An ultra-low emission coal power fleet for cleaner but not hotter air

Yana Jin1,2,*, Wei Peng3 and Johannes Urpelainen4

1 William & Mary, Williamsburg, United States of America
2 Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, Stockholm, Sweden
3 School of International Affairs and Department of Civil and Environmental Engineering, Penn State University, University Park, PA, United States of America
4 Johns Hopkins School of Advanced International Studies (SAIS), Washington DC, United States of America

E-mail: yjin05@wm.edu

Keywords: air pollution, climate change mitigation, coal-fired power plants, emerging economies, flexible coal, ultra-low emission

1. Introduction

Concerns about climate change have provoked global backlash against coal-fired power generation, which remains the backbone of major power systems in China, India, and elsewhere. Air pollution has galvanized opposition to coal-fired power generation, but counting on concerns over air pollution to promote the coal-to-renewables shift in the long run is a risky bet. As the Chinese experience shows, the best available technologies now enable coal-fired power plants to stop producing air pollution. By investing in an ultra-low emission (ULE) coal fleet, emerging countries can solve the air pollution problem in an affordable manner.

Recognizing this reality, we call for an updated view regarding the role of coal power in emerging countries and in the global effort to avoid climate disruption. The prospect of a ULE coal fleet is a major short-term opportunity for emerging countries around the world. With the best available technology, virtually removing air pollution from coal-fired power generation brings substantial health benefits.

This approach need not compromise long-term decarbonization. Emerging countries can rely on ULE to solve their air pollution problem now and then prepare for a low-carbon future by making coal-fired power plants more flexible suppliers of electricity when intermittent renewables fail to do so. As technological progress continues to address the intermittency problem and policymakers develop tools to encourage flexible generation, reducing reliance on coal-fired power generation will likely become easier and less expensive.

2. Ultra-low emission technology and performance

The best available pollution control technology for coal-fired power plants is ULE technology. ULE-retrofitted coal units emit SO2, NOx and PM2.5 at levels below 35, 50 and 10 mg/Nm3 (on base of dry flue gas, 6% O2), comparable to natural gas units. Three groups of mature technologies form the basis of ULE: low-NOx burners (LNBs) and selective catalytic reduction (SCR) for NOx, electrostatic precipitator (ESP) or fabric filter (FF) for PM, and flue gas desulfurization (FGD) for SO2 (Romero and Wang 2019). The operation of ULE technologies needs electricity and thus increases CO2 emissions, but this effect is relatively small, as the average coal consumption rate for power supply is increased by only 0.81% (or 2.51 g kWh−1). When combining efficiency-improving adjustments with the ULE facilities, the ratio drops to 0.53% (Wei et al 2017). ULE coal power is both technically feasible and economically affordable in emerging countries.

China has already made rapid progress in reducing air pollution from its coal fleet. In 2015, the Chinese government mandated that the deployment of ULE facilities be finished by 2020. By May 2019, more than 800 GW (or 80%) of the national coal fleet had been converted to ULE units. In 2017, China’s national ULE retrofit cost was 0.07–0.37 US cents kWh−1. The on-grid tariff for electricity generated by ULE units increased, but still remains one-third lower than that of gas fired units.5

Over the past decade China’s national emission standards for SO2, PM and NOx from coal power plants were tightened twice, by two orders of magnitude (figure 1). By operating the ULE retrofit equipment, the most stringent standards can be achieved. This is shown in 2014–2017 data from a continuous emissions monitoring systems (CEMS) network covering almost all the power capacity in China (Tang et al 2019). Despite concerns regarding the credibility and accuracy of CEMS data, substantial

5http://energy.people.com.cn/n1/2019/0213/c71661-30641808.html
Figure 1. The pathway of a 2 °C-consistent global coal-fired power generation fleet. The graphic shows how the global coal-fired power generation fleet needs to evolve over time to first reduce air pollution and then mitigate climate change. From left to right, the columns indicate increasingly advanced technology. The rows summarize implications for air quality and health, climate mitigation, and cost of power generation. In air quality and health benefits, indoor health benefits follow 20 years later because the risk of chronic disease has a delay of onset.

