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ABSTRACT

Carbon Rollercoaster: A Historical Analysis of Decarbonization in the United States*

This paper documents the evolution of US carbon emissions and discusses the main factors that contributed to the historical carbon emissions rollercoaster. We divide the discussion into four periods – up to 1920, 1920-1960, 1960-2005 and after 2005. For each period, we discuss the main drivers of national carbon emissions. We then discuss trends in carbon emissions in the electricity sector. Electricity sector emissions were initially very small, but would become the largest source of US carbon emissions over the period 1980-2015, and the largest contributor to decarbonization since 2007. In the final section, we distill lessons from the U.S. experience that may inform decarbonization strategies in developing economies.**

JEL Classification: N72, Q31, Q48, Q54

Keywords: carbon emissions, decarbonization, energy transition, electricity sector, environmental regulation, clean air act, climate policy

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The United States was the world's largest source of carbon emissions for more than a century. In 1888, the United States surpassed Great Britain in terms of annual carbon emissions, and it remained the leading source of emissions until 2005, when as shown in Figure 1, it was overtaken by China.

The dominance of the US economy in carbon emissions was not simply because of its large population. Black lines in Figure 2, panels A and B, show the trajectories of total and per capita carbon emissions from fossil fuels and industry in the United States. In 1888, the US economy emitted 370 million tons of carbon dioxide (CO_2). In 2005, the US economy emitted 6.1 billion tons, an increase of more than a factor of fifteen. Land use changes can also affect carbon emissions, primarily through deforestation for land clearing, fuel wood, and wood products.[1]

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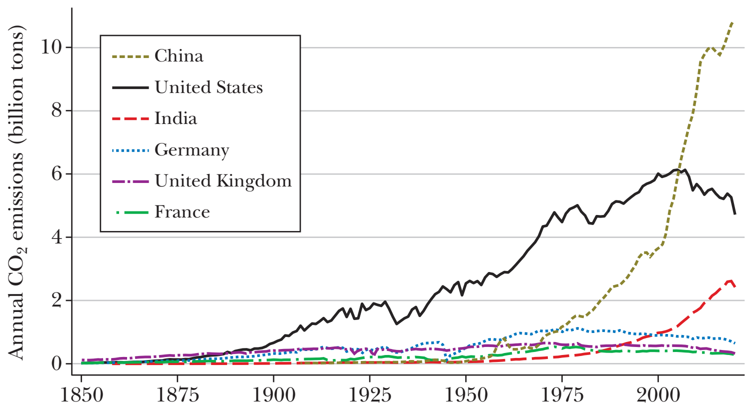
[1] The net carbon emissions from land use and forestry changes include carbon released from activities such as deforestation, planting trees, logging, and the degradation of forests (including timber

Figure 1
Carbon Dioxide Emissions for Selected Countries



Source: The data underlying this figure come from Ritchie, Rosado, and Roser (2023).
Note: This figure plots annual total carbon dioxide emissions from fossil fuels and industry in selected countries (in billions of tons).

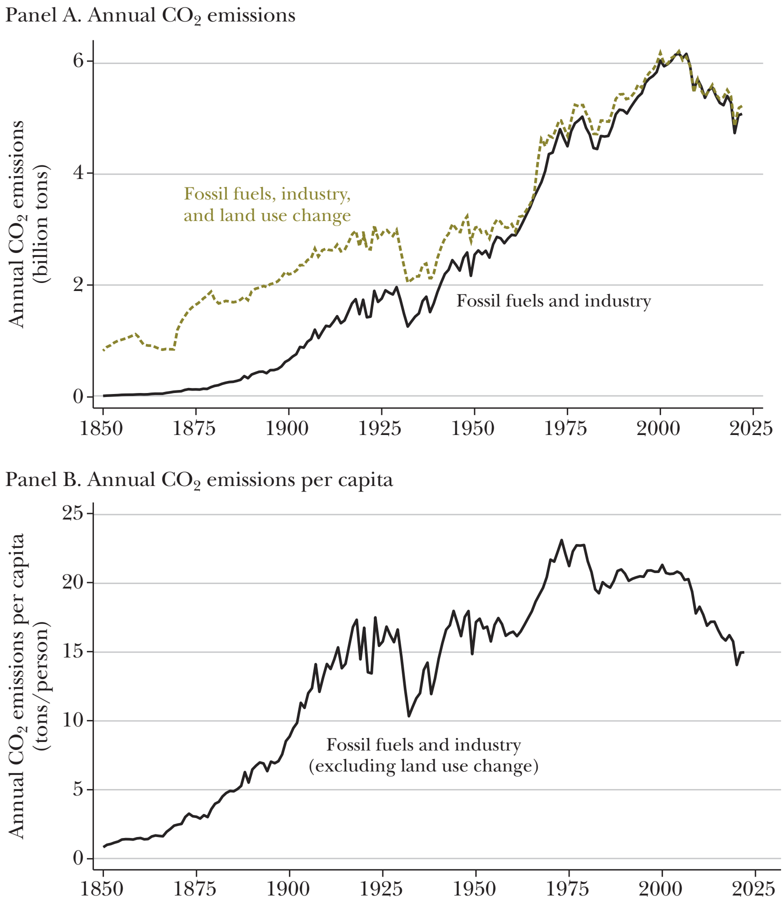
The dashed line in Figure 2, panel A, shows that land use changes were relatively important initially but contributed an increasingly small share of carbon emissions after 1940. Thus, this paper focuses on emissions from fossil fuels and industry. As shown in Figure 2, panel B, on a per capita basis, US carbon emissions were 6.3 tons in 1888, peaked at 23.1 tons in 1973, and declined to 20.7 tons by 2005. On a per capita basis, the United States surpassed Great Britain in 1903 and was surpassed by Australia in 2009.[2]

The growth rate of US carbon emissions and carbon emissions per capita shows striking variation over time. Although carbon emissions displayed a rising general trend over the twentieth century, Figure 2 indicates that the United States also experienced sustained periods of acceleration and deceleration in both total carbon emissions and per capita emissions. Our understanding of this historical variation in carbon emissions is surprisingly limited. Most studies do not go back very far in time. Those that do cover long historical periods tend to focus on decompositions and high-level trends in fuel use (Tol, Pacala, and Socolow 2009; Henriques and Borowiecki 2017).

harvesting). It also covers practices like shifting cultivation (where forests are cleared for farming and then abandoned), forest regrowth after logging or agricultural abandonment, as well as emissions from burning or draining peatlands (Friedlingstein et al. 2025). It is important to point out, however, that "[c]omparison of estimates from multiple approaches and observations shows . . . a persistent large uncertainty in the estimate of land-use change emissions" (Friedlingstein et al. 2025, p. 968).

[2] A number of small fossil-fuel-rich countries in the Middle East have even higher per capita carbon emissions, but are not comparable to the United States along other dimensions.

Figure 2
CO_2 Emissions and Per Capita CO_2 Emissions in the United States



Source: The data underlying this figure come from Ritchie, Rosado, and Roser (2023).
Note: The top panel of this figure plots annual total carbon dioxide emissions in the United States from fossil fuels and industry as well as from fossil fuels, industry, and land use change (in billions of tons). The bottom panel of this figure plots annual carbon dioxide emissions per capita (in tons per person).

