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Coal, Gas, or Nuclear: Asia's Inconvenient Energy Choice

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EXECUTIVE SUMMARY

This working paper considers the potential for natural gas and nuclear power to displace coal in key Asian and Pacific Rim countries and explores the policy levers that could enhance fuel switching.

Main Argument

Because of its wide availability, low cost, and relatively modest infrastructure requirements, coal is the dominant fuel in Asia for nontransportation uses, and Asia is the world's dominant consumer of coal. However, burning coal causes air pollution problems and is a major contributor to climate change. Renewables and energy efficiency have an important role to play in helping the world move away from coal and other fossil fuels, but over the next several decades, Asia's carbon dioxide emissions from the energy sector will be a stronger function of the competition between coal, natural gas, and nuclear. Public skepticism about nuclear power has driven countries like Japan, Germany, and Indonesia to pursue policies that comparatively favor coal, whereas public opinion in other countries like China, South Korea, India, and the U.S. has been relatively more negative about coal, and thus their governments have had more scope to pursue nuclear. Even in traditionally pro-nuclear countries like China and South Korea, however, cracks in support for nuclear energy may be emerging. Going forward, government policies on carbon pricing, natural gas pricing, and nuclear support will crucially shape the balance of coal, gas, and nuclear in the supply mix.

Policy Implications

- In much of Asia, nuclear power is already economically competitive with alternatives in theory; in practice, however, costs can escalate drastically due to regulatory delays, and only states with existing nuclear energy capability and mostly supportive public opinion, such as China and perhaps South Korea, have much prospect of significant growth in nuclear energy over the next two decades.
- In the U.S., low natural gas prices and competitive wholesale electricity markets mean that nuclear energy can only become economic with the advent of cheaper technologies.
- Price liberalization that allows gas prices to be determined by supply and demand rather than set administratively can encourage the development of additional gas supply in countries with significant gas resources.
- Imposition of a carbon price will help make natural gas, as well as of course nuclear, more competitive in Asia and also encourage the development of an energy system that is more resilient against future climate policy shocks.
- There is a strong logic for collaboration between nuclear startups in the U.S., where the regulatory climate for deploying new nuclear technologies is difficult, and pro-nuclear-power countries in Asia. That said, excessively loose regulation would pose risks for the entire global nuclear sector, which would be badly damaged by another accident.

Oil may be the world's most popular fuel for transportation, but coal is its dominant fuel for everything else. This is both a statement of fact and a testament to coal's competitive advantages. In 2013, coal accounted for 29% of the world's primary energy demand, second only to oil, and 41% of its electricity generation, unrivaled by any other energy source.[1] Coal is cheap relative to alternatives and widely distributed around the world. All it requires for large-scale, long-distance transport are railways, ports, and bulk ocean carriers. Coal has neither the geopolitical baggage of oil, the capital-intensive transportation requirements of natural gas, the site specificity and vulnerability to droughts of hydro, the safety and security concerns of nuclear, or the high cost and intermittency of wind and solar. For emerging economies in particular, coal is almost invariably the most economic and accessible choice for power—the world's default fuel for electricity generation and industry.

Because the negative environmental externalities of coal go largely unpriced, the dominance of coal presents major environmental problems. Coal emits significantly more carbon dioxide (CO_2) per unit of energy produced than any other major fossil fuel. In many developing countries, coal is used without adequate controls on local pollutants such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulates, leading to acid rain, smog, and serious health problems.[2]

Global coal use is expected to grow, which will only heighten these problems. The International Energy Agency (IEA) predicts an 11% increase in coal use from 3,929 million tons of oil equivalent (Mtoe) in 2013 to 4,414 Mtoe in 2040.[3] (Unless otherwise noted, IEA projections cited in this paper are from the IEA's central scenario, the New Policies Scenario.[4]) The largest growth will occur in Asia, especially India and Southeast Asian countries. In 2013, Asia accounted for 71% of the world's coal consumption (versus 38% of the world's GDP and 54% of its population); in 2040, the IEA projects that the region will account for 80%.[5] This

[1] International Energy Agency (IEA), *World Energy Outlook 2015* (Paris: OECD/IEA, 2015), 584–86.

[2] If environmental regulators require it, emissions of SO_x, NO_x, and particulates can be dramatically reduced with modern abatement technologies. Capture and storage of CO_2, on the other hand, has not yet been demonstrated to be economic.

[3] IEA, *World Energy Outlook 2015*, 584.

[4] This scenario incorporates climate policies already in place as well as policies that governments have announced but not yet implemented.

[5] Coal consumption is from IEA, *World Energy Outlook 2015*, 278. We define Asia here as the IEA's groupings of OECD Asia Oceania plus non-OECD Asia; Eurasian and Central Asian countries are thus not included. GDP and

trajectory of coal growth is not compatible with meeting the target of limiting warming to two degrees Celsius that the Intergovernmental Panel on Climate Change deems necessary to avoid the worst climate change risks.

More aggressive government policies to curtail greenhouse gas emissions could alter this trajectory, shifting the playing field so that coal alternatives become more attractive, or so that coal is burned with carbon capture and storage (CCS) technology that keeps CO_2 from being released into the atmosphere. The coal industry has pushed CCS; most environmental NGOs, for their part, insist that coal must be replaced by wind and solar. In reality, neither CCS nor wind and solar are likely to be the principal supply-side technologies influencing coal-related CO_2 emissions over the next two decades. CCS is just too expensive as an add-on to an energy source whose main attraction is its low cost, and recent demonstration projects have experienced serious cost overruns and performance problems.[6] Wind and solar will continue to expand worldwide, but they have three major drawbacks that make them incapable of displacing large amounts of coal in the near and medium term. First, they are more costly than conventional energy technologies. Second, they are difficult to scale quickly enough to make a major dent in fossil fuel energy generation. (Although the compound annual growth rate in non-hydro renewable energy worldwide was 7.9% between 2000 and 2013, versus 4.1% for coal, the absolute increase in energy supply from coal was over fifteen times that of renewables—1,586 Mtoe versus 101 Mtoe—because it started from a much higher base.[7]) Third, and most importantly, the intermittent character of wind and solar means that they are unable to fully substitute for a baseload energy source like coal, at least until storage technologies become much more affordable. This means that renewables are not by themselves able to supply energy security for a country, even though they do not require procurement of fuel.