Tall stack: emissions from tall flue gas stacks of coal-fired power plants
Household stoves: emissions from cooking-and-heating stoves as an ambient air pollution source
Mobile: emissions from vehicles and non-road mobile sources
CCS: carbon capture and storage
O&M: operations and maintenance cost
Short-lived climate pollutants: black carbon, methane and tropospheric ozone that are powerful climate forcers remaining in the atmosphere for much shorter time than CO₂ but have much stronger potential to warm the atmosphere

pollution reductions have been validated using other methods as well (Karplus et al 2018).

Given that China was able to add effective air pollution controls on its massive coal fleet in less than five years, deploying ULE retrofits also holds promise for other countries. In 2015, India set ambitious new emissions standards for power plants, which are close to China's 2011 standards (figure 1). Retrofit costs to meet these standards are estimated to be 0.45–1.58 US cents kWh⁻¹ (Garg et al 2019). These costs are higher than those in China's, as Indian coal-fired power plants currently have inadequate air pollution control equipment.

Eliminating air pollutants from the coal fleet would translate into major air quality improvement and public health benefits for these populous countries (figure 1). In 2013, 0.52 million premature deaths in China and 0.27 million in India were attributable to PM₂.₅ pollution from coal-fired power generation (Gao et al 2018). Thus, compared to the baseline coal fleet in 2013, ULE retrofits can avoid these adverse health impacts. The benefits increase further if countries also aim to electrify their transportation and residential sectors (Peng et al 2018, Zhang et al 2019).

3. Implications for energy and climate policy

The climate implications of transitioning to a ULE fleet require careful thought. At first glance, ULE does not seem to favor global low-carbon development. The massive deployment of ULE retrofits in coal power plants may lock in high levels of CO₂ emissions in the power sector, if a young and large coal fleet remains in normal operation for extra decades.

To manage a ULE fleet and buy time towards decarbonization is a grand challenge. Coal power’s long and fundamental role in the energy system implies economic, political, and societal struggles in this transition, and calls for coordination across jurisdictions and sectors (Markard 2018). Here we first highlight three engineering implications that will be vital for a climate-friendly ULE coal strategy, and then summarize lessons from China’s recent experience for economics and public policy.

3.1. Retrofitting selected units

Early retirement of coal units is necessary. To limit global warming to 2 °C, let alone 1.5 °C, by the
end of the century, an average lifetime of only 20–35 years is permissible, far shorter than the historical value of 46 years (Cui et al 2019). The first step is to identify units with high pollution, health, and climate impacts. The next is to identify whether alternative and cleaner power is available and affordable to the end-users. If yes, retirement can start immediately from those units that have the lowest cost effectiveness of upgrading—those not worth ULE or flexibility retrofits.

A climate-friendly ULE strategy should only entail retrofitting existing coal capacity. New ULE coal can be justified only for a few exceptions on the basis of development priorities such as universal electricity access and necessary industrial development. Without alternative modern energy resources, it may be reasonable to have limited ULE coal in the least developed countries. However, adding new ULE units in an established energy system is risky. Sustaining the role of coal-fired power generation in a carbon-constrained world depends on yet unproven assumptions, such as carbon capture and storage (CCS) being widely available soon after 2050 (Selosse and Ricci 2017). In general, new capacity should not be coal-fired.

Finally, the ULE units need technology improvements to allow for more flexible generation. In the future, coal power should play a supportive role in managing peak power demand, instead of always running at maximum capacity as a baseload power source. Coal plants must be capable of more frequent start-ups, deep cycling, and rapid load changes, which requires a flexibility retrofit (figure 1). Compared to the mature, standardized ULE technology, flexible coal is complicated as there are more system control components. On the other hand, adding flexibility can be considered consistent with early retirement because coal units under flexible generation depreciate faster. ULE units with flexibility retrofits have a higher emissions intensity for CO₂ and NOₓ, but the absolute emissions are lower as they operate at lower load factors (Gu et al 2016). Because flexible ULE coal both reduces air pollution and mitigates climate change, it buys time for governments and investors to improve CCS technologies before making massive capital investments.

3.2. Lessons from China

Despite impressive progress, China’s ULE coal strategy could be more cost-effective and climate-friendly.

The role of small (and often old) units should be re-examined. Over the past decade, small units from 100 to 200 MW were chosen to retire first, whereas large units (300, 600, 1000 + MW) were prioritized for ULE retrofits (Gu et al 2016). However, starting ULE retrofit from small units is more efficient due to the lower marginal abatement cost (Zhao et al 2016). Furthermore, although small units are more carbon intensive under standard operation, they can be useful in flexible generation to balance intermittent renewables. Small units can adopt several peak shaving operation modes, whereas large units can only apply a low-load mode. Many small units thus can add up to balance the load more smoothly, contributing to major cost savings at the system level (Gu et al 2016).