This paper documents the changing trends in US carbon emissions and discusses the main factors that contributed to the historical carbon emissions rollercoaster. We divide the discussion into four periods: up to 1920, 1920–1960, 1960–2005, and after 2005. For each period, we discuss the main drivers of national carbon emissions. We then discuss trends in carbon emissions in the electricity sector. Electricity sector emissions were initially very small, but would become the largest source of US carbon emissions over the period 1980–2015, and the largest contributor to decarbonization since 2007. In the last section, we offer some lessons for what developing economies might learn from the US experience.

Increases in Carbon Emissions up to 1920

The Economy up to 1920

Both total and per capita US carbon emissions rose rapidly up to about 1920, as shown in Figure 2. Two interrelated factors played key roles. The first was early US development of fossil fuels. Other economies had larger endowments, but the United States invested in extracting them earlier. The second was the use of these fossil fuels to support economic activity. In the absence of development of fossil fuels and the subsequent expansion of economic activity, carbon emissions would have remained low.

By the early twentieth century, the United States was the world's leading producer of fossil fuels (Wright 1990), producing 39 percent of world coal, 65 percent of world petroleum and 95 percent of world natural gas. This is despite having about 23 percent of the total world endowment in 1989 (reserves plus historical cumulative production) of coal and 20 percent of world endowment in petroleum. The US economy was also a top producer across a broad range of industrial minerals including iron ore, copper, lead, and zinc, among others. Other countries also had large natural endowments of minerals, including fossil fuels. What distinguished the United States was early development of its resources through state mineral surveys, state investment in mining education, and the incentives for discovery provided in federal mining laws (David and Wright 1997). State and federal policy was a catalyst that increased both economic activity and carbon emissions.

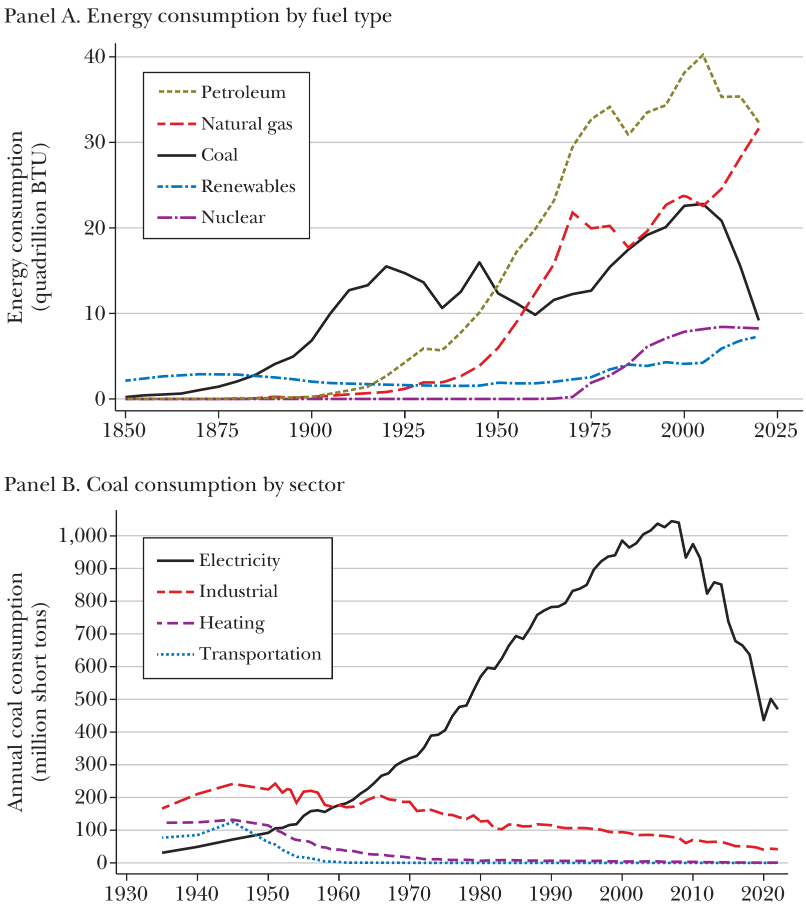
Coal became the largest source of energy for the US economy starting around 1880, as shown in Figure 3, when it surpassed renewables. In this era, renewables were wood and hydropower. In 1920, coal remained the dominant fossil fuel, although petroleum and to a lesser extent natural gas were beginning to play small roles in consumption.

Coal and other fossil fuels were used to support economic activity, such as transportation. For example, coal represented 90 percent of railroad fuel in 1880 (Atack 2024). In 1915, railroads consumed slightly more than one-quarter of all bituminous coal consumed by the US economy and a smaller share of anthracite coal. Petroleum was initially refined into kerosene for lighting, but became increasingly important as petroleum fueled cars, trucks and airplanes.

Electricity and steam generated by fossil fuels powered US manufacturing during this time (Lafortune et al. 2021). Up to 1880, industrial production grew steadily (Davis 2004, 2006). After 1880, it began to grow more rapidly. And after 1910, it began to exhibit increasing returns to scale (Lafortune et al. 2021). Consistent with these trends, carbon emissions per dollar of GDP rose up to World War I (Muller 2022).

Fossil fuels helped the United States surpass the United Kingdom to become the leader in world industrial production (Wright 1990). One of the distinctive characteristics of US manufacturing exports between 1880 and 1920 was their high and rising intensity in nonreproducible natural resources. Coal was a key input

Figure 3
Energy and Coal Consumption in the United States



Source: The data underlying this figure are from US Energy Information Administration (2024b). Panel B is based on data from the US Geological Survey (various years) and Cintron (1995).
Note: Panel A of this figure plots annual total primary energy consumption (in quadrillion British thermal units) by source. Renewables include wood, hydropower, and more recently wind and solar power. Panel B of this figure plots annual total coal consumption (in million short tons) by sector.

into iron and steel products, and iron and steel products along with petroleum products were increasing shares of US exports. By 1913, these two categories represented 38 percent of US exports, and the shares would climb above 50 percent in the 1920s. Petroleum exports were initially kerosene and later included gasoline, diesel, aviation gasoline, and other products. During World War I, petroleum products took on enormous strategic importance as motorcycles, cars, trucks, and airplanes played critical roles.

The high fossil fuel intensity of early exports raises an important point. Our discussion will focus on territorial emissions from the burning of fossil fuels. These do not include the carbon emissions associated with imported and exported goods or services. Data series on consumption-based emissions are only available from 1990 onward. Over that period, consumption-based emissions for the United States were generally not more than 10 percent higher than territorial emissions (Ritchie, Rosado, and Roser 2023).

The Electricity Sector up to 1920

Total coal consumption by US electric utilities increased dramatically from 1882 to 1920. Coal consumption in the electricity sector was small in the first few decades following the opening of the first commercial electricity plant, Thomas Edison's Pearl Street power plant in New York City, in 1882. By the turn of the twentieth century, electric utilities consumed roughly nine million tons of coal per year, accounting for just 3 percent of total US consumption. Annual coal consumption by electric utilities rose to 37 million tons by 1920. Despite this increase, however, the electricity sector accounted for just 7 percent of total US consumption by 1920 (US Census Bureau 1976).

