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Perspective

Enabling a Rapid and Just Transition away from Coal in China

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SUMMARY

As the world's largest coal producer and consumer, China's transition from coal to cleaner energy sources is critical for achieving global decarbonization. Increasing regulations on air pollution and carbon emissions and decreasing costs of renewables drive China's transition away from coal; however, this transition also has implications for employment and social justice. Here, we assess China's current coal-transition policies, their barriers, and the potential for an accelerated transition, as well as the associated environmental, human health, and employment and social justice issues that may arise from the transition. We estimate that the most aggressive coal-transition pathway could reduce annual premature death related to coal combustion by 224,000 and reduce annual water consumption by 4.3 billion m^3 in 2050 compared with business-as-usual. We highlight knowledge gaps and conclude with policy recommendations for an integrated approach to facilitate a rapid and just transition away from coal in China.

CLIMATE CHANGE AND CHINA'S DEPENDENCE ON COAL

Human-induced greenhouse gas emissions are the main cause of average global warming of approximately 1°C since the beginning of the industrial era. The additional warming anticipated to continue in the future represents an imminent threat to human societies if it is not mitigated. Deep decarbonization of energy systems is needed to avoid the catastrophic consequences of climate change. According to the Intergovernmental Panel on Climate Change (IPCC), keeping global warming within a 1.5°C overall target (approximately 0.5°C warmer than today) requires global net anthropogenic CO_2 emissions to decline by about 45% from 2010 levels by 2030 and to reach net-zero emissions by around 2050.[1]

Coal is the largest source of global energy-related CO_2 emissions. Coal accounted for 44% of the 33 $GtCO_2$ of global energy-related CO_2 emissions in 2019, of which two-thirds came from coal use for electricity generation.[2] Achieving the 1.5°C target set out in the Paris Agreement requires coal and other fossil fuels to be phased out in the next 30 years. The scale of this transition would be unprecedented given the heavy dependence on fossil energy at present: 84.3% of the world's primary energy consumption in 2019 came from coal (27%), natural gas (24.2%), and oil (33.1%).[3]

China's dependence on coal is a major hurdle to global decarbonization. In 2019, China accounted for about 28.8% of the global energy-related carbon emissions.[3] Coal has been the fundamental fuel behind China's economic growth and the spread of electricity access to its entire population.[4] China is now the world's largest coal producer and consumer—consuming half of global coal production and importing 20% of the global coal traded in 2018.[5,6] It is also the world's main international provider of finance for the building of new coal-fired power plants.[7] Coal accounted for 60% of China's primary energy consumption in 2018, contributing 50% of the country's fine particulate matter ($PM_{2.5}$) pollutants and 70% of its carbon emissions.[8]

Coal's dominance in China's energy mix has created severe environmental and public health consequences.[9] Outdoor air pollution has been a leading risk factor for mortality, contributing to an estimated 1.2 million premature deaths in China in 2017.[10] Dispersed coal combustion from small burners and residential uses are the main cause of heavy pollution in the Beijing-Tianjin-Hebei metropolitan area.[11] Burning 1 metric ton of scattered coal discharges 10.7 kg of $PM_{2.5}$ and 10.2 kg of SO_2: the emission rates are 49 times and 9 times higher, respectively, than