Incentives can make or break the desired transition. After years of weak compliance, China used the powerful target-responsibility tool to incentivize local authorities to invest in pollution control. The latter quickly mandated the installation of air pollution control retrofits in coal-fired power plants (Jin et al 2016). Economic incentives such as price premia, higher planned capacity factors, and a reduced pollution fee made it profitable to operate the retrofits in power plants (Xu 2011). China has only finished 20% of the flexibility retrofit target by 2020*, and the economic value of flexibility needs to be revealed by market mechanisms, such as dynamic electricity pricing that encourages generation when intermittent supplies are not available. When flexible coal technology matures, appropriate incentives can support the management of a low-carbon power system based on renewables. These incentives could also reduce political opposition of the energy transition towards renewables, as owners of coal-fired power plants will be compensated for the flexibility they provide.

Major capital investment decisions require dynamic thinking and some form of centralized authority. Together with retrofits, China implemented the ‘replacing small units with large ones’ policy. Considering the remaining lifetime is longer for new and large units, the long-term accumulated air pollution control and energy saving benefits of such a policy are in doubt. Moreover, during 2014 to 2016, the approval of new projects was temporarily delegated to provincial governments. Newly approved units flooded the market, and Beijing quickly froze local authorization. Most of the projects were cancelled, however significant numbers of units are still under construction (Alkon and Wong 2020). Over the past decade, the result of these costly replacements and new capacity developments was an enormous coal fleet that consisted of large and young units. These units raise barriers to the energy transition away from a baseload of coal-fired power generation, as their large size and young age make early retirement costly to the owners and the society.

4. Prospects and challenges

Most emerging countries will need coal power over a long period of time. Expensive natural gas especially

*http://www.ccc.org.cn/detail/index.html?1-282218 (accessed: 14 June 2020)
in the Asia-Pacific region prevents a massive switch from coal to gas. Despite the large resource potential for renewables (Khare et al 2013, He and Kammen 2014, 2016), coal is needed until technologies like storage which can solve the renewable intermittency problem become widely available. The ULE technology makes this coal-intensive outlook cleaner. Air pollution can be eliminated in an affordable manner through ULE coal power.

Decarbonization mainly depends on how the existing coal fleet is managed. Chinese power plants have an average lifetime of 24 years (Cui et al 2019), which is in the ‘safe’ range for climate stabilization goals. China has the investment capacity to add flexibility retrofits to ULE coal and further decarbonize the power sector by increasing renewables. Political and social conditions are also favorable for a low-carbon outlook. China’s domestic strong political will and global climate negotiations reinforce this commitment.

From the perspective of development and energy infrastructure choices, other emerging countries face difficult decisions. It is unclear whether increasing the share of ULE coal can buy them time for a low-carbon transition when compared to alternative strategies. Obviously, individual countries may have different optimal pathways depending on their resource endowments and economic development.

Uncertainty is amplified when one considers factors beyond the energy system. As China’s experience shows, to achieve a climate-friendly ULE coal strategy is a high-stake public policy challenge. It is doubtful whether and how other countries can implement and enforce the policies needed to move into a ULE-based, flexible generation system. Will they be able to implement retrofits and commit to running them for 20 instead of 40 years? These costly investments require a high level of political commitment and institutional capacity, and India, for example, has already faced difficulties enforcing air pollution standards for coal-fired power plants (Garg et al 2019). The challenge is urgent because today’s investments in coal-fired power generation will have effects for decades to come.

Acknowledgments

Y J thanks Shiqiu Zhang and Dongyang Zhao at Peking University for inspiring this perspective. Y J was funded by the Environmental Science and Policy Mellon Postdoc program and the Global Research Institute at William & Mary, and the Mäler Scholarship programme of the Beijer Institute of Ecological Economics.

Author contributions

Conceptualization, methodology, investigation, writing (review and editing): Y J, W P and J U; article screening, writing (original draft), visualization, supervision, project administration: Y J

Data availability statements

Any data that support the findings of this study are included within the article.

ORCID iDs

Yana Jin https://orcid.org/0000-0001-9123-0407
Wei Peng https://orcid.org/0000-0002-1980-0759

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