The growth in coal consumption by electric utilities reflected a national rise in electricity generation. Between 1900 and 1920, total generation by electric utilities increased from less than two billion kilowatt-hours to nearly 40 billion kilowatt-hours (US Census Bureau 1976). This increase was driven by rising demand for electricity. At the turn of the century, less than 5 percent of homes were equipped with electric lights and less than 5 percent of manufacturing was powered by electricity (Lebergott 1976; Devine 1983). Over the next four decades, there was a sharp increase in coal-fired generation as electricity replaced steam power in manufacturing and the nation's homes began to electrify.[3]

Despite the rise in generation, the electricity sector remained a minor contributor to total US carbon emissions through the early twentieth century. Indeed, Figure 3, panel B, highlights that electricity was the smallest of the coal-consuming sectors in 1933, when the series on coal consumption by sector begins.

In summary, over the period up to 1920, carbon emissions grew rapidly. Growth was driven by early development of fossil fuels and their use to support economic activity, including transportation, manufacturing, and exports. While carbon emissions from the electricity sector would later be large, its emissions were small during the period up to 1920. Had the development of fossil fuels and the expansion of economic activity not occurred, carbon emissions would have remained low.

[3] By 1920, just over one-third of US homes were wired for electricity. Even in electrified homes, electricity consumption was limited, as few families could afford to purchase major electric appliances. As a result, residential consumption accounted for just 7 percent total electricity use in 1920 (Lebergott 1976; US Census Bureau 1976).

Slower Growth in Carbon Emissions from 1920 to 1960

The Economy from 1920 to 1960

If the trends from 1900 to 1920 had continued, there would have been more rapid increases in carbon emissions overall and a continuation in growth of per capita emissions up to 1960. Instead, we see slower growth overall, a flattening of emissions per capita, and sharp declines during the Great Depression decade (1929–1939). What drove the changes in the non–Great Depression years? Three factors appear to have contributed. The first is the changing energy mix, which had implications for carbon emissions, because petroleum and natural gas have lower carbon emission factors per unit of energy than coal. The second is thermal efficiency improvements, which allowed more output to be created from the same amount of energy. The third was the continuation of a preexisting trend in which services made up an increasing share of employment and GDP. All three slowed the growth of carbon emissions. In their absence, carbon emissions would have been higher.

Figure 3, panel A, shows changes in the energy mix that began around 1920. Coal consumption, which had been rising rapidly, began to flatten and even fall. This pattern continued until about 1960, when coal consumption began to rise again. Figure 3, panel B, highlights shifting sectoral use of coal. Electricity sector consumption was rising and by 1960 was equal to industrial consumption. Industrial consumption was fairly flat, and consumption for heating and transportation were falling. The declines in heating and transportation reflected a shift to petroleum and natural gas for fuel. Oil and natural gas began to replace coal for residential and commercial heating in many parts of the country. Locomotives and ships shifted from coal-fired to diesel engines.

The period from 1920 to 1960 was one of rapid improvements in thermal efficiency and growth in total factor productivity in the US economy (Jorgenson 1984; Gordon 2017; Field 2018; Bakker, Crafts, and Woltjer 2019). The increases in thermal efficiency were due to a number of factors, including increases in the efficiency with which coal was converted into electricity and possibilities that electricity opened for more efficient use of capital and labor in many industries (Jorgenson 1984; Rosenberg 1998).[4] Although output increased, greater efficiency in converting input heat to output slowed the growth in carbon emissions.

The service sector as a share of employment and services as a share of GDP were both rising over the period 1920–1970. These were continuations of a preexisting trend. In 1880, 26 percent of civilians were employed in the service sector (Fuchs 1980). By 1920, the share was 35 percent; by 1960, it was 52 percent. In line with this trend, the share of GDP accounted for by service-producing industries increased steadily since 1947, when data first became available (Yuskavage and

[4] There is some evidence that thermal efficiency was improving even before 1920, especially in the electricity sector. The electricity sector was, however, small before 1920.

Fahim-Nader 2005). These changes are important because the service sector has lower average carbon emissions than goods-producing sectors (Suh 2006).

The Electricity Sector from 1920 to 1960

Between 1920 and 1960, growth in carbon emissions in the electricity sector slowed as well. Unlike the overall economy, this change was largely not driven by the changing energy mix in electricity. Figure 3, panel B, shows the expanding role of electricity generation in total US coal consumption. By 1960, the electricity sector consumed the most coal of any sector. Further, despite increases in federal investments in hydroelectric capacity, the shares of electricity generation from coal and natural gas increased over this time period. In 1960, coal was used for 55 percent of all electricity generation and 69 percent of fossil fuel electricity generation. Instead, the slowdown in carbon emissions in the electricity sector, like the overall economy, was driven by increases in productivity.

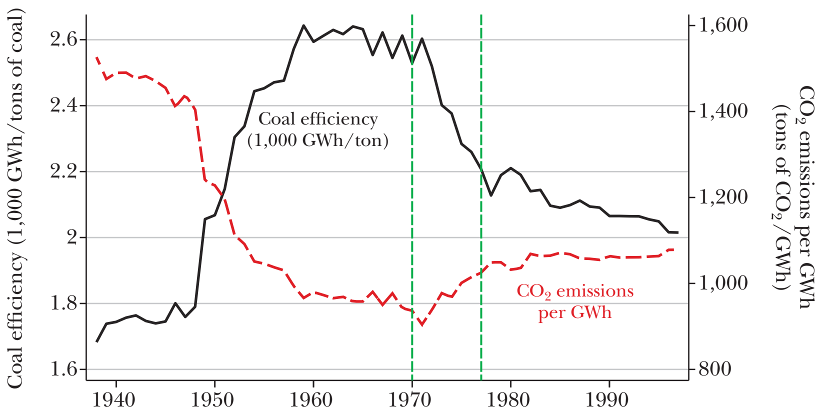
Increases in productivity in the electricity sector were due to interrelated changes in technology, transmission, and state and federal policy. Coal-fired electricity plants generate electricity by heating water into high-pressure steam in order to spin turbines and ultimately to generate electrical energy. The period from 1920 to 1960 was characterized by technological advancements that allowed new plants to utilize steam with higher temperature and pressure—with the associated improvements in thermal efficiency. In particular, in the post–World War II era, the electricity industry benefited from wartime-related improvements in design and metallurgy that supported larger scale (Lovell 1941; Rosenberg 1998).[5]

The continued development and interconnection of high voltage transmission infrastructure also played a crucial role by reducing the reliance of communities on small, local electricity producers. This interconnected grid enabled utilities to build larger and more efficient electricity plants farther away from demand centers (Clay et al. 2025).

State and federal policies seeking to broaden access to electricity also contributed to the improvements in productivity in the pre–World War II era, but mostly as an unintended consequence. Beginning in 1907, states began regulating the electricity sector, establishing rate-of-return regulation and enacting territorial monopolies. These new regulations reduced the borrowing costs for private electric utilities and allowed them to exploit economies of scale (Hausman and Neufeld 2002; Knittel 2006). These policies reinforced the shift away from smaller and less efficient municipal plants to larger-scale privately owned utilities. At the same time, they promoted consolidation of privately owned utilities, which were better able to exploit economies of scale under the new regulation. Thus, state and federal policies helped reduce carbon emissions per unit of electricity.

[5] The effects on scale are evident in Supplemental Appendix Figure A.1, which documents the size of the largest generating unit and the average unit size in each year (Hales 1976). The size of the largest unit increased dramatically around 1950, and the average size installed in a given year began to trend up around the same time.