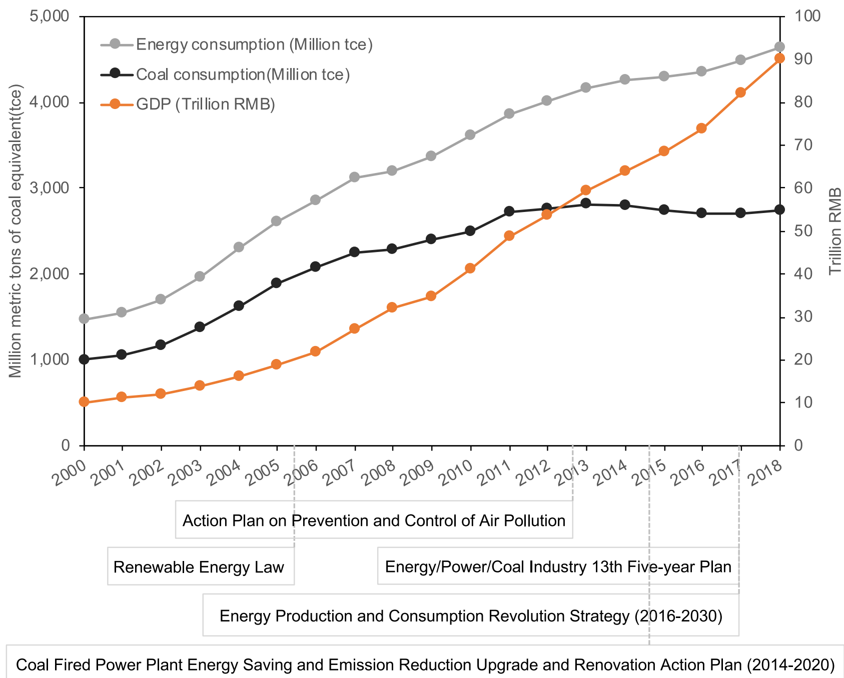

Figure 1. GDP, Total Energy Consumption, and Coal Consumption in China, 2000–2018

Timeline of key coal regulations are listed at the bottom. China's coal consumption has decoupled from energy consumption. Source: National Bureau of Statistics,[21] http://www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm.

those of coal-fired power plants.[12] In 2017, indoor pollutants emitted by Chinese households burning coal caused about 750,000 deaths from respiratory diseases.[10]

As such, coal is at the center of enormous energy, environmental, and climate challenges in China and worldwide. China's transition away from coal is critical to addressing the global climate challenges as well as national and regional challenges related to air pollution, human health, and social and environmental justice. Here, we propose an integrated approach to accelerating China's transition away from coal. China's ability to manage a rapid and just transition away from coal toward a lower-carbon energy system will have an outsized influence on global climate change mitigation and sustainable energy for all.

CURRENT POLICIES AND BARRIERS

China has introduced a series of policies to curb coal consumption and its impacts (Figure 1). In 2013, The State Council released the Action Plan on Prevention and Control of Air Pollution, which planned to constrain direct coal consumption to 65% of primary energy by 2017 through a combination of alternatives (coal to gas, coal to electricity), renewables, and energy efficiency measures.[13] In 2014, China planned to limit coal's share in primary energy to 62% by 2020 while introducing an ultra-low emissions policy for new coal-fired power plants to limit PM, SO_2, and NO_x emission concentrations to 10, 35, and 50 mg/m^3 by 2020, respectively, which is equivalent to the performance of gas turbines.[14] In 2015, China announced plans to reach peak carbon emissions by no later than 2030 while deriving 20% of its primary energy from non-fossil sources in preparation for the Paris climate talks.[15] These goals were integrated into China's nationally determined contributions to Paris Agreement emissions reductions. In 2016, China released the 13th Five-Year Plan (2016–2020) for its energy, coal industry, and power sectors, which proposed goals and policies to improve efficiency, close backward mines, aid workers, and cap coal output, use, and coal power capacity during the planning period.[16–18] In 2017, China's National Development and Reform Commission released the Energy Production and Consumption Revolution Strategy, 2016–2030, which further detailed energy decarbonization targets including non-fossil primary energy shares of at least 15% (2020), 20% (2030), and 50% (2050) as well as reduction of carbon emission per unit of gross domestic product (GDP) by 60%–65% in 2030 compared with 2005 levels.[19] In 2019, China's National Energy Administration began implementing China's Renewable Electricity Quota and Assessment Method with total and non-hydro quotas at the province level to fulfill the non-fossil primary energy goals.[20]

These measures have achieved some positive outcomes. Coal use has flattened out since 2013 while overall energy use and GDP have risen (Figure 1),[22,23] which demonstrates what an active and earlier coal-transition policy enacted in China could deliver. However, they appear to be inadequate for achieving the IPCC 1.5°C or even 2°C maximum-warming goals.[24,25] Multiple models show that achieving these goals requires coal's share in China's electricity generation to approach 0% by 2050.[26–28] Several barriers are impeding China's rapid transition away from coal.