Over at least the next twenty years, the carbon emissions of the energy sector—and especially the energy sector in Asia—will on the supply side be shaped most importantly by the

population figures are from the World Bank, World Development Indicators, http://data.worldbank.org/data-catalog/world-development-indicators. GDP is by purchasing power parity, in constant 2011 international dollars.

[6] Both the Boundary Dam CCS project in Saskatchewan and the Kemper CCS project in Mississippi have faced major issues, with Kemper being the more troubled project of the two.

[7] IEA, *World Energy Outlook 2015*, 57.

competition between coal, natural gas, and nuclear energy.[8] This basic fact is inconvenient and therefore often goes unacknowledged. Environmental groups tend to breezily assert that replacing coal with renewables is straightforward and cost-effective.[9] The general public would also prefer to believe that renewables can solve all our problems such that difficult choices are not necessary. Governments in countries with strong antinuclear movements, like Germany and Japan, do not draw attention to the fact that nuclear phase-outs go hand in hand with growth in the share of fossil fuels.

From the policymaker's perspective, coal, gas, and nuclear all have their respective advantages and disadvantages. Coal is cheap and available, but coal plants are capital-intensive and have serious environmental issues. Natural gas has historically been more expensive and perceived as less energy secure, but gas plants are cheap, largely benign from a local pollution standpoint, and less carbon-intensive than coal plants by about a factor of two. (There is one very important caveat to the presumed climate benefits of natural gas, which is that the industry must take care of, and governments must regulate, fugitive methane emissions in both upstream and downstream operations, as methane is a very potent greenhouse gas.) The main concerns about nuclear energy are safety, security, waste storage, and very high capital costs that can rapidly turn a project unprofitable, especially if public and regulatory acceptance falter. The upsides are zero-carbon operation, no local pollution, and cheap fuel.

The goal of this paper is to explore the choice among coal, gas, and nuclear energy in the countries that consume the most coal, especially in Asia. It will look at how resources, institutions, policies, and public opinion in these countries have influenced the balance of coal, gas, and nuclear to this point as well as what policy tools are available to encourage greater substitution of coal with gas or nuclear energy in the future.

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[8] Efforts to reduce energy demand through efficiency are very important but beyond the scope of this paper.

[9] See, for example, Christine Shearer, Nicole Ghio, Lauri Myllyvirta, Aiqun Yu, and Ted Nace, "Boom and Bust 2016: Tracking the Global Coal Plant Pipeline," Coalswarm, Sierra Club, and Greenpeace, March 2016, http://sierraclub.org/sites/www.sierraclub.org/files/uploads-wysiwig/final%20boom%20and%20bust%202017%20(3-27-16).pdf. This report performs a very valuable service by tracking the coal plant pipeline but vastly oversimplifies the ease of replacing coal.

The Balance of Coal, Gas, and Nuclear in Major and Emerging Major Coal Consumers

Table 1 displays the 2013 total primary energy demand for coal, natural gas, and nuclear power for the ten largest coal-consuming countries, as well as the five Southeast Asian countries that are poised to significantly increase their coal consumption. Coal's most important application is in the power sector, but for some countries, there is appreciable consumption outside the power sector as well. The table suggests a few high-level observations about opportunities for displacing coal.

Table 1 *Total Primary Energy Demand (Power Sector and Outside Power Sector) for Coal, Natural Gas, and Nuclear: (a) Top 10 Coal Consumers, (b) Top 5 Southeast Asian Coal Consumers*

(a)	Total Coal (Mtoe)	POWER SECTOR (Mtoe)			OUTSIDE POWER SECTOR (Mtoe)	
		Coal	Gas	Nuclear	Coal	Gas
China	2045	1040	28	29	1005	127
United States	432	397	230	214	35	447
India	341	223	15	9	118	34
Japan	121	70	81	2	51	43
Russia	108	69	281	45	39	160
South Africa	95	59	0	4	36	5
Germany	82	67	17	25	15	63
South Korea	78	54	25	36	24	27
Poland	53	37	1	0	16	14
Australia	46	42	12	0	4	23

(b)	Total Coal (Mtoe)	POWER SECTOR (Mtoe)			OUTSIDE POWER SECTOR (Mtoe)	
		Coal	Gas	Nuclear	Coal	Gas
Indonesia	32	29	13	0	3	31
Thailand	17	8	23	0	9	19
Vietnam	16	6	8	0	10	2
Malaysia	15	13	18	0	2	24
Philippines	11	9	3	0	2	0.2

Source: IEA, *Coal Information 2015* (Paris: OECD, 2015); IEA, *Gas Information 2015* (Paris: OECD, 2015); and IEA, *Electricity Information 2015* (Paris: OECD, 2015).

First, China uses almost five times as much coal as the next largest consumer, the United States, so it is no surprise that China's actions are of particular importance. The Chinese government is well aware of the disadvantages of coal and is moving aggressively to build out both natural gas infrastructure and nuclear power. The IEA projects relatively flat consumption of coal in China through 2040.[10] An important question is whether China can go beyond just peaking coal consumption to actually reducing coal use by more than is currently projected.

Second, countries where substantial growth in coal consumption is expected provide important opportunities to shift the carbon emissions trajectory at relatively lower cost. The IEA forecasts that India's coal consumption will increase by nearly a factor of three (488 Mtoe in 2013 to 1,334 Mtoe in 2040) and that Southeast Asia's coal consumption will increase by more than a factor of three (130 Mtoe in 2013 to 446 Mtoe in 2040).[11] The major Southeast Asian coal consumers shown in Table 1 all use a mix of coal and natural gas at present. Anything that shifts this mix toward being relatively more gas-heavy could significantly reduce future coal consumption.

Third, there are substantial opportunities beyond the power sector for reducing coal use, especially in China, where consumption outside the power sector is almost as large as consumption within it. Most of the coal consumed outside China's power sector is directly used by industry. Iron and steelmaking is the largest category of industrial use, accounting for about 18% of China's total coal use, followed by nonmetallic mineral production (mainly cement), industry self-use (mainly coal to power mining operations), and chemical production. China's cement and chemical production operations are unusually dependent on coal compared with other countries, which suggests they could be good candidates for substituting coal with natural gas.[12] There is also an appreciable quantity of coal used directly in residential and commercial applications (68 Mtoe in 2013), which would likely be the first priority for replacement by gas.

Fourth, preserving and where possible growing nuclear capacity in countries that already have nuclear power capability is crucial to minimizing global fossil fuel use. As shown in Table

[10] IEA, *World Energy Outlook 2015*, 278.

[11] IEA, *World Energy Outlook 2015*, 278.

