figure 7). Nevertheless, in addition to other environmental consequences of fracking, uncontrolled methane leaks at fracking wells may significantly reduce the overall carbon emission benefits of using natural gas to replace coal and petroleum.[37]

FIGURE 9 ESTIMATED CO_2 EMISSIONS FROM ELECTRICITY GENERATION (in million metric tons)



Source: "Table 11.6. Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector (Million Metric Tons of Carbon Dioxide)", available at https://www.eia.gov/totalenergy/data/monthly/pdf/sec11.pdf, accessed 18 July 2022.

4.6 Industrial and manufacturing uses of energy saw less growth in renewable energy than the electric power sector saw, but still experienced a slight "greening". The shale revolution contributed to a decline in US industries' direct uses of petroleum and continued a long-term decline in industries' direct uses of coal, both of which were substituted by natural gas. Meanwhile, industries' uses of electricity became greener, as the overall US electrical grid increasingly shifted from coal towards natural gas and renewable energy.

4.7 Falling costs to solar and wind energy, partly driven by advances in manufacturing in China, have energised the expansion of renewables in the United States. Newly installed natural gas generators in the United States cost roughly $900-1,100 per

37 See Jeff Tollefson, "Methane leaks erode green credentials of natural gas", *Nature* 493, no. 12 (2013).

kilowatt of capacity to construct, a figure roughly unchanged in the last decade. Utility-scale solar PV costs remain much higher, at around $1,700 per kilowatt of capacity to install in 2019, but had fallen steeply from over $3,700 per kilowatt in 2013. In two leading states in the installation of new solar capacity, Georgia and Florida, the price to install solar PV generators fell to around $1,200-1,300 per kilowatt of capacity in 2019, making solar roughly competitive with the costs of constructing combustion-based generators. The costs of installing wind generators have fallen similarly: in the US South in 2019, installation costs fell to an average of $1,166 per kilowatt of installed capacity, from a national average of $1,895 per kilowatt in 2013.[38]

4.8 The falling costs and low operating costs of installing solar panels have created the historically unusual trend of a decentralisation of US electrical production. In 2019, US electricity producers added 5,450 megawatts of solar capacity: of this capacity, a third came from large projects of over 100 MW, while 20.5% came from small projects of under 10 MW, suggesting more dispersed electrical generation and more opportunities for smaller firms to enter renewable energy markets.[39]

4.9 Falling prices have also led household-based solar electrical generation to soar, from a total of 4.9 gigawatt hours in 2014 to over 30 gigawatt hours in 2021, and trending towards a staggering 30% year-on-year electrical production increase as of March 2022.[40] Energy decentralisation may help reduce transmission costs, spread renewable energy more quickly and in places where it is more efficient (for instance, due to natural sun cover), and bring unprecedented economic returns of energy investments directly to households. However, decentralisation could also risk greater instability in US energy grids as it becomes more difficult to monitor and control widely dispersed and decentralised energy supply and demand.

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38 "Construction cost data for electric generators installed in 2019", https://www.eia.gov/electricity/generatorcosts/, last accessed 24 May 2022.

39 Ibid.

40 *Electric Power Monthly*, US Energy Information Administration, April 2022, table 1.2.E, https://www.eia.gov/electricity/monthly/current_month/april2022.pdf, accessed 24 May 2022; "Table 1.17.A. Net Generation from Solar Photovoltaic", https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_1_17_a, accessed 24 May 2022.

4.10 Meanwhile, the United States has steadily assembled an infrastructure of electric vehicle charging stations, supported by a mix of federal and state-level subsidies and tax credits. In 2021, the US Department of Energy estimated there were over 40,000 public EV charging stations nationwide.[41] The 2021 federal Bipartisan Infrastructure Law provided funds to state governments to install 500,000 charging stations nationwide by 2030, though some private estimates have suggested that the United States would eventually need millions of public charging stations.[42]

4.11 Development of hydrogen-based vehicle infrastructure has been far slower. In 2020, the Department of Energy estimated there were just 43 retail hydrogen refuelling stations in the United States, increasing to 48 by May 2022 and with another 55 planned. All are located in either Hawaii or California where several thousand hydrogen-based vehicles are in use.[43] Few jurisdictions outside California have formulated policies specific to hydrogen fuel.

4.12 Lastly, the United States has benefitted from growing efficiency gains in more traditional consumer-facing technologies. From 2010 to 2017, average US fuel efficiencies rose 16% for new passenger cars (to 39.4 miles per gallon), as large automotive companies competed to achieve greater efficiencies and meet rising government standards.[44] Unlike in past periods of rising vehicle fuel efficiencies, the current trend features an array of consumer services to speed mass adoption of new climate-friendly technology. These services include a suite of vehicle software offered by Tesla to attract new drivers of its electric cars, with packages offering home solar panels to charge one's vehicle, as well as a growing number of large

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41 "Electric Vehicle Benefits and Considerations", https://afdc.energy.gov/fuels/electricity_benefits.html, accessed 24 May 2022.

42 "Building the electric-vehicle charging infrastructure America needs", https://www.mckinsey.com/industries/public-and-social-sector/our-insights/building-the-electric-vehicle-charging-infrastructure-america-needs, accessed 24 May 2022.