First, a rapid transition requires early retirement of substantial coal-generation capacity while canceling newly planned coal projects.[29,30] China has been canceling planned coal projects since 2016 due to overcapacity and air pollution concerns, and canceled more than 130 GW of planned coal projects in 2019 alone.[30] However, by the end of 2019, about 80% of China's coal capacity was built after 2000 (Figure 2). Many studies have shown that continued operation of existing coal plants is incompatible with the 1.5°C pathway.[31] Hence, a rapid transition away from coal requires an earlier retirement of plants than would be necessary owing to purely operational criteria. The recent COVID-19 pandemic is closing the window for coal and speeding coal's demise in the United States and Europe. However, in China the need for economic stimulus might relax investment in coal power, hence allowing for a continued role for coal in the near future.[32]

Second, China's coal consumption extends beyond the power sector. Power generation accounted for 58.8% of China's total coal consumption in 2019, with the rest attributed to industrial

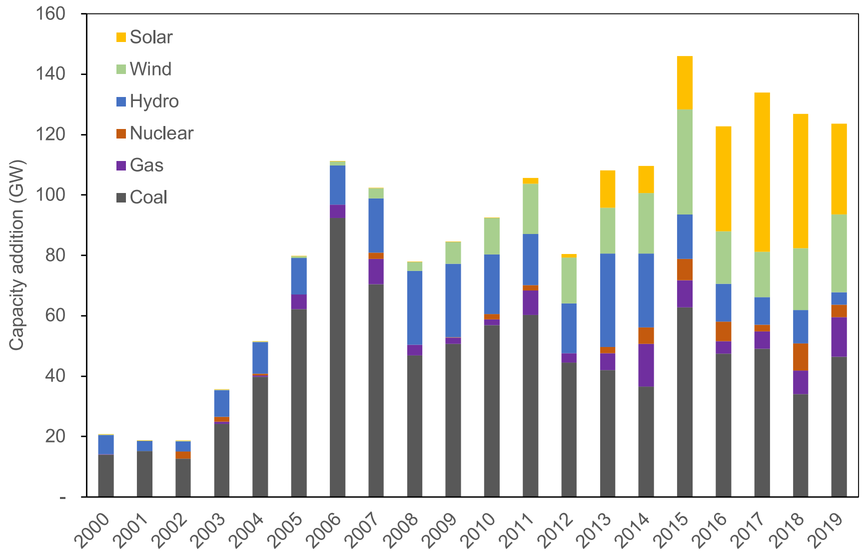

Figure 2. China's Annual Newly Added Capacity by Technology from 2000 to 2019
Source: Electricity Quick Statistics from 1999 to 2019, China Electricity Council. Note: the capacity additions are calculated based on the statistics of total capacity by technology of two consecutive years. The source data of all charts are available for download at https://github.com/drganghe/Rapid-and-Just-Coal-Transition-in-China and https://doi.org/10.5281/zenodo.3949850.

uses (e.g., coal burners and production of iron and steel accounted for 16.4% of total coal consumption, building materials for 9.4%, chemicals for 7.4%, and residential and other uses for 8%).[33] Electrification and efficiency improvements could largely replace coal use in the building sector (coal for heating) and the transport sector (coal to oil products). However, there are still significant barriers to replacing coal use in China's industrial sector.[34] In addition, the dispersed coal use in the residential sector is more difficult to regulate compared with the relatively centralized and well-documented power and industrial sectors.[35]

Third, a rapid transition presents economic and social challenges including impacts on employment, local tax revenues, and existing coal-asset owners (the stranded-assets problem). In Shanxi, one of the largest coal producers in China, coal-related industries contributed 29% of its GDP and 46% of its tax revenues in 2018. Given that coal is one of the largest sources of employment, GDP, and tax revenues in coal-producing regions, this reliance on coal presents persistent inertia to transition away from coal without additional assistance policies.