Figure 4
Coal Efficiency and Carbon Emissions per Gigawatt-Hour



Source: This figure is based on data on power plant operations from 1938 to 1994 from Clay et al. (2025).
Note: In this figure, we plot annual nationwide coal efficiency: annual total electricity production from coal-fired power plants (in 1,000 GWh) divided by annual total tons of input coal burned (in tons). In addition, we plot annual total carbon dioxide emissions divided by coal-fired electricity production (in tons of emissions per GWh of output). We translate input heat energy from coal to carbon emissions using a conversion factor of 211.63 pounds of CO_2 per million BTU of coal (EIA 2024a). The green vertical dashed lines represent the 1970 Clean Air Act and the 1977 amendments.

As a result of these changes in technology, transmission, and state and federal policy, the electricity sector witnessed substantial improvements in coal efficiency (coal-fired electricity generation divided by tons of coal burned for generation). Drawing on aggregate data on electricity generated and coal burned by electric utilities from 1920 to 1960 (US Census Bureau 1976), we calculate that coal efficiency increased by more than 400 percent. The patterns are consistent with the findings of Bakker, Crafts, and Woltjer (2019).

Beginning in 1938, we have annual power-plant-level data, which allow us to examine changes in coal efficiency and carbon emissions in more detail (Clay et al. 2025). The coal efficiency of coal-fired electricity plants improved substantially between 1938 and 1960, as illustrated in Figure 4. In 1940, it took 573 tons of coal to generate a gigawatt-hour of electricity. By 1960, this had fallen to 386 tons per gigawatt-hour.

These improvements in coal efficiency resulted in a 34 percent decline in carbon emissions per gigawatt hour of electricity between 1940 and 1960.[6] To put this decline in perspective, annual total carbon emissions from coal-fired generation in 1960 was 387 million tons, but would have been 589 million tons if total coal-fired

[6] Throughout the paper, we translate input heat energy from coal to carbon emissions using a conversion factor of 211.63 pounds of CO_2 per million BTU of coal (US Energy Information Administration 2024a).

generation in 1960 was produced at the aggregate carbon emissions per gigawatt hour of electricity in 1940.

Beginning in the 1930s, the federal government was a major driver of the expansion in hydroelectric capacity. This period, known as the "Big Dam Era," witnessed the construction of major federal hydroelectric generation stations, including the hydroelectric plants run by the Tennessee Valley Authority and the Bonneville (Oregon) Power Administration (Billington, Jackson, and Melosi 2005). The ability to develop these new sources of hydropower also depended on the technological innovations in transmission technology, which allowed for cost-effective use of remote sources of hydropotential (Lovell 1941). Thus, federal policy with respect to hydroelectric generation helped slow the growth in carbon emissions, because hydroelectric generation does not emit carbon.

This expansion in hydroelectric capacity reduced reliance on coal-fired generation and contributed to the decline in the share of electricity production from coal over this period. Hydroelectricity resources produced roughly 16,000 gigawatt-hours of electricity in 1920 and roughly 47,000 gigawatt-hours of electricity in 1940. To put these magnitudes in perspective, if the 31,500 additional gigawatt-hours produced by hydro in 1940 relative to 1920 was instead produced by coal, carbon emissions from coal-fired electricity production would have been 41 percent higher in 1940 (an increase of roughly 38.5 million tons in carbon emissions).[7]

Rising coal consumption in the electricity sector brought with it concerns about air pollution, because emissions of conventional air pollutants were large, highly visible, and increasingly concentrated in specific locations. Public concern about the impacts of local air pollution were spurred by high-profile episodes such as the Donora Smog in 1948, which killed 20 people and caused respiratory problems for thousands more in Pennsylvania, and the Great Smog of London in December 1952, which led to about 12,000 deaths (Bell and Davis 2001). The perceived value of having electricity produced by a nearby coal-fired plant evolved over this time. Looking at data for local areas surrounding all major US coal-fired plants from 1938 to 1962, Clay, Lewis, and Severnini (2024) suggest that earlier in this period, expansions in coal capacity for electricity production led to decreases in local infant mortality, but later additional increases led to increases in infant mortality.

Despite these concerns, there was little federal or state action to address air pollution during this time frame. The Air Pollution Control Act of 1955 allocated

[7] Aggregating over the coal-fired fleet in 1940, burning 639 short tons of coal resulted in one gigawatt-hour of electricity. Therefore, a 31,500 gigawatt-hours increase in coal-fired generation corresponds to a 20.1 million tons increase in coal burned. Applying a conversion rate of 3,826.88 pounds of CO_2 per short ton of coal burned (US Energy Information Administration 2024a), we obtain that roughly 38.5 million more tons of carbon would have been emitted if the increase in hydro production between 1920 and 1940 was instead produced by the 1940 coal-fired fleet. Because carbon emissions from the coal-fired fleet in 1940 were roughly 94 million tons of CO_2, the 38.5-million-tons increase from counterfactually replacing hydro output with coal output amounts to a 41 percent increase in CO_2 emissions. All of the numbers underlying this calculation come from the US Energy Information Administration. They are adjusted prior to 1949 based on US Bureau of the Census (1960, p. 507).

funding for studying the issue, but did not implement regulatory measures. Electric utilities faced no immediate threat of government regulation and made minimal efforts to reduce local air pollution emissions. Environmental considerations were scarcely mentioned in annual reports of the Federal Power Commission. Its 1966 report, "Steam-Electric Plant Construction Cost and Annual Production Expenses," included, for the first time, a section on "environmental influences on plant design, construction, and operation." The report highlighted that air pollution, among other issues, was becoming a significant socioeconomic concern for the electric power industry (Federal Power Commission 1967, p. ix). Although experimentation with "baghouses" (which use fabric bags to trap pollutants as they are emitted) and other pollution-abatement technologies began in the 1940s, few coal-powered electricity plants had installed such systems before 1960.

Over the period 1920–1960, the economy experienced changes in energy mix, thermal efficiency improvements, and increases in the service sector as a share of overall employment and GDP. The electricity sector experienced rapid increases in productivity as measured by coal efficiency, and the federal government made large investments in hydroelectric dams. Taken together, these changes slowed the growth in carbon emissions overall and led to the flattening of carbon emissions per capita. In the absence of these changes, carbon emissions would have been much higher.

Faster Growth in Carbon Emissions from 1960 to 2005

The Economy from 1960 to 2005

US carbon emissions grew rapidly from the 1960s up to 2005, except for a period in the 1970s and early 1980s, as shown earlier in Figure 2. Why do we see faster growth over the period 1960–2005 as compared to 1920–1960? The primary story, both economy-wide and for the electricity sector specifically, is a changing energy mix driven in part by crises and regulation. Figure 3, panel A, shows the increase in consumption of all fuel types between 1960 and 2005. Petroleum and natural gas rose, fell during the energy crises, and then rose again. Coal, after falling in the years before 1960, began to increase steadily. Nuclear began to contribute significantly around 1970. Renewables increased more slowly. In the absence of crises and regulation and holding total energy consumption constant, coal consumption would likely have grown more slowly or even declined. Given that alternative fossil fuels, nuclear, and renewables have lower carbon emissions, total carbon emissions would have increased more slowly if coal had grown more slowly or declined.

Two other factors, which had contributed to slower growth in previous periods, made smaller contributions in this period. Thermal efficiency improved more slowly relative to the previous period and output continued to expand, increasing overall emissions (Jorgenson 1984; Metcalf 2008). Further, gains from ongoing shifts to the service sector were smaller, because of smaller differences in emissions in the service and goods sector.