[12] Kevin J. Tu, "Appendix: A Statistical Review of Coal Supply, Demand, and Transport in China," in *The Global Coal Market: Supplying the Major Fuel for Emerging Economies*, ed. Mark C. Thurber and Richard K. Morse (Cambridge: Cambridge University Press, 2015).

1, the top seven coal-consuming countries all have nuclear power capability. (Japan's generation was negligible in 2013 due to the post-Fukushima idling of nuclear capacity.) The reality is that for the foreseeable future it will be possible to expand nuclear only where substantial capacity already exists, and often not even there. The five Southeast Asian countries shown have all contemplated developing nuclear power, and some of them have concrete plans, but none are moving forward at present, in part due to public concerns about safety that will be discussed in the next section.[13] The reality is that even if they did press forward, developing nuclear power capability is so time-consuming—on the technical side and, even more importantly, the institutional one—that it would likely be decades before significant coal could be displaced by nuclear. Much more important from a climate change perspective is that existing nuclear capacity around the world not be allowed to decline—first and foremost in the United States, which is the world leader in nuclear generation (799,000 gigawatt hours (GWh) in 2014, versus 418,000 GWh for second-place France[14]). And yet, barring some policy action to extend the lifetime of old nuclear plants and make them more competitive in an electricity market featuring very cheap gas, the United States faces a slew of retirements of old nuclear plants without a significant pipeline of new nuclear units to replace them.[15] Germany illustrates how nuclear retirements can reinforce the primacy of coal in the energy mix. Between 2000 and 2013, the 73.2 terawatt hour (TWh) increase in combined wind and solar generation in Germany was almost entirely negated by reduced nuclear generation (72.3 TWh), with coal generation declining only slightly (10.8 TWh).[16] China has aggressive plans to grow its nuclear fleet, but

[13] For more on Southeast Asia's nuclear capacity, see John Ruwitch, "Analysis: Southeast Asia Goes Slow on Nuclear," Reuters, February 2, 2012, http://www.reuters.com/article/us-asia-nuclear-idUSTRE8110HM20120202. Many Southeast Asian countries, with the important exception of Indonesia, also have surplus power capacity at the moment.

[14] International Atomic Energy Agency (IAEA), "Nuclear Share of Electricity Generation in 2015," https://www.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

[15] Data from the IAEA indicates that the median age of U.S. nuclear power plants is 37 years. See IAEA, "Nuclear Share of Electricity Generation in 2015." The Nuclear Regulatory Commission issues licenses to commercial reactors for a period of 40 years, renewable for another 20 years. For background on this policy, see U.S. Nuclear Regulatory Commission, "Backgrounder on Reactor License Renewal," http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.html.

[16] Data from IEA, *Electricity Information 2015* (Paris: OECD, 2015). Renewable subsidies significantly increased the price of power in Germany in the process.

these plans will not result in a net increase in global nuclear generation if countries like the United States, Germany, and Japan allow their existing plants to retire.

Fifth, most of the large coal-consuming countries in Table 1 are already accessing substantial quantities of natural gas; the question is whether they can significantly increase the share of gas. In all the countries in Table 1 except China, India, and South Africa, natural gas constitutes at least one-fifth of the combined primary energy demand for coal, natural gas, and nuclear. In China's case the low share of gas says more about the scale of coal than anything else; the country is the world's third-largest natural gas consumer.[17] As will be discussed later in this paper, the largest obstacle to increasing the share of gas in power generation is coal's lower cost.

Public Opinion and Government Priorities

Public opinion helps shape the way governments prioritize coal, gas, and nuclear energy.[18] As shown in **Figure 1**, two governments with aggressive programs to develop nuclear, China and South Korea, both have publics that, as of 2008, were significantly more negative about coal and oil power than nuclear power. A tracking poll by the Korea Nuclear Energy Agency found that public support for nuclear power in South Korea dipped in the wake of the 2011 Fukushima Daiichi accident (as well as subsequent scandals over fake certifications for nuclear plant equipment) but had largely recovered as of 2015.[19] By contrast, public support for nuclear power in Japan plummeted after Fukushima and has not yet recovered, complicating government efforts to restart idled reactors and forcing greater dependence on coal, oil, and natural gas.[20] The governments of Indonesia and Thailand have explored developing nuclear energy, but a negative

[17] IEA, *Natural Gas Information 2015* (Paris: OECD, 2015).

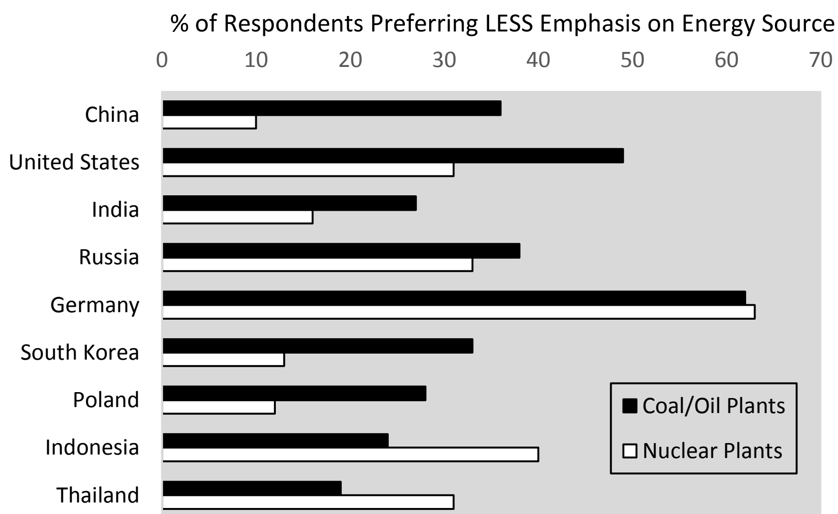
[18] Causality in the other direction is also possible if governments aggressively promote those energy sources that they wish to pursue among their citizens.

[19] Korea Nuclear Energy Agency, "2015nyeon 12wol wonjalyeog gugmin-insigjosa gyeolgwa" [May 12, 2015, Nuclear Power National Survey Results], January 4, 2016, http://knea.or.kr/new/news/insidedata_view.asp.