Fourth, the motivations and incentives of key stakeholders in the coal value chain are not always aligned. The central government, which focuses on social stability and environmental regulations, often favors more stringent targets for the coal phaseout compared with local officials, whoe promotion s mainly based on economic growth and thus may be motivated to delay or weaken phaseout implementation.[36] Indeed, coal interest groups are resistant to the transition. One manifestation is the collusion between coal regulators and coal-producing firms affecting workplace safety and leading to high death rates in coal mines.[37] Coal-related stakeholders and interest groups, as the major "losers" from the structural change, could also be a persistent barrier to coal transition.[38]

THE CASE FOR A FASTER TRANSITION AWAY FROM COAL

Despite the barriers, several developments and opportunities suggest that China has the capacity to accelerate its transition away from coal. The coal phaseout increasingly aligns with energy economics and public-policy priorities, particularly the urgent need to cut air pollution and greenhouse gas emissions from coal combustion.

Coal consumption in China peaked in 2013 and has roughly plateaued since then. COVID-19 led to an immediate drop in coal use but this rebounded soon when economics were back on track.[39,40] Slowing GDP growth, a structural shift away from heavy industries, and more proactive policies on air pollution and clean energy have all contributed to this plateauing effect.[41] In 2017, China's National Development and Reform Commission announced plans to cap coal power capacity at 1,100 GW and to stipulate a minimum average efficiency of 40% for all existing coal powerplants by 2020.[42] However, China's coal power capacity reached 1,040 GW by the end of 2019, which leaves only 60 GW space to grow if this policy is strictly adopted. Nonetheless, the introduction of a coal cap, even if the cap might be adjustable, is an indicator of the mindset shift from unconstrained coal expansion to coal control policy.

Declining costs for other electricity technologies are making a rapid coal phaseout more economically attractive. The costs of solar photovoltaics (PV), wind, and battery storage have decreased rapidly in the past 10 years. The global weighted-average levelized cost of electricity of utility-scale solar PV, onshore wind, and battery storage has fallen by 82%, 40%, and 87%, respectively between 2010 and 2019.[43,44] Additional projected cost reductions would present opportunities for more aggressive renewable-energy deployment and power-sector decarbonization than assumed in previous policy efforts. For example, one study suggests that continued cost trends for renewables will result in 62% of China's electricity coming from non-fossil sources by 2030 at a cost that is 11% lower than achieved through a business-as-usual approach. China's power sector could halve its carbon emissions (compared with 2015 levels) at a cost about 6% lower compared with a business-as-usual scenario.[45] Another recent study shows the technical and economic feasibility of phasing out China's coal power plants by 2040 if all new electricity demand is met by non-coal generators and all existing coal generation is replaced with non-coal generation at least by the end of the original coal-plant depreciation schedules, i.e., beginning in the early 2020s.[46]

Co-benefits from reduced air pollution and water use also increase the attractiveness of a rapid coal phaseout. Air pollution control is a top priority for the Chinese government. For example, the implementation of Air Pollution Prevention and Control