By the 1960s and early 1970s, US oil and gas markets faced challenges. On the oil side, consumption and imports were rising, because domestic production was too low to meet demand (Akins 1973; Painter 2012; Hamilton 2013). President Richard Nixon created a Cabinet Task Force on Oil Import Controls to investigate oil imports in 1969 (Bohi and Russell 2013). However, the task force's final report, *The Oil Import Question*, in early 1970 suggested that price increases would be limited and the market share of oil imports would remain small. In early 1973, price controls associated with rising inflation, together with the end of the Bretton Woods fixed-exchange-rate agreement and the resulting depreciation of the dollar, were causing gasoline shortages.

Natural gas was facing significant supply and demand imbalances as early as the 1950s, which caused prices to rise (Akins 1973; Davis and Kilian 2011). The rapid increase in prices led to the 1954 Supreme Court case *Phillips Petroleum Company v. Attorney General of Wisconsin* (347 US 672 [1954]), which held that natural gas prices were subject to federal regulation. The court ruling led to declining investment in gas production, and by 1970, this had begun the curtailment of natural gas deliveries to industrial customers.

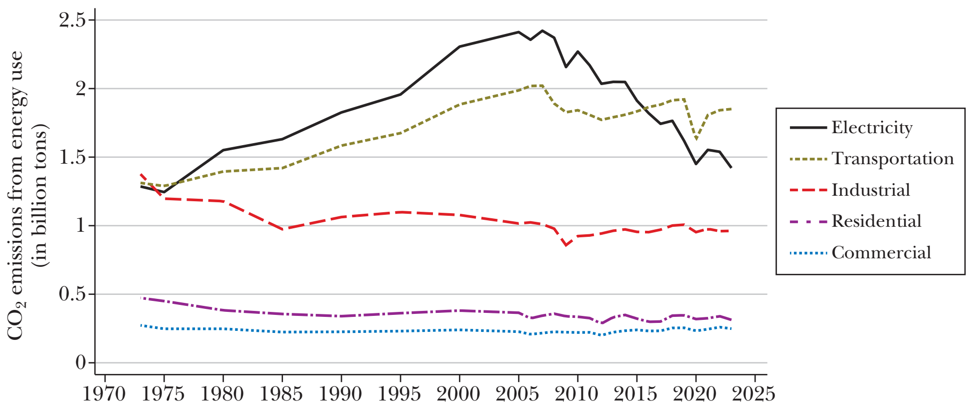
These preexisting issues were greatly exacerbated by how global energy markets were affected by aftereffects of the Arab-Israeli Yom Kippur War in 1973 and the Iranian Revolution in 1978–1979 (Painter 2012; Hamilton 2013; Brew 2019). The Organization of Petroleum Exporting Countries (OPEC) had been founded in 1960 for its members to obtain greater leverage with the major multinational oil companies. In 1971, the major oil companies and six OPEC members in the Persian Gulf signed the Tripoli Agreement. In October 1973, Arab and some non-Arab members of OPEC declared an embargo against the United States and other countries that supported Israel in the 1973 war and subsequently cut production. The real price of imported oil rose dramatically, from $10.67 per barrel in 1972 (in 2007 US dollars) to $36.05 in 1974 (Seiferlein 2007, p. 171). Turbulence in the Middle East kept prices high. Unrest in Iran and the Iran-Iraq War caused further disruption, driving oil prices to $62.71 per barrel in 1980.

Figure 5 shows carbon emissions by sector starting in 1973, when the data series begins.

In 1973, emissions from the industry, transportation, and electricity sectors were quite similar and much higher than emissions from the commercial and residential sectors.[8] By 1980, the electricity sector had the largest emissions. It remained the largest sector until 2005. Emissions from the transportation sector rose over the period as well, although more slowly than the electricity sector. In contrast to the electricity and transportation sectors, industrial emissions fell somewhat up to 1985 and were fairly flat thereafter. By 2005, industrial emissions were half or less than half of the transportation sector and the electricity sector.

[8] The commercial sector consists of service-providing businesses and organizations, while the industrial sector is made up of goods-providing businesses and organizations.

Figure 5
Carbon Emissions by Sector



Source: The data underlying this figure come from US Energy Information Administration (2025b).
Note: This figure plots annual total carbon dioxide emissions from energy use by sector from 1973 to 2024 (in billion tons).

The Electricity Sector from 1960 to 2005

Like national carbon emissions, emissions from the electricity sector rose rapidly. This faster growth was driven by three factors. First, coal consumption in the sector continued to rise, as documented in Figure 3, panel B. By 2005, coal consumption was five times what it had been in 1960. This in part reflects the fact that legislation during the energy crisis of the 1970s and the accident at the Three Mile Island nuclear power plant in Pennsylvania made it difficult to build new plants that utilized other fuel sources. Second, there were limited additional technological improvements after 1960. Third, the electricity industry was particularly affected by the 1970 Clean Air Act and 1977 amendments, such that the resulting actions taken to reduce local air pollution contributed to increasing carbon emissions.

Various regulations passed during and after the crisis reinforced the continued use of coal in electricity and other sectors. The first major piece of legislation was the Energy Supply and Environmental Coordination Act of 1974, which required that, if feasible, electric power plants burning oil and natural gas would have to convert to coal (Meltz 1975). This law was then largely superseded by the Fuel Use Act of 1978. Edward Lublin, Acting Deputy Assistant General Counsel for Coal Regulations in the Department of Energy, wrote: "The Fuel Use Act prohibits new facilities and allows DOE to prohibit existing facilities, from using petroleum or natural gas as a primary energy source unless DOE determines to grant to such facility an exemption from the Fuel Use Act's prohibitions (Lublin 1981, p. 355)." This pro-coal legislation was often justified in terms of energy independence, given the abundant US reserves of coal. The legislation covered both electric utilities and major industrial fuel-burning installations, although much of the Department of

Energy enforcement effort focused on electric utilities. While the legislation did not induce widespread conversion to coal at existing oil and gas plants—most utilities delayed any such conversion due to high cost, even when faced with conversion orders—new plants built after this legislation almost exclusively burned coal. Thus, these regulations increased carbon emissions.

Roughly concurrent with the energy crises of the 1970s, many nuclear power plants opened (Joskow 2006; Davis 2012). However, there was increasing resistance to nuclear power even beginning in the 1960s. Groups opposed to nuclear power filed legal cases. Federal agencies responded with safety-related changes and permitting and regulatory processes, and construction of nuclear power plants was delayed. These federal actions drove up costs, in some cases even among plants already under construction. In light of the pending cost increases, many proposed nuclear plants were canceled in the mid- to late 1970s.

Despite tightening standards, enough nuclear plants opened in the 1970s that nuclear power's share of total net electricity generation increased to around 10 percent. In 1979, a serious accident at Three Mile Island in Pennsylvania further highlighted the risks of nuclear power. After Three Mile Island, no new nuclear power plant construction was authorized until 2012. Because nuclear plants displaced coal-fired electricity generation—one gigawatt-hour of nuclear generation resulted in a roughly 0.8 gigawatt-hour decrease in coal-fired generation historically (Adler, Jha, and Severnini 2020)—the nuclear upheaval kept coal consumption higher than it would otherwise have been.