43 "Hydrogen Fueling Stations", https://afdc.energy.gov/fuels/hydrogen_stations.html, accessed 24 May 2022; "Alternative Fueling Station Locator", https://afdc.energy.gov/stations/#/find/nearest?fuel=HY&lpg_secondary=true&country=US&hy_nonretail=true, accessed 17 May 2022; "Hydrogen Basics", https://afdc.energy.gov/fuels/hydrogen_basics.html, accessed 24 May 2022.

44 "Average Fuel Efficiency of U.S. Light Duty Vehicles" (Table 4-23), https://www.bts.gov/content/average-fuel-efficiency-us-light-duty-vehicles, accessed 24 May 2022.

companies (such as Google and General Motors) experimenting with self-driving vehicle transport services grounded on electric vehicles.

4.13 Improving technology and a relative shift towards large narrowbody jets have moderated increases in emissions from passenger airplanes. US airlines have achieved greater fuel efficiencies than other airlines operating in the Pacific with the replacement of four-engine widebody aircraft with newer two-engine designs.[45] The next generation for airline fuel efficiencies may be electricity-powered planes, a prospect attracting Silicon Valley titans such as Google co-founder Larry Page.[46]

4.14 More mundane technologies have also benefitted from efficiency improvements. A 2021 Consumer Technology Association report estimated that average laptop energy use fell from 25-30 watts in 2005-2013 to 13 watts in 2020, while television energy use fell from 100-115 watts in a similar period to 81 watts in 2020, as newer liquid-crystal and LED displays replace older technologies.[47] In 2015, lighting comprised 10% of US household energy use, but its energy use is steadily vanishing. In March 2022, the US Department of Energy estimated that in 2020, over 60% of all US homes used LEDs for at least half their lighting (up from 4.4% in 2015), while half of recently built housing units contained no halogen or incandescent lighting at all. This change was partly spurred by a 2007 law mandating higher efficiency lighting and by Chinese manufacturers achieving dramatically lower prices for LED lights.[48]

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[45] "Low-cost carriers and U.S. aviation emissions growth, 2005 to 2019", https://theicct.org/wp-content/uploads/2021/06/LCC-emissions_growth-mar2021.pdf, accessed 24 May 2022.

[46] "The largest electric plane ever to fly", https://www.bbc.com/future/article/20200617-the-largest-electric-plane-ever-to-fly, accessed 24 May 2022; "The challenges and opportunities of battery-powered flight", https://www.nature.com/articles/s41586-021-04139-1, accessed 24 May 2022; "Welcome to Larry Page's Secret Flying-Car Factories", https://www.bloomberg.com/news/articles/2016-06-09/welcome-to-larry-page-s-secret-flying-car-factories, accessed 24 May 2022.

[47] Bryan Urban, Kurt Roth and Julia Olano, "Energy Consumption of Consumer Electronics in U.S. Homes in 2020", Fraunhofer USA / Consumer Technology Association, August 2021.

[48] "Residential Energy Consumption Survey", https://www.eia.gov/consumption/residential/data/2020/index.php?view=characteristics, accessed 24 May 2022; "Energy-efficient light bulbs: The DOE is about to change the rules", https://www.cnet.com/home/smart-home/energy-efficient-light-bulbs-department-of-energy-changing-rules, accessed 24 May 2022.

4.15 These small-scale efficiencies have spread quickly and 'organically' in the United States through climate-conscious investments by firms, climate-conscious preferences of individual consumers and dramatic declines in prices for improved technologies strengthening market incentives for climate-friendly practices. US policies towards marketable technologies were heavily directed at producers, which invested in long-term product development and manufacturing shifts, rather than at consumers. As a result, US residential energy consumption has stagnated or declined, even as the number of households has increased alongside the number of electronics within each household.

Conclusion

5.1 The United States and China have committed to cooperating on tackling the climate crisis despite rising geopolitical tensions. Given their substantial differences in political and governance structures, monetary settings, and prevailing market technologies and geographic conditions, the two countries demonstrate varied strengths and weaknesses in promoting climate investment.

5.2 The United States and China need to continue climate dialogue and energy cooperation to jointly explore pathways to net zero carbon footprints. They have pledged to achieve carbon neutrality by 2050 and 2060 respectively, an essential development for the Paris Agreement's goal of limiting global warming to 1.5 degrees Celsius from pre-industrial levels.

5.3 Long-term monetary and economic conditions in the two countries – epitomised by high savings and prolonged low interest rates – have promoted both highly speculative investments and more positive, climate-friendly investments. The two can learn from each other's monetary and financial trade-offs experience, as well as develop central bank policies to promote a positive climate transition. In the United States, monetary conditions have been associated with a rise in start-ups experimenting with new climate-friendly technologies and practices, while conditions in China have supported a rapid expansion of clean energy infrastructure undertaken by local governments.

5.4 Changes in technologies and markets show both the degree to which the United States and China have benefitted from each other in the climate sphere, and opportunities for each country to observe and learn from the other. The remarkable spread of renewable energy was achieved thanks to research, investments and enormous spending demand in both countries. While the United States may learn from China's government-led approach to creating markets for new technologies, China may learn from the dispersed spread of renewable energy and 'natural' emergence of more efficient technologies fostered by active and open markets in the United States.

5.5 In April 2021, two meetings signalled hope for renewed US-China cooperation in climate: US Special Presidential Envoy for Climate John Kerry met China Special Envoy for Climate Change Xie Zhenhua in Shanghai and Xi Jinping addressed a virtual climate change summit hosted by US President Joe Biden. However, cooperation in climate investment can only be maximised when there is an understanding of core differences in governance, monetary and market technology drivers.