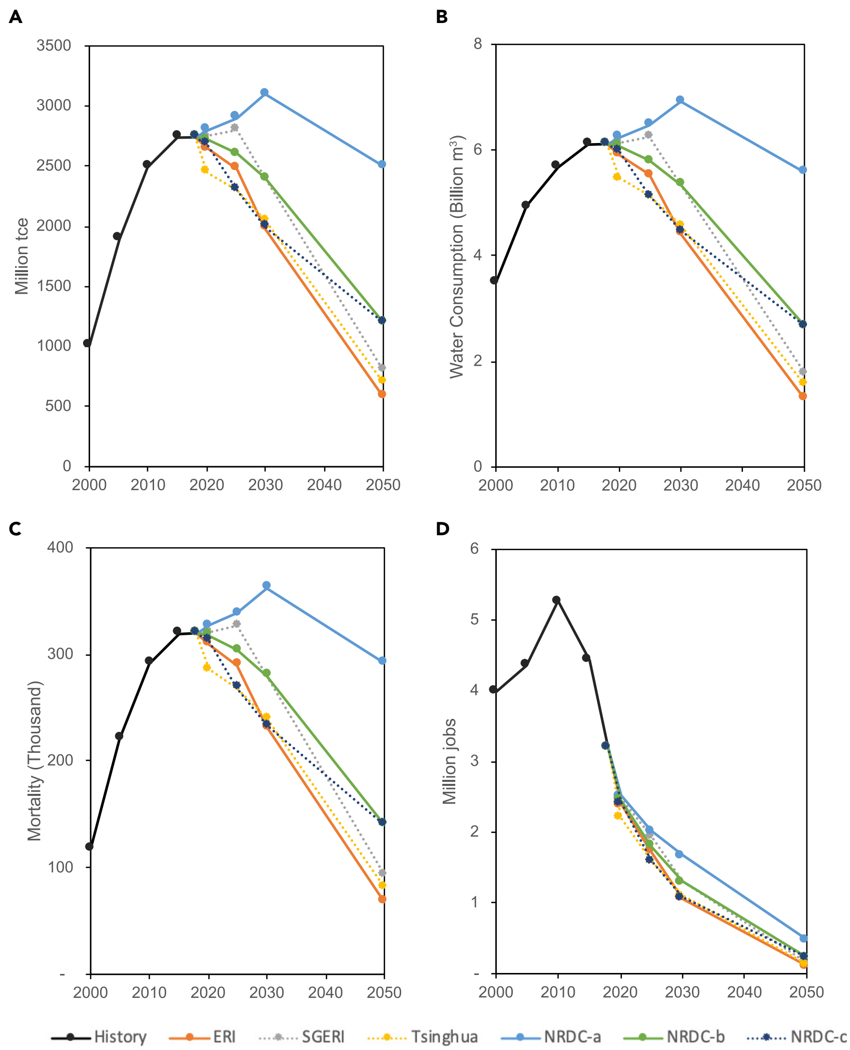

Figure 3. Notable Scenarios of Coal Consumptions and Their Impacts up to 2050 in China

(A) Coal consumption. Solid lines are three selected representative scenarios that indicate high, medium, and low coal consumption trajectories.

(B) Coal-related water consumption. Total coal-related water consumption is summed from coal power water consumption for cooling and coal mining water consumption.

(C) Mortality to which coal contributes. We assume that the mortality rate of coal use stays the same as that of 2013. 2013 coal consumption was 2,809 MTCE, and premature deaths in 2013 attributed to all coal use was reported as 328,011.[50]

(D) Employment in the coal mining sector. We assume a declining employment rate[50] in the coal industry arising from efficiency improvement and penetration of mechanical mining. The rates are set based on historical trends and experts' inputs. Source: Data up to 2018 are historical data from China Statistical Yearbook 2019 and IEA[54] (International Energy Agency); coal consumption projections are extracted from research by ERI[55](Energy Research Institute in National Development and Reform Commission), SGERI[56] (State Grid Energy Research Institute), Tsinghua[25] (Tsinghua University), LBL[57] (Lawrence Berkeley National Laboratory), and NRDC (Natural Resources Defense Council).[58] Water consumption, mortality, and employment data are authors' estimates based on coal consumption scenarios and the source data are available at https://doi.org/10.5281/zenodo.3949850.

Action Plan—issued by the State Council of China in 2013—reduced annual average concentrations of $PM_{2.5}$ by 33.3% in 74 key cities between 2013 and 2017. The improved air quality in 2017 reduced deaths by 47,240 in the 74 cities, compared with mortality in 2013.[23] Based on the coal consumption projections from multiple high-profile research institutions, we estimate that the most aggressive coal-transition pathway could reduce premature death related to coal combustion by 224,000 in 2050 compared with the business-as-usual scenario.[47–50] Similarly, our maximum estimated reduction in water consumption is about 4.3 billion m^3 in 2050.[51–53] Figure 3 illustrates the ranges of potential impacts and co-benefits.