Electricity generation from coal as a share of all generation declined starting in the mid-1960s and then flattened in the 1970s. The share increased in the 1980s and remained above 50 percent up to 2005. Both oil and natural gas fell as shares of energy production over 1960–2005. The effects of Three Mile Island are less evident, because many nuclear plants were under construction and so would come online in the years following the accident. In the absence of the accident, however, it is likely that additional plants would have been built.[9]

After tremendous improvements in technology between 1940 and 1960, there were limited additional technological improvements to increase thermal efficiency. Until then, coal-fired power plants were operated at relatively low pressures. So-called "supercritical" boilers, developed after 1959, represented a major technological shift, using higher pressures to generate more efficient steam. They offered efficiency gains through reducing the need for some equipment and benefiting from economies of scale. Initially, the industry moved toward adopting supercritical technology, and by the mid-1970s, it seemed poised to replace older designs. However, by the 1980s, this shift reversed, and supercritical technology was largely abandoned (Joskow and Rose 1985). As noted in Joskow and Rose (1985), this reversal may have stemmed from higher outage rates and maintenance costs among supercritical units, as well as flagging electricity demand growth in the 1980s. These

[9] The effects of the energy crisis on the mix of fuels in the electricity sector is illustrated in Supplemental Appendix Figure A.2.

factors made it less attractive to build very large supercritical units that benefit from economies of scale.

Electrical utilities did not face significant pressure to curb emissions prior to 1960, although air pollution had been a source of local concern before that time. The period from 1960 to 2000 witnessed the emergence of the federal government's role in combating local air pollution. The 1963 Clean Air Act marked the first legislation granting the federal government authority to regulate air pollution. However, this law mainly created a small number of "abatement conferences," which brought together state and local officials, industry representatives, and federal authorities to discuss pollution sources, assess their impact, and seek voluntary agreements to reduce emissions before resorting to enforcement actions or legal steps. They were an early attempt to resolve air quality issues collaboratively. In the end, the 1963 legislation resulted in minimal enforcement to reduce air pollution.

The regulatory landscape changed dramatically with the passage of the 1970 Clean Air Act, which represented the first comprehensive federal effort to address local air pollution on a national scale. The 1970 Clean Air Act focused on reducing major local air pollutants—such as ambient ozone, particulate matter, and carbon monoxide. The United States saw sharp decreases in local air pollution emissions after 1972 (Cropper et al. 2023). The 1970 Clean Air Act had indirect effects on carbon emissions, even though CO_2 was not regulated at the time. As we describe below, efforts to cut local air pollution often increased carbon emissions. The 1970 Clean Air Act and subsequent amendments in 1977 coincided with less efficiency in converting coal to electricity sold and higher carbon emissions, as illustrated earlier in Figure 4. The aggregate implications of this shift from 1970 to 1990 are meaningful: annual total carbon emissions in 1990 from coal-fired generation was 1,607 million tons, but would have been 1,415 million tons if the same amount of coal-fired electricity had been generated at 1970 levels of carbon emissions per gigawatt-hour. Similarly, the aggregate kilowatt hours of electricity sold per ton of coal burned decreased from 2,529 in 1970 to 2,065 in 1990. Thus, regulation increased coal consumption and carbon emissions.

Compliance with environmental regulations reduced the efficiency with which coal was converted to electricity and increased carbon emissions for three reasons. First, the adoption of pollution-abatement technologies contributed to the declines in coal efficiency. These technologies (such as scrubbers, selective catalytic or noncatalytic reduction, and electrostatic precipitators) were implemented to control emissions of sulfur dioxide, nitrogen oxides, and particulate matter, respectively. However, these devices also require nontrivial amounts of energy to operate. Because the power plant must devote some of the energy it produces to operating pollution-abatement technology, it can sell less energy to the market. In addition, using some types of pollution-abatement technology lowers the thermal efficiency of power generation. For both reasons, the installation and operation of these technologies contribute to decreases in gigawatt-hours of electricity sold per tons of coal burned.

Second, in order to comply with the new regulations, many plants shifted towards burning coal with lower sulfur and heat content from the western United

States (Clay et al. 2025). Burning lower-sulfur coal reduced emissions of sulfur dioxide. But the fuel switching may also have lowered thermal efficiency, because plants are optimized to burn a particular type of coal (Joskow 1985). In addition, low-sulfur coal has lower heat content: more tons of coal are required to produce the same amount of heat input. This only had a small effect on carbon emissions, however, because carbon emissions per unit of heat are only slightly higher for western sub-bituminous coal than eastern bituminous coal (US Energy Information Administration 2025a).

Third, environmental legislation involved looking at emissions of criteria pollutants on a county-by-county basis. When a county was designated as "nonattainment," and not meeting emissions goals, power plants often responded by reducing output from that plant (Clay et al. 2025). These reductions may have led to plants producing at suboptimal efficiency levels.[10]

These three compliance methods highlight a significant trade-off between local pollution and carbon emissions. While the Clean Air Act effectively reduced local pollution, it may have inadvertently led to an increase in carbon emissions. The increase in carbon emissions per gigawatt-hour of electricity sold after 1970 underscores the challenge of balancing local air quality improvements with broader environmental impacts.

In summary, faster growth in carbon emissions at its most basic level was the result of higher energy consumption, including increases in coal consumption, a high carbon-emission fuel. In contrast to 1920–1960, there were limited improvements in thermal efficiency and limited gains from the ongoing shift to services. Both had helped offset the rise in carbon emissions prior to 1960. Unlike the previous period, the electricity sector was also a major source of emissions and the largest source of emissions from 1980 to 2005. Part of this was driven by the overall growth of the electricity sector. The energy crisis and the Three Mile Island accident reinforced the use of coal to produce electricity. This led to higher emissions, because coal has higher carbon emissions per unit of energy than oil, natural gas, and especially nuclear and renewables.

Declining Carbon Emissions from 2005 onward

After 150 years of nearly continuous increases in US carbon emissions, why do we suddenly see declines in carbon emissions after 2005 (as shown in Figure 2)? Given the importance of the electricity sector for emissions by 2005, we will discuss the economy and the electricity sector together in this section.

[10] Consistent with this insight, Supplemental Appendix Figure A.3 documents that aggregate coal efficiency decreased by more from 1970 to 1990 among coal-fired plants located in counties that ever faced nonattainment between 1972 and 1994 relative to coal-fired plants located in counties that never faced nonattainment between 1972 and 1994.

The patterns in Figure 3, panel A, presented earlier, suggest that these decreases in carbon emissions may have been driven by the substantial declines in petroleum and coal consumption and modest increases in renewables. Natural gas consumption increased, but this increase did not offset declines in the other two fossil fuels. In the absence of these declines in petroleum and especially coal, carbon emissions would have been substantially higher.

The key to understanding the decline in coal and the increase in natural gas is the natural gas fracking revolution. Coal had been the dominant energy source for electricity generation for decades, reaching its peak in the mid-2000s with over one billion short tons consumed annually. However, coal consumption saw a dramatic drop in the 2010s, falling by almost half by the early 2020s. Figure 3, panel B, highlights a sharp decline in US coal consumption for electricity generation starting around 2008. Not coincidentally, Figure 2 shows a drop in both total and per capita carbon emissions for the US economy starting about the same time.

Hydraulic fracturing, known as "fracking," involves pumping water, sand, and chemicals into underground rock formations. This creates fractures in the rock that allow drilling for natural gas. The "fracking revolution" unlocked vast reserves of natural gas in the United States, which in turn led to a drop in US natural gas prices of over 60 percent between 2008 and 2015. As a result, natural gas quickly displaced coal as the primary fuel for electricity generation. This switch reduced carbon emissions, because natural gas emits roughly 50–60 percent less carbon than coal when burned for energy.