[20] Daniel Aldrich, James Platte, and Jennifer F. Sklarew, "Despite Meltdowns, a Tsunami and Public Opposition, Japan May Soon Restart a Nuclear Power Plant—or Several," *Washington Post*, July 20, 2015, https://www.washingtonpost.com/blogs/monkey-cage/wp/2015/07/20/despite-meltdowns-a-tsunami-and-public-opposition-japan-may-soon-restart-a-nuclear-power-plant-or-several.

public view of nuclear (or a lack of public confidence in their governments' ability to properly manage the technology) in these countries makes this option politically difficult. Indonesia has turned to its rich coal resources as its default energy source. In Thailand, NGOs have effectively blocked construction of domestic coal plants, so the state electricity company has focused instead on building coal plants in Laos and Cambodia from which it can import power.[21] The German public is extremely negative about both nuclear and thermal power and seems tolerant of high electricity prices, which makes the government's emphasis on renewable energy politically sensible even though it has done little thus far to shrink coal generation and associated CO_2 emissions.[22]

Figure 1 *Relative Unpopularity of Coal/Oil and Nuclear Power Plants in 2008*



Source: WorldPublicOpinion.org, "World Publics Strongly Favor Requiring More Wind and Solar Energy, More Efficiency, Even If It Increases Costs," 2008, http://www.worldpublicopinion.org/pipa/pdf/nov08/WPO_Energy_Nov08_longart.pdf.

Public opinion may not always reflect the actual risks, benefits, and challenges of different energy sources, of course. As an example, fatality rates from accidents in nuclear power plants have historically been several orders of magnitude lower than those from coal mining,[23] and the

[21] I am grateful to Bart Lucarelli for this point.

[22] Carbon capture and storage has also gone nowhere in Germany due to a lack of public support.

[23] Peter Burgherr and Stefan Hirschberg, "Comparative Risk Assessment of Severe Accidents in the Energy Sector," *Energy Policy* 74 (2014): S45–S56.

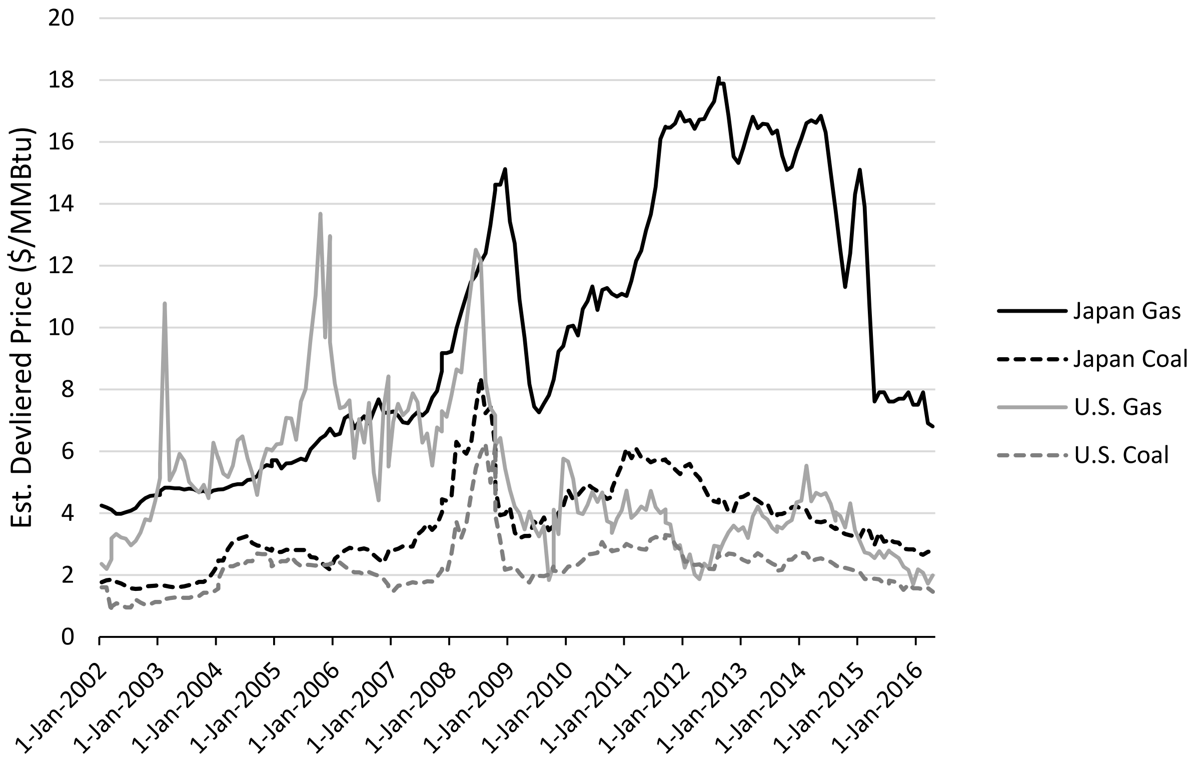
disadvantage for coal is far greater if mortality from air pollution is taken into account.[24] At the same time, the prospect of unseen but deadly radiation from a nuclear accident can inspire fervent antinuclear movements even while opposition to coal use remains fairly muted, as in Japan. The average layperson may also underestimate the practical and economic challenges associated with high market penetrations of renewable energy.[25] Government policymakers face an imperative that survey respondents do not, which is to ensure the adequacy, reliability, and affordability of an energy supply mix made up of imperfect real-world fuels and generating technologies.

How policymakers weigh coal, natural gas, and nuclear tends to come down to how they prioritize energy security, local pollution, and climate change, and also to the strength of the antinuclear movements in their respective countries. Japan, South Korea, and other countries in Asia with few indigenous energy resources have quite understandably prioritized the energy security of imports, and for them coal has historically provided a more affordable, less supply-constrained fuel than natural gas. This is illustrated in **Figure 2** for the case of Japan. Oil-linked prices made natural gas particularly unaffordable in Asia from 2012 through 2014; gas prices have since come down with the advent of lower oil prices and plentiful liquid natural gas (LNG) supply.

[24] Clean Air Task Force, "The Toll from Coal," September 2010, http://www.catf.us/resources/publications/files/The_Toll_from_Coal.pdf.

[25] For more on these public perceptions, see WorldPublicOpinion.org, "World Publics Strongly Favor Requiring More Wind and Solar Energy, More Efficiency, Even If It Increases Costs," 2008, http://www.worldpublicopinion.org/pipa/pdf/nov08/WPO_Energy_Nov08_longart.pdf.