A JUST TRANSITION AWAY FROM COAL

Transitioning rapidly away from coal presents social justice issues, particularly concerning the potentially precipitous elimination of coal-related jobs. For example, in 2019, eight EU countries—France, Italy, Ireland, Denmark, Spain, the Netherlands, Portugal, and Finland—announced that they would phase out coal-fired electricity by 2030. While the transition is driven both by market economics and governmental regulations, such a short time frame is unlikely to give workers in coal-related industries sufficient time to plan for, retrain for, and transition to new, similarly remunerative careers without policy support. For this reason, the near-term sacrifice made by workers and affected communities for global climate stability merits societal assistance that goes beyond the usual welfare systems or social safety nets. Coal-transition support is therefore a necessary measure for coal workers and should be considered by policymakers in coal-dependent countries.

Coal-related employment in China has already been declining for years as China's strategic plan to transition toward a more sustainable and service-based economy has undermined the economics of coal. After a decade of rapid expansion that helped power China's boom, the number of workers directly employed in coal companies peaked at 5.3 million in 2013, dropping to 4.88 million in 2014 and 3.21 million in 2018 (Figure 3D). In particular, coal production and washing jobs started declining after the Chinese coal industry started to phase out older production capacity in 2016. Remaining coal workers are mainly those with relatively low education and skill levels, making further resettlement of laid-off coal workers more difficult. Many more coal-related jobs will disappear as the production efficiency of China's coal industry improves through mechanization.

China's coal-related jobs are distributed unevenly across provinces (Figure 4). For example, Shanxi is one of China's largest coal-producing provinces. It possesses approximately one-third of China's total coal deposits, and coal is considered

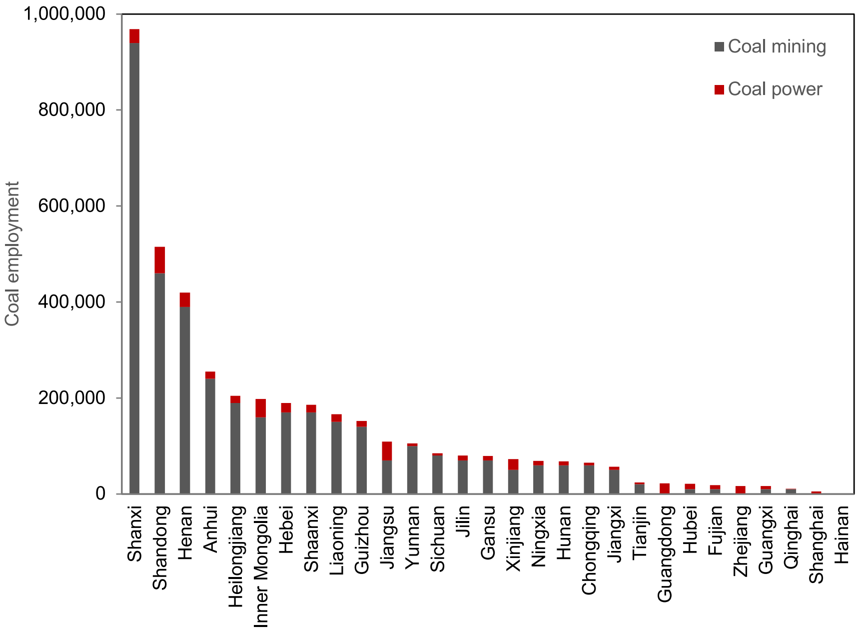

Figure 4. China's Employment in Coal Mining and Coal Power across Provinces in 2015

Coal mining jobs are centered at a few coal-producing provinces, and coal power jobs are more dispersed. Sources: coal mining employment data are from NRDC;[61,62] coal power employment data are from the Center for Global Sustainability, University of Maryland.[63]

a source of regional identity as well as income.[59] Shanxi's coal-related employment followed the national growth trend through 2011. It is difficult to find precise provincial data for more recent years, but 2016 statistics published by the Global Subsidies Initiative and the International Institute for Sustainable Developed indicated that Shanxi's coal industry alone employed approximately 976,000 workers.[60] The regional coal mining employment of Shanxi constitutes almost one-fifth of the industry's total national employment.