The rise of renewable energy sources like wind and solar also contributed to the reduction in the use of coal for electricity generation in the United States. Technological innovation and declining costs helped make renewables more attractive. Government policies, including tax incentives and state-level renewable portfolio standards, further encouraged the shift to renewables. In 2010, only 2 percent of US total electricity generation came from wind and solar resources (US Energy Information Administration 2024b). However, wind power alone accounted for about 10 percent of US electricity generation in 2023, over quadruple its contribution from a decade earlier. Solar power accounted for about 4 percent of electricity generation in 2023, as compared to only 0.03 percent in 2010.

At the same time renewables were becoming more competitive from a cost perspective, regulation was making coal-fired generation more expensive. We have already seen that regulation—the 1970 Clear Air Act and the 1977 Amendments—reduced the efficiency of coal-fired power plants. Further regulation including the 1990 Clean Air Act Amendments made coal even more unattractive.

Changes were also occurring in the transportation sector. After the early 2000s, the US government took significant legislative steps to improve fuel efficiency in response to energy security concerns, rising oil prices, and growing awareness of climate change. Two landmark laws—the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007—played a central role in tightening fuel economy standards. The Energy Policy Act of 2005 laid the groundwork by promoting alternative fuels and energy efficiency, including incentives for hybrid and alternative fuel vehicles. However, the more transformative legislation was the Energy Independence and Security Act of 2007, which mandated the first substantial increase in the Corporate Average Fuel Economy (CAFE) standards since the 1970s. It required automakers to raise the average fuel economy of new passenger cars and light trucks to 35 miles per gallon by 2020, up from roughly 25 miles per gallon at the time. The Act also expanded the Renewable Fuel Standard, pushing more ethanol and biofuels into the gasoline supply. These laws helped limit the growth of carbon emissions in the transportation sector.

Carbon emissions in the electricity sector began to fall around 2005, as shown in Figure 5. By 2016, transportation became the largest carbon-emitting sector. By 2024, carbon emissions in the electricity sector had fallen almost one billion tons from their peak in 2005. Thus, the electricity sector was responsible for virtually all of the decline in carbon emissions in the economy in the 2000s.

At present, the electricity sector faces a new challenge. Electricity consumption from data centers is rising rapidly with the large-scale development and use of artificial intelligence. Data centers accounted for just 2 percent of total US electricity consumption in 2018 but over 4 percent in 2023—and could consume 7 to 12 percent of total US electricity by 2028 (Shehabi et al. 2024). Meeting this growing demand will require substantial investment in new generation resources—with significant carbon-emissions implications depending on whether the added load is met by new gas-fired plants, expanded wind and solar capacity, or delayed coal plant retirements.

In summary, US carbon emissions began declining around 2005 after more than a century of growth, largely due to major shifts in the electricity sector. The widespread adoption of hydraulic fracturing made natural gas cheaper, allowing it to replace coal—which emits significantly more carbon—as the dominant source of electricity. Simultaneously, wind and solar power expanded due to falling costs, technological innovation, and supportive policies. Environmental regulations also made coal generation more expensive and less efficient. As a result, electricity-sector emissions fell by nearly one billion tons between 2005 and 2024, accounting for almost the entire national decline. However, rising electricity demand from data centers, driven by artificial intelligence, presents a new challenge for future decarbonization.

Implications for Developing Countries

Our analysis underscores several lessons from the US experience that may inform ongoing decarbonization efforts, particularly in developing economies where energy demand is rising rapidly. While each country will face unique institutional, political, and technological constraints, historical patterns offer useful guidance on avoiding carbon-intensive development paths and navigating the complex trade-offs between local and global environmental objectives.

First, coal remains a major fuel source for electricity generation worldwide, particularly in low- and middle-income countries (IEA 2025a). As electricity demand from industry and households rises, the electricity sector is likely to play an increasingly central role in global carbon emissions (IEA 2024, 2025b). The US experience offers a precedent: by the mid-twentieth century, electricity generation had become the dominant consumer of coal. A similar pattern may emerge elsewhere unless countries adopt cleaner electricity-generation technologies.

Second, our findings underscore the central role of technological progress and coal-efficiency gains in curbing carbon emissions. In the United States, rapid innovation significantly contributed to efficiency gains between 1920 and 1960. In the electricity sector specifically, major advances—such as more efficient generators, high-voltage transmission lines, and economies of scale from centralized production—substantially lowered the amount of coal needed to generate electricity. By adopting proven technologies and investing in emerging innovations, research, and local capacity-building, developing economies may be able to expand electricity access while limiting carbon emissions.

Third, the US experience demonstrates how geopolitical shocks and policy responses can have unintended and enduring effects on the energy mix. The energy crises of the 1970s, coupled with efforts to enhance energy security, inadvertently deepened the nation's reliance on coal. Similarly, public backlash to nuclear accidents—Three Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011—led the United States, Germany, and others to scale back nuclear power in favor of fossil-fuel generation (Severnini 2017; Adler, Jha, and Severnini 2020; Jarvis, Deschenes, and Jha 2022). Given the long lifespans of energy infrastructure, these short-term policy responses had enduring consequences for carbon emissions. These historical episodes underscore the need to anticipate the long-run environmental and climate implications of energy decisions made in response to crises.

Finally, our analysis highlights the persistent challenge of designing environmental regulations that address both local and global pollutants. In the United States, the Clean Air Act of 1970 and its 1977 and 1990 amendments led to major reductions in harmful local pollutants such as sulfur dioxide and particulate matter. However, some of the compliance strategies, including the installation of scrubbers and a shift to low-sulfur coal with lower heat content, inadvertently increased overall coal consumption and thus carbon emissions. While many advanced economies are now seeking to transition toward renewables that do not emit local or global pollution in the generation process, developing countries that continue to rely on fossil fuels may face similar trade-offs. As emerging technologies such as carbon capture, utilization, and storage (CCUS) and hydrogen production become more widespread, it is essential to evaluate their broader environmental impacts. For instance, while CCUS can lower carbon emissions, it may increase releases of other pollutants, including ammonia (Waxman, Huber-Rodriguez, and Olmstead 2024).

Moving forward, effective climate and energy policy must draw on historical experience to design frameworks that minimize unintended consequences. Developing countries can avoid some of the pitfalls encountered by the United States by investing in efficient technologies, avoiding overreliance on coal, responding strategically to geopolitical shocks, and crafting environmental regulations that reflect both local and global pollution objectives. By fostering innovation, maintaining regulatory flexibility, and holistically accounting for environmental externalities, policymakers can more effectively meet their climate goals while ensuring energy access and fostering economic growth.