Figure 2 *Relative Affordability of Natural Gas and Coal for Japan and the United States*



Note: This figure uses the following estimations of delivered prices, sampled monthly, for natural gas and coal in Japan and the United States: Japan gas—LNG Japan Corporation import price from all countries in Japan for 1/1/2000–5/31/2014, arrival-based import price into Japan from the Ministry of Economy, Trade and Industry (Japan) for 6/1/2014–4/11/2016; Japan coal—Newcastle price (free on board (FOB), 6,000 kilocalorie (kcal) per kilogram (kg) net as received) + assumed $15 per tonne shipping, converted to $ per million British thermal units (MMBtu); U.S. gas—Henry Hub price; and U.S. coal—CSX coal price (one month ahead, FOB onto barges on the Ohio or Big Sandy rivers, 6700 kcal/kg) converted to $/MMBtu.

Source: Bloomberg.

In the United States, burgeoning unconventional gas production starting in the late 2000s has resulted in a completely different energy security calculus. Since 2009, natural gas prices have fallen into the same neighborhood as delivered coal prices on an energy basis. When the higher efficiencies and lower fixed costs of natural gas plants are taken into account, natural gas is clearly more economic than coal for electricity generation. New environmental regulations that aim to limit emissions—both the Mercury and Air Toxics Standards and, potentially, the Clean Power Plan[26]—shift the economics even more clearly toward gas.

[26] This federal effort to reduce U.S. greenhouse gas emissions has been in legal limbo since implementation was stayed by the U.S. Supreme Court in February 2016.

The rich reserves of coal, natural gas, and oil in the United States give policymakers a great deal of flexibility, including to pursue modest climate policies like the Clean Power Plan at low cost to the economy. At the same time, low electricity prices resulting from low gas prices are making it more difficult for zero-carbon sources like nuclear, wind, and solar to compete in the market. In the case of nuclear, in particular, the likely result is a spate of premature retirements that will make it difficult and expensive to achieve desired reductions in CO_2 emissions.[27]

Policymakers in major emerging economies like China and India are focused above all on ensuring that a lack of energy does not impede economic development, and both countries have leaned on their large domestic coal resources as the principal means of doing so. Concern that coal production was constraining economic growth is what first spurred the Chinese government to begin liberalizing the coal market in 1979.[28] Still today, an effective heuristic for predicting whether China will pursue a specific energy policy is to ask what the impact of the policy will be on the country's perceived energy security.[29] India has made high-profile commitments to increase solar energy, partly in the face of pressure around the Paris Climate Conference in December, but Indian policymakers still see coal as the only energy source that can reliably support economic growth, and they target a doubling of domestic coal output by 2020.[30]

As a country begins to better meet its citizens' basic economic needs, the public will start to focus more on concerns like air pollution and associated health issues, and the government will need to respond. In a 2015 survey by the Pew Research Center, 77% of Chinese respondents said that their families were better off financially than five years ago, but 76% said that air pollution was a very big (35%) or moderately big (41%) problem—second only to corrupt

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[27] Wayne Barber, "UBS Warns More Nuclear Retirements on the Way," *Power Engineering*, September 28, 2015, http://www.power-eng.com/articles/2015/09/usb-warns-more-nuclear-retirements-on-the-way.html; and Thomas Overton, "U.S. Faces Wave of Premature Nuclear Retirements," *Power*, January 14, 2015, http://www.powermag.com/u-s-faces-wave-of-premature-nuclear-retirements.

[28] Wuyuan Peng, "The Evolution of China's Coal Institutions," in Thurber and Morse, *The Global Coal Market*.

[29] Morse, Rai, and He describe how some outside commentators misread the energy security focus of China's carbon capture and storage program as principally a climate policy focus. For more on this issue, see Richard K. Morse, Varun Rai, and Gang He, "The Real Drivers of Carbon Capture and Storage in China," in Thurber and Morse, *The Global Coal Market*.

[30] Tommy Wilkes, "India to Rely on State Miners to Meet Coal Target—Minister," Reuters, March 28, 2016, http://in.reuters.com/article/india-coal-idINKCN0WU0UB.

officials in the ranking of citizen concerns.[31] The Chinese government is clearly quite concerned about improving air quality, and there is the potential for air quality initiatives and regulations to lead to some displacement of coal.[32] For example, the city of Beijing is shutting down the coal power plants within the city and switching to natural gas facilities in an effort to improve air quality. According to a Pew survey in India, 77% of respondents rated air pollution as a very big problem—fifth in the ranking of concerns behind crime, lack of employment opportunities, rising prices, and poor quality schools.[33] Economic concerns may still loom slightly higher in India than in China, but the Indian government also faces significant pressure to improve air quality.[34] Efforts to fight local pollution in India—for example, through SO_2 controls—could have benefits for the climate in cases where they result in substitution away from coal rather than simply the implementation of SO_2 scrubbers.[35] Local air quality is of course an important good that should be pursued in its own right—for example, through SO_x, NO_x, and particulate abatement technologies—even when no climate benefit results.

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[31] Richard Wike and Bridget Parker, "Corruption, Pollution, and Inequality Are Top Concerns in China," Pew Research Center, September 24, 2015, http://www.pewglobal.org/files/2015/09/Pew-Research-Center-China-Report-FINAL-September-24-2015.pdf. In another study from the same year, 18% of Chinese respondents said that climate change is a "very serious problem," with 57% saying it is a "somewhat serious problem." See Bruce Stokes, Richard Wike, and Jill Carle, "Global Concern about Climate Change, Broad Support for Limiting Emissions," Pew Research Center, November 5, 2015, http://www.pewglobal.org/files/2015/11/Pew-Research-Center-Climate-Change-Report-FINAL-November-5-2015.pdf.

[32] BinBin Jiang et al., "The Future of Natural Gas Consumption in Beijing, Guangdong and Shanghai: An Assessment Utilizing MARKAL," *Energy Policy* 36 (2008): 3286–99.

[33] Bruce Stokes, "The Modi Bounce: Indians Give Their Prime Minister and Economy High Marks, Worry about Crime, Jobs, Prices, Corruption," Pew Research Center, September 17, 2015, http://www.bloomberg.com/news/articles/2015-03-24/beijing-to-close-all-major-coal-power-plants-to-curb-pollution.

[34] Air pollution in India comes from multiple sources including transportation and burning of agricultural waste, but coal power plants appear to be a significant contributor. See Lauri Myllyvirta, "Satellite Data: How India's Coal Power Expansion Triggered an Air Pollution Crisis," Greenpeace Energy Desk, May 23, 2016, http://energydesk.greenpeace.org/2016/05/23/satellite-data-india-coal-power-plants-air-pollution-crisis.