Employment is a key element of a just transition away from coal, which came to the fore following the Paris Agreement in the context of community renewal and the creation of high-quality jobs.[64,65] When China initiated policies to shrink its coal industry, it established policies to mitigate the impacts on affected groups. The central government has promised to provide 100 billion Yuan (~14.3 billion US dollars) in total for redundant workers in coal and steel industries since 2016. In recent years, relevant government departments have introduced policies to promote the settlement and re-employment of coal workers. For example, the central government formulates specific employment-support policies for unemployed coal workers, providing them with free employment guidance, job placement, consultation, and other services. Some subsidies are offered to laid-off coal workers who have difficulty finding jobs immediately. State-owned coal enterprises should provide skills training, such as entrepreneurship training for former employees who are willing to start their own businesses.

A successful coal transition involves changes through the whole coal value chain transition. Various ancillary, upstream, and downstream industries will also decline during the coal phaseout, and thus a just transition applies to them as well. The power-generation sector, coal-transportation sector, and many other industries have already experienced structural adjustments because of China's transition. Employment will also decline in the coal-fired power industry, which is China's largest coal consumer. A 2010 study by the International Labor Organization estimated that, on average, 62 workers would lose their jobs for each 10 MW in capacity closure at that time, and only 10% of those would be re-employed in new capacities, with the remaining 90% requiring employment assistance.[66] To assess the actual employment impact and tackle the issue along the coal value chain, analysis at finer geographic resolution and targeting each of the major corporations will be needed.

A just transition away from coal also relates to energy access for low-income groups that rely on abundant, cheap, and readily available coal for basic electricity service and winter heating. Electricity access is fundamental to education, public health, and digital services. China achieved electricity for all by the end of 2015 through a mix of distributed technology and grid extension largely powered by coal.[67] A large nationwide household survey in 2013 showed that coal contributed about 11.4% of rural households' energy supply[68] and about 6% and 29.6% of the rural households still use coal as a main fuel for cooking and space heating, respectively.[69] From the winter of 2017 to the spring of 2018, "coal to electricity" and "coal to gas" policies were vigorously promoted in the Beijing-Tianjin-Hebei areas. The energy substitution was capable of generating large air pollution mitigation and human health benefits.[70,71] However, owing to the rush for quick results and inadequate planning and implementation, some areas in Hebei faced gas shortages, and basic winter heating supplies could not be guaranteed.[72] Policy makers will have to address the social and environmental justice issues of removing coal as an energy supply option among rural households.

CONCLUSION AND POLICY IMPLICATIONS

The scale and scope of China's transition away from coal are unprecedented. Coal consumption peaked in the United Kingdom at 180 million metric tons of coal equivalent (MMTCE) in 1957 and in the United States at 780 MMTCE in 2007—only 6.4% and 27.9% of China's coal consumption level at 2,810 MMTCE in 2013 as the peak to date. The ability of China to manage this transition in a rapid and just manner will have a significant impact on how China and, to a large extent, the world use energy and address climate change. Here we propose an integrated political-socioeconomic perspective targeting an integrated value chain to highlight a few overarching strategies and policy implementations to accelerate China's transition away from coal. We further identify important unanswered questions about the transition.