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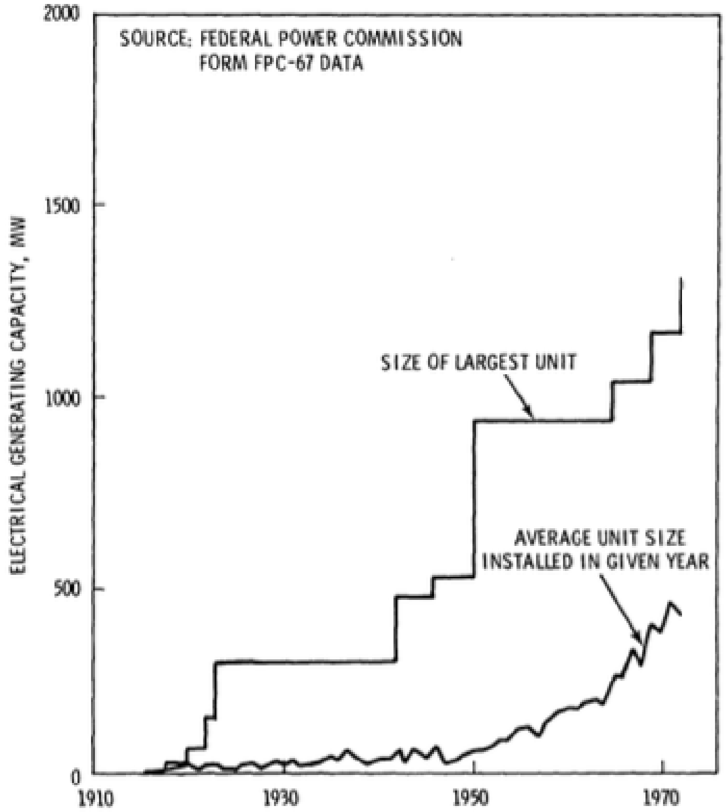
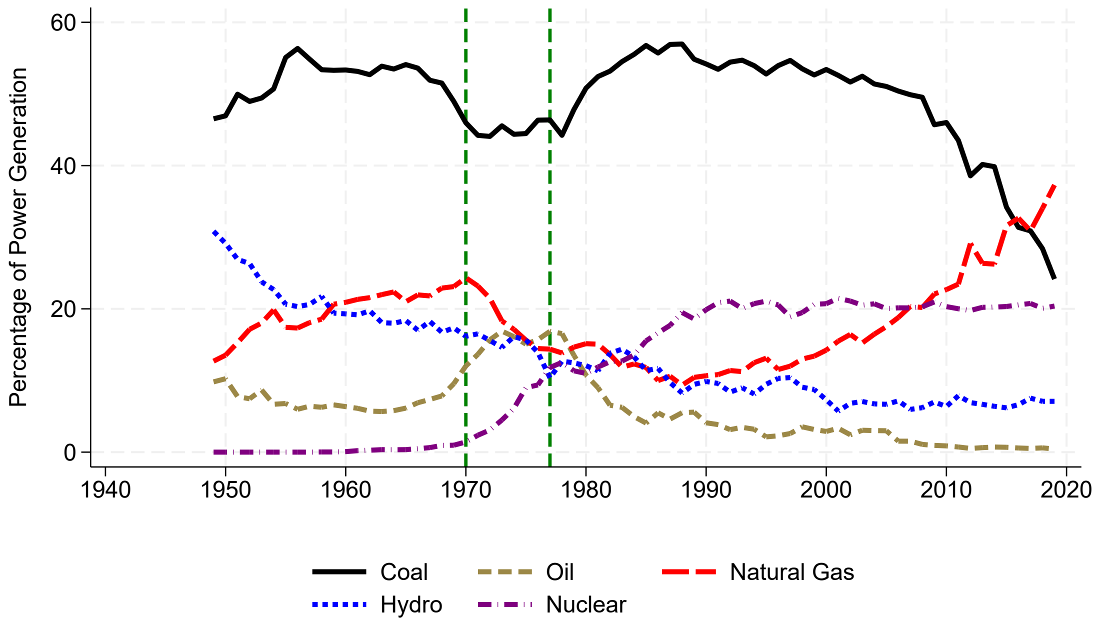
A Online Appendix

Figure A.1: Trends in Power Plant Electrical Generating Capacity



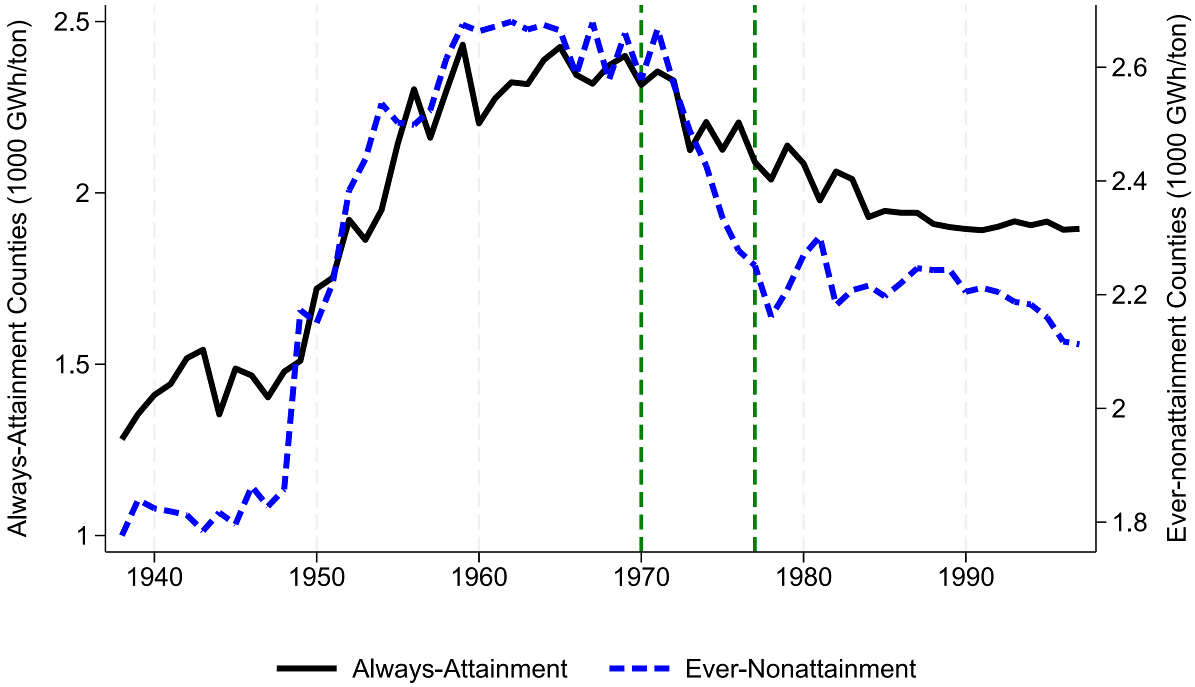
Notes: This figure documents the average and maximum capacities (in MW) of electricity generating units in each year. The data used to construct this figure comes from Federal Power Commission Form FPC-67. *Source*: Figure 3, Hales (1976).

Figure A.2: Net Electricity Production by Fuel Source



Notes: This figure plots annual total net electricity production by source. This figure is based on data from the U.S. Energy Information Administration (EIA) and Schurr and Netschert (1960). Data are only available beginning in 1949. The vertical dashed green lines denote the passing of the 1970 Clean Air Act and its amendments in 1977 respectively.

Figure A.3: Coal Efficiency by County Attainment Status



Notes: This figure plots annual aggregate coal efficiency: annual total electricity production from coal-fired plants (in 1,000 GWh) divided by annual total tons of input coal. We plot annual aggregate coal efficiency separately for plants in counties that never faced nonattainment between 1972-1994 ("always-attainment counties", the solid black line on the left y-axis) and plants in counties that faced nonattainment at least once between 1972-1994 ("ever-nonattainment counties", the dashed blue line on the right y-axis). Nonattainment counties must take compliance actions to bring their pollution levels back into attainment. This figure is based on data on power plant operations from 1938-1994 from Clay et al. (2025).