[35] Michael P. Jackson, "The Future of Natural Gas in India: A Study of Major Consuming Sectors," Stanford University, Program on Energy and Sustainable Development, Working Paper, no. 65, October 2007, http://pesd.fsi.stanford.edu/sites/default/files/Jackson_WP65_India_gas.pdf.

Policies That Could Enhance the Market Share of Gas and Nuclear Energy

Relative cost is the first-order determinant of how much coal can be displaced by gas and nuclear energy in Asia. For now, as suggested by Figure 2, natural gas remains significantly more expensive than coal in Asia on a per million British thermal units (MMBtu) basis—although in certain applications, such as residential heating and chemicals production, gas has characteristics that make it more attractive than coal, explaining the relatively higher penetration outside the power sector (see Table 1). Nuclear energy has a much lower marginal cost than coal or gas, but its high upfront costs (in part the result of regulatory requirements)—and the way these costs escalate whenever there are construction and regulatory delays—have caused challenges for firms trying to build nuclear plants within a competitive market framework. The vast majority of existing nuclear capacity—in the United States, France, Russia, Japan, South Korea, China, India, and elsewhere—was built as part of concerted government programs to deploy the technology.

While fundamental resource, technology, and transportation considerations determine the baseline economics for coal, natural gas, and nuclear, various government policies can have a major effect on the relative economic competitiveness of these resources. The remainder of this section discusses three main categories of policies that could lead to more displacement of coal, especially inefficient coal: (1) introduction of carbon pricing, (2) market reforms for natural gas, and (3) support for nuclear energy research, development, and deployment, including through international collaboration.

Introduction of Carbon Pricing

Carbon pricing—either by means of a carbon tax or a cap-and-trade system—takes into account the negative climate externalities of different energy sources. It thus provides a strong boost to nuclear energy and a moderate boost to natural gas, given that a typical natural gas plant emits about half the CO_2 per unit energy output of a typical coal plant. Assuming a long-term coal price of $2.60/MMBtu (equivalent to the current Newcastle coal price of $48/tonne plus an assumed shipping cost of $15/tonne) and a natural gas price into Japan of $7/MMBtu (significantly above current spot prices into Japan, which are around $4.50/MMBtu), a carbon price in Japan of approximately $25/tonne of CO_2 would be required to make a new natural gas power plant economically equivalent (same levelized cost of electricity) to a new coal plant.[36] This is significantly above current carbon prices around the world—California/Québec prices were around $13/tonne and European Union prices were around $6/tonne as of April 2016—but it is not unreasonable to think that carbon prices in OECD Asia will reach this level within the next decade or so.[37] Modeling by Zhang et al. suggests that an escalating carbon tax in China could lead to a substantial substitution of coal with natural gas in that country as well.[38]

Given that planned power plant lifetimes are long and strong gas supplies in North America and Australia should be able to support a $7/MMBtu price of gas in Asia over a long period (even taking into account the cost of liquefaction, shipping, and regasification), developing new natural gas power plants in Asia seems compatible with long-term energy security goals. Choosing gas over coal can be viewed as a hedge against the possibility of stronger climate policy in the future.

Market Reforms for Natural Gas

Natural gas resources frequently fail to be exploited to their full potential because the pricing regime in the country where they are found does not properly incentivize development of gas fields and the expensive infrastructure required to transport gas to customers. An important contributor to the unconventional gas revolution in the United States was the liberalized gas pricing regime that produced high prices for gas (as high as $13/MMBtu) in the second half of the 2000s. China and India, by contrast, have historically had cost-plus regimes for gas pricing

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[36] The following assumptions were used for calculating the levelized cost of electricity: discount rate of 5%; 1,000 megawatt capacities and 40-year plant lifetimes; coal plant has $3,000 per kilowatt (kW) overnight capital cost, 80% capacity factor, $38 per kilowatt-year fixed operations and maintenance (O&M) cost, $4.50 per megawatt hour (MWh) non-fuel variable O&M cost, 9,000 British thermal units (Btu) per kilowatt hour (kWh) heat rate, and 1 tonne CO_2/MWh emissions rate; and gas plant has $1,000/kW overnight capital cost, 80% capacity factor, $13 per kilowatt-year (kWy) fixed O&M cost, $3.50/MWh non-fuel variable O&M cost, 7,000 Btu/kWh heat rate, and 0.5 tonne CO_2/MWh emissions rate. The capital cost, O&M, and heat rate estimates roughly follow U.S. Energy Information Administration (EIA), "Capital Cost Estimates for Electricity Plants," April 12, 2013, http://www.eia.gov/forecasts/capitalcost.

[37] Indeed, even the IEA's most conservative scenario, the Current Policies Scenario, assumes that South Korea will see a carbon price for power and industry users of $20/tonne in 2020 and $30/tonne in 2030. See IEA, *World Energy Outlook 2015*, 42.

[38] Xiliang Zhang, Valerie J. Karplus, Tianyu Qi, Da Zhang, and Jiankun He, "Carbon Emissions in China: How Far Can New Efforts Bend the Curve?" *Energy Economics* 54 (2016): 388–95.

that have kept prices low—and the incentives to develop domestic gas low along with them.[39] (A 2011 Pacific Energy Summit paper explored the broader problem of how efforts to incentivize use of natural gas through low prices can discourage the development of domestic gas.[40]) Both countries have tried in recent years to bring gas prices closer to levels that reflect supply and demand, including through the use of hybrid pricing regimes with both planned and market components.[41] Indian policymakers have struggled in particular to overcome resistance to price liberalization from fertilizer producers and power companies, which are accustomed to receiving gas at very low prices. Controlled domestic gas prices have constricted expansion of gas supply in other countries around the world too—from Bangladesh, which now contemplates turning to coal-fired power plants because low gas prices have resulted in overutilization and underdevelopment of domestic gas, to Nigeria, which exports significant LNG but leaves much of its gas resources untapped because domestic gas prices do not support gas development for in-country use.[42]

The development of more indigenous gas in Asia would help reduce the price differential between North America and Asia over the long term. Achieving this requires not only reforming pricing structures but also, where applicable, loosening the grip of state-owned enterprises. An underappreciated contributor to the U.S. shale gas success story was the combination of a massive and diverse oil services sector with nimble independent oil companies, which allowed rapid cycles of experimentation. China's policymakers, pragmatic as always, recognize that the unconventional gas sector will only reach its potential if there is openness to a diversity of

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[39] Under cost-plus pricing, a supplier can only charge its costs plus some allowable rate of return. Unlike market pricing based on supply and demand, cost-plus pricing creates little incentive to pursue innovations that could reduce costs and expand supply opportunities, because the supplier will not profit much from them.