Creating a Task Force

A dedicated task force or commission should be mandated to facilitate the transition and serve the best interests of affected stakeholders, including the states, corporations, workers, communities, and consumers along the coal value chain. This commission should have as wide a societal and geographic representation as possible to ensure that all stakeholders are included. A special task force was designated in Germany, through the German Coal Commission (GCC), and in Canada, through the Task Force on Just Transition for Canadian Coal Power Workers.[73,74] In the German case, the GCC not only guided labor policies but also advised on the coal-plant retirement deadline. One way to jump-start such a commission in China would be to create a coal transition special task force in the already functioning National Energy Commission. The task force would produce long-term goals, strategies, and policy recommendations, and leave implementation and enforcement details to administrators and legislators. Because the transition will span over 30 years, it also makes sense to build flexibility into the task force, including periodic milestones and revisions.

Implementing Instrumental Policies

Several additional policies would accelerate the transition. (1) Manage demand growth through efficiency. Future coal capacity is responsive to future energy demand,[26] and energy efficiency can reduce electricity consumption by as much as 5,000 TWh in 2050 compared with a business-as-usual scenario.[75] (2) Restrict the construction of new coal powerplants. No new coal plant should be allowed when comparable clean energy alternatives exist, which is increasingly a reality as renewable costs decline and renewable electricity achieves grid parity.[45] (3) Allow for earlier retirement of existing coal plants, prioritizing locations and plants where the operational economics are unfavorable. Adopt a rule for coal plants to retire no later than their decommission or depreciation schedule. (4) Phase out subsidies to the coal industry. China's coal industry is already declining and shedding jobs, but continuing subsidies keep it competitive. Support to coal production and coal-fired powerplants include providing overseas financing for up to 24.5 GW of coal-fired power plants through the funding of the state-owned enterprises.[7] Removing coal (and other fossil-fuel) subsidies would help alternative energy sources compete on a level playing field.[76] (5) Significantly increase investment in solar, wind, and energy storage to continue driving renewable expansion and integration. (6) Build international partnerships on coal phaseout. It would be significant if China partners with other countries in a coalition or other forms of clubs[77–79] to share strategies and experiences, support just-transition programs, scale up coal transition beyond the domestic efforts, and step up to global leadership.

Coupling of Transition Plans with Just Treatment of Workers and Their Communities

Just-transition measures should include retraining coal workers, especially those at the beginning of their careers, for economic activities aligned to the broader economic transition and diversification strategies. One example of a feasible re-employment activity would be a new public program for environmental restoration. Appropriate programs would require skill sets similar to those coal workers already have, or present low barriers to entry. Program funding could come from a tax on pollution and carbon emissions.[80] Such an approach would also enhance social equity, yielding a double dividend by curbing emissions while funding the just transition. Additional just-transition measures should include enhancing the social safety net of health, retirement, and unemployment insurance at the national, provincial, and local levels. Support should be directed to workers, not corporations, otherwise it would merely be another form of subsidy to the coal industry.

Important questions about China's transition away from coal remain to be answered, many of which revolve around the pace of technological innovation and societal changes. Disruptive technologies, such as nuclear fusion, might reshape the energy landscape and accelerate the coal transition, although uncertainty still surrounds the viability and potential timeline of commercial fusion. If coal has any future, it will be highly dependent on large-scale deployment of carbon capture, sequestration, and utilization—a technology that works but has not been proven economically viable at meaningful scales.[26,36] Renewables and large-scale electricity storage have their limitations as well. Challenges include developing the materials, manufacturing, installation, and integration capabilities to enable those technologies to replace coal rapidly. The life-cycle environmental impacts of battery storage also require further investigation. Finally, the transition away from coal must overcome inertia related to established social, economic, and infrastructure systems.

As the ancient Chinese philosopher Laozi, one of the founders of Taoism, said, "A journey of a thousand miles begins with a single step." China has taken its first steps to transition away from coal. The journey ahead will be a winding one—but, with effective plans and policies, it could be a rapid and just one as well.

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AUTHOR CONTRIBUTIONS

G.H. conceptualized the research, analyzed data, and wrote the manuscript; J.L. and Y.Z. helped conceptualize the paper and contributed writing; W.Z. assisted with data collection and analysis; G.L. assisted with literature review and writing; and C.Z., W.P., M.L., and F.Y. contributed conceptualization, comments, and revisions.

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