[40] Mark C. Thurber and Joseph Chang, "The Policy Tightrope in Gas-Producing Countries: Stimulating Domestic Demand without Discouraging Supply" (paper presented at the 2011 Pacific Energy Summit, Jakarta, Indonesia, February 21–23, 2011).

[41] For a discussion of China's recent gas pricing reforms, see Sergey Paltsev and Danwei Zhang, "Natural Gas Pricing Reform in China: Getting Closer to a Market System?" *Energy Policy* 86 (2015): 43–56. For a discussion of gas pricing reform in India, see Ernst & Young, "Natural Gas Pricing in India," 2014, http://www.ey.com/Publication/vwLUAssets/EY-natural-gas-pricing-in-India/$FILE/EY-natural-gas-pricing-in-India.pdf.

[42] Mark C. Thurber, Ifeyinwa M. Emelife, and Patrick R.P. Heller, "NNPC and Nigeria's Oil Patronage Ecosystem," in *Oil and Governance: State-Owned Enterprises and the World Energy Supply*, ed. David G. Victor, David R. Hults, and Mark C. Thurber (Cambridge: Cambridge University Press, 2012).

participants—private and state-owned, foreign and domestic—and they are trying to move the market framework in this direction, although existing market structures have significant inertia.[43]

Coal development is sometimes held back by institutional issues too. In fact, cumbersome frameworks for developing coal resources and infrastructure in a number of countries have probably prevented coal from becoming even more dominant than it already is. For example, India's domestic coal production has been constrained by a murky land rights regime, a still mostly centrally planned approach to allocating coal to end users, a bureaucratically encumbered state-owned coal company, and unrest in coal regions.[44] The world's leading coal exporter, Indonesia, has exhibited increasing government interference in the coal sector and deteriorating investment frameworks.[45] In the United States, opposition on climate grounds has cast doubt on plans for new coal export terminals in the Pacific Northwest (although low international coal prices are arguably just as responsible for the unclear prospects of the projects at the present time).[46] Such constraints on coal sector expansion make the fuel incrementally less competitive than natural gas, just as a (highly improbable) ban on unconventional gas extraction techniques in North America would enhance coal's prospects relative to gas. Non-environmentally motivated roadblocks to coal expansion can be an environmentalist's best friend.

Even policies that are not explicitly focused on the coal, gas, or nuclear sectors can nevertheless affect their relative competitiveness. In China, for example, the energy sector is considered a strategic sector and given access to capital at lower rates than other industrial or commercial concerns, which in effect makes energy technologies with higher upfront costs (e.g.,

[43] For a review of some of the issues, see David Sandalow, Jingchao Wu, Qing Yang, Anders Hove, and Junda Lin, "Meeting China's Shale Gas Goals," Columbia School of International and Public Affairs, Center on Global Energy Policy, http://energypolicy.columbia.edu/sites/default/files/energy/China%20Shale%20Gas_WORKING%20DRAFT_Sept%2011_0.pdf.

[44] Jeremy Carl, "The Causes and Implications of India's Coal Production Shortfall," in Thurber and Morse, *The Global Coal Market.* While India's government has expressed optimism that it can double production by 2020 (see Wilkes, "India to Rely on State Miners to Meet Coal Target"), such targets have not always been met in the past.

[45] Bart Lucarelli, "Government as Creator and Destroyer: Indonesia's Rapid Rise and Possible Decline as Steam Coal Supplier to Asia," in Thurber and Morse, *The Global Coal Market*.

[46] Mark C. Thurber, "U.S. Coal to Asia: Examining the Role of Transportation Constraints in Energy Markets," in Thurber and Morse, *The Global Coal Market*.

nuclear or coal power plants) look more attractive than they otherwise would relative to technologies with lower upfront cost (e.g., natural gas plants).[47]

Government Support for Nuclear Energy Research, Development, and Deployment

In theory, nuclear energy is already competitive or nearly competitive for baseload generation in Asia. A simple (and simplistic) modeling exercise that ignores nuclear decommissioning costs and assumes no special regulatory obstacles to nuclear suggests that all it would take to make the levelized cost of electricity (LCOE) from a new nuclear plant equal to that of a new coal plant would be for the delivered coal price to rise to $76/tonne of coal (versus an assumed $63/tonne in Asia today) or for a carbon tax of under $10/tonne of CO_2 to be levied.[48] (In the United States, the gas price would have to triple, from $2/MMBtu currently to $6/MMBtu, for a new nuclear plant to start looking competitive against gas units.)

The difficulty is that in most countries today nuclear costs are highly subject to regulatory uncertainty and associated delays. Because so much of nuclear's cost is incurred upfront, its levelized cost is extremely sensitive to the cost of capital (which we assumed in our simple analysis to be the same as for coal or natural gas units), and any delay or risk premium that must be incorporated into the cost of capital has a major adverse impact on the LCOE. Recent nuclear projects in the United Kingdom, Finland, and France have seen huge cost escalations (in part due to efforts to incorporate new technologies with better safety characteristics). In fact, the French power company Electricity of France may require significant (and controversial) support from the French government to proceed with its Hinkley Point C nuclear power station in the United Kingdom.[49] The LCOE analysis here also assumed that the facilities run uninterrupted, at an 80% capacity factor, over their entire lifetimes. This means that, for nuclear energy to remain cost-effective, the industry can afford no more breaches in public confidence such as occurred after the Fukushima Daiichi accident.

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[47] Jiang et al., "The Future of Natural Gas Consumption in Beijing."

[48] This modeling used all the same assumptions as for the previous coal/gas comparison in relation to carbon pricing, with the following additional details for nuclear: $5,500/kW overnight capital cost, 80% capacity factor, $93/kWy fixed O&M cost, $2.00/MWh non-fuel variable O&M cost, 10,400 Btu/kWh heat rate, and $1/MMBtu fuel cost.

[49] Kiran Stacey, "EDF Faces State Aid Hurdle over Hinkley Point Project," *Financial Times*, April 22, 2016; and Michael Stothard, "Nuclear Reactor Clean-up Weighs on EDF," *Financial Times*, April 19, 2016.

In order for nuclear energy to displace substantial amounts of coal in Asia (and gas in the United States) in the future, there will need to be new reactor technologies that are both significantly cheaper and perceived as less risky than current alternatives. Governments will need to support not only research and development activities but also deployment of pilot reactors. North America has a surprisingly vibrant landscape of organizations working to develop new nuclear energy technologies, including small modular reactors.[50] It also has, in the United States at least, an inhospitable regulatory environment when it comes to deploying anything other than the light-water reactor technology used in existing U.S. nuclear plants.[51] This suggests there is scope for collaboration between North American nuclear startups and nuclear energy firms in countries with a more favorable environment for actual deployment, such as South Korea or China.[52] At the same time, it will be crucial to make sure safety standards are high wherever new reactors are deployed. This requires more than just skilled bureaucratic oversight; in the United States, the positive experience with the Institute of Nuclear Power Operations has shown that ongoing benchmarking and safety improvement efforts within the industry also play a key role in warding off complacency and enhancing operational performance.

Conclusions: Overall Prospects for Fuel Switching Away from Coal in Asia

The most viable options for switching away from coal vary by country. Among the countries we considered, India is likely to have the most difficulty replacing coal. Liberalization of gas prices could encourage more development of domestic gas, but this is challenging due to the political power of gas-consuming industries. Moreover, India's electricity sector is still not very market-based in how it procures fuel, which makes it ill-equipped to pay for higher-priced domestic or imported gas. Given the prospect that India will remain heavily coal-dependent for a

[50] Samuel Brinton, "The Advanced Nuclear Industry," Third Way, June 15, 2015, http://www.thirdway.org/report/the-advanced-nuclear-industry.

[51] Edward Geist, "Overcoming Obstacles to Advanced Nuclear Technologies," RAND Corporation, RAND Perspective, 2015, http://www.rand.org/content/dam/rand/pubs/perspectives/PE100/PE156/RAND_PE156.pdf.

[52] India might be another candidate in theory, but, according to the nuclear industry, a nuclear-focused civil liability law passed in 2010 is deterring foreign provision of technology. See World Nuclear Association, "Nuclear Power in India," updated April 2016, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/india.aspx.

long time, the Indian government should focus on ensuring that coal plants are as efficient as possible and have the best possible controls on local air pollution.

In most countries considered in this paper, gas should be able to play a significantly larger role than it currently is. In China, further liberalization of natural gas prices and a greater willingness to let the market decide which end users can have gas will create the right incentives for continued expansion of the gas supply. Broader movement in Asia toward pricing based on gas-on-gas competition rather than oil indexation could help create the conditions for expansion of gas consumption over the long term, although current low oil prices may have dulled the perceived urgency of such reform. (These issues are discussed at length in a 2015 summit paper by Peter Hughes and Daniel Muthmann.[53])

Carbon pricing will also help the cause of gas. As climate impacts become more and more apparent, pressure to price carbon, and price it higher, will only increase for Asian countries, especially those in the OECD. At current gas and coal prices, the gap between the levelized cost of electricity from new gas and coal plants is modest enough that opting for gas is a sensible hedge against future carbon policy tightening.

Over the next two decades at least, nuclear is likely to displace significant coal only in a very limited number of countries, notably China and perhaps South Korea. (Even in China and South Korea, there is increasing debate over whether planned expansions of nuclear energy are prudent.) Most everywhere else, nuclear is too unpopular (despite a historical safety record that is no worse than coal), too expensive relative to alternatives (which is especially an issue where competitive wholesale electricity markets exist), or overseen by institutions that local citizens view as incapable of safely regulating the technology. Countries that do not already have nuclear power capability will not be able to build it out quickly.

In countries that do have significant nuclear fleets, like the United States, the imperative is to somehow prevent wholesale retirement of existing capacity, which in every country where it has happened so far has meant more fossil fuel use (or less reduction in fossil fuel use than would otherwise have occurred). The share of electricity generation from coal in the United States dropped from 50% as of 2006 to around 34% in 2015 as a result of displacement by cheap

[53] Peter Hughes and Daniel Muthmann, "Gas in Asia: From Regional Premium to Global Commodity?" (summit paper from the 2015 Pacific Energy Summit, Beijing, China, May 27–29, 2015).

gas,[54] and a Black & Veatch report predicted it could fall to near 20% by 2038. However, the same report also suggested that nuclear generation in the United States could roughly halve over the same period, negating a good portion of the climate benefit.[55]

The hope for nuclear over the longer term is that smaller, more modular technologies might prove both safer and less vulnerable to the obstacles that are bedeviling the current crop of new facilities, specifically high capital cost, a tough regulatory environment, and public opposition. Collaboration between nuclear start-ups in North America and countries like China and South Korea, where deployment of new technologies is still possible, could play a key role.

Southeast Asia remains a major question mark for the future of coal consumption. Indonesia, Thailand, and Malaysia all produce appreciable quantities of gas, but domestic resources appear insufficient to meet growing energy demand, and coal is the “default fuel” as usual. Indonesia is a large coal producer and the world’s largest exporter, and it has been engaged in a major buildout of coal power for electricity generation.[56] Other countries in Southeast Asia are clearly struggling with the tension between environmental objectives and perceived energy security. Vietnam recently announced plans to lean more heavily on gas, nuclear, and renewables, sharply contradicting the energy blueprint it laid out as recently as 2015, which had envisioned a major buildout of coal-fired capacity.[57] As international pressure for action on climate change ramps up, these kinds of tensions will only grow stronger.

Public opinion surveys show that wind and solar are far more popular than nuclear, coal, or natural gas. But policymakers are tasked with meeting energy security, climate, and local environmental goals without constraining economic growth. For the moment, this leads back to the question of which is the lesser of the “three evils” on which we have focused in this paper.

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[54] U.S. EIA, “Short-Term Energy and Summer Fuels Outlook: Electricity,” http://www.eia.gov/forecasts/steo/report/electricity.cfm.

[55] Rob Patrylak and Ann Donnelly, “2013 Energy Market Outlook and Industry Trends” (webcast presentation, July 16, 2013), http://bv.com/docs/reports-studies/2013-energy-market-outlook-and-industry-trends.pdf.

[56] Lucarelli, “Government as Creator and Destroyer,” in Thurber and Morse, *The Global Coal Market*. For more on Indonesia’s energy challenges, see Natalie Bravo et al., “Indonesia: A Regional Energy Leader in Transition,” NBR, NBR Special Report, December 2015, http://nbr.org/publications/issue.aspx?id=326.

[57] Ed King, “Vietnam to Phase Out Coal, Invest in Gas and Renewables,” *Climate Home*, January 25, 2016, http://www.climatechangenews.com/2016/01/25/vietnam-phase-coal-invest-gas-renewables.