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

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Abstract

This paper explores the factors underlying periods of slower and more rapid growth in historical carbon emissions in the United States, the world's largest carbon emitter from 1890-2005. The paper begins by documenting changes in carbon emissions for the U.S. economy as a whole over the twentieth century. We next focus on the largest carbon emitting sector — electricity generation — making three key points. First, increases in productivity played a key role in reducing carbon emissions from 1940-1960. Second, the energy crisis of the 1970s and regulations related to the crisis reinforced the use of coal, which has higher carbon emissions when burned than oil or natural gas. Third, the Clean Air Act of 1970 and its amendments in 1977 reduced local air pollution per unit of electricity at the expense of increased carbon emissions. We discuss the broader implications of these three points for economies working to reduce carbon emissions.

1 Introduction

World carbon emissions have risen dramatically over the last 150 years. To reverse this trend and move towards a low carbon future, it is necessary to understand the roles that productivity, regulation, and other factors have played in determining carbon emissions. Our understanding of these factors is surprisingly limited. A large literature has focused on the question of whether the relationship between per-capita carbon emissions and income is consistent with an environmental Kuznets Curve (Shahbaz and Sinha, 2019). Most studies of the drivers of carbon emissions more broadly do not go back very far in time. Those that do cover long historical periods tend to focus on decompositions using aggregate national data, rather than firm or plant specific data (Tol, Pacala and Socolow, 2009; Henriques and Borowiecki, 2017).

This paper explores the factors underlying periods of slower and more rapid growth in historical carbon emissions in the United States, the world's largest carbon emitter from 1890-2005. We begin by documenting changes in carbon emissions for the U.S. economy as a whole over the twentieth century. U.S. carbon emissions rose dramatically from 1890 to 2005 both in absolute terms and on a per capita basis. Strikingly, the growth rates of carbon emissions and carbon emissions per capita are not at all constant. The graphs, particularly the graph for per capita emissions, resemble a roller coaster. Namely, per-capita carbon emissions exhibited rapid growth in some periods, stagnation in others, and notable declines during the Great Depression and in more recent years. We discuss these patterns as they relate to the work in economics and economic history on the development of fossil fuel endowments in the United States during the nineteenth century, the use of fossil fuels in U.S. manufacturing and exports, variation in total factor productivity over time, and energy transitions in the twentieth century.

We next focus on the largest carbon emitting sector in the United States — electricity generation, using annual power plant level data beginning in 1938. We focus on electricity generation because it has historically been a critical input to the American economy.

Further, the power sector is increasingly important today as the United States moves towards electrifying other carbon intensive sectors such as heating and transportation.

The paper makes three key points about the electricity sector, which have implications for understanding carbon emissions in other sectors as well. The first point is the important role that increases in productivity played in reducing carbon emissions. Using detailed annual plant level data, we show that the electricity industry experienced dramatic increases in productivity from 1940 to 1960. In the absence of these productivity gains, U.S. carbon emissions would have been 34% higher.

The second is the role that the energy crisis of the 1970s and regulations related to the crisis played in reinforcing the use of coal, which emits more carbon emissions when burned than other fuels. During this period, the Federal Energy Administration restricted the building of new oil and natural gas power plants and forced some existing oil and natural gas plants to begin using coal. Investment in nuclear power also slowed in the 1970s due to the rising costs of nuclear power, stalling completely after the accident at Three Mile Island in 1979. Because of rising demand for electricity, coal consumption in the electricity sector continued to climb.

The third is that the Clean Air Act of 1970 and its amendments in 1977 reduced local air pollution emissions per unit of electricity at the expense of increased carbon emissions. For coal fired power plants, the air pollution regulations led to installation of electrostatic precipitators, baghouses, and scrubbers, which require substantial energy to run. While the use of these technologies reduce local pollution emissions, the energy required to run these technologies result in increased carbon emissions per unit of electricity sold. Between 1970 and 1990, coal consumption and carbon emissions per gigawatt hour produced rose by more than 13% across coal fired power plants.

These three points have implications for economies working to reduce carbon emissions. First, we highlight the central role of technology and productivity in influencing carbon emissions. From 1900 to 1960, a series of major technological innovations in the

U.S. power sector coincided with large decreases coal intensity. In more recent decades, as the sector's productivity has stagnated, coal intensity has increased. In many developed economies, productivity may play a limited role in current decarbonization efforts. In some developing economies, however, productivity improvements in the electricity sector and the broader economy may play a more important role in decarbonization.

Second, we highlight how geopolitical events and crises can shape carbon emissions over the longer-run. In the U.S., the energy crisis of the 1970s and regulations related to the crisis reinforced the use of coal. Developed and developing countries should be attentive to events that directly or indirectly reinforce the use of carbon emitting fossil fuels. Rapid shifts away from nuclear power in response to Three Mile Island (1979), Chernobyl (1986), and Fukushima (2011) in the United States, Germany, and other countries is one example (Severnini, 2017; Adler, Jha and Severnini, 2020; Jarvis, Deschenes and Jha, 2022).

Finally, the analysis highlights the challenge for environmental regulation in meeting the dual objectives of reducing *both* local and global emissions. In the United States, the Clean Air Act of 1970 and its amendments in 1977 successfully reduced local air pollution per unit of electricity, but these declines came at the expense of increased carbon emissions. Many developed economies are moving quickly towards the use of renewable energy sources, which do not emit either local or global air pollutants. Some other economies, however, remain heavily reliant on fossil fuels, including coal, and so may face the same tradeoff between local pollutants and carbon emissions that the historical United States did.

2 Historical Carbon Emissions

2.1 Background

U.S. carbon emissions rose dramatically from 1890 to 2005 both in absolute terms and on a per capita basis. Prior to 1890, Great Britain was the largest emitter and after 2005, China is the largest emitter. The United State's dominance in carbon emissions was not simply because of its population. On a per capita basis, the United States surpassed Great Britain in 1903 and was surpassed by Australia in 2009.[1]

Figure 1 shows the trajectory of total and per capita carbon emissions from fossil fuels and industry in the United States. In 1890, the U.S. emitted 400 million tons of carbon dioxide (CO_2), while in 2005, it emitted 6.1 billion tons. On a per capita basis, emissions were 6.5 tons per person in 1890; at its peak in 1973, it was 23.1 tons; and in 2005, it was 20.7 tons.[2]

The growth rate of carbon emissions and carbon emissions per capita in Figure 1 shows striking variation over time. The graphs, particularly the graph for per capita emissions, resemble a roller coaster. Over certain periods, emissions rose rapidly. Over other periods, emissions were relatively flat. During the Great Depression and in more recent periods, emissions fell.

Figure 1 highlights that the increase in carbon emissions was due to two factors – land use changes and increased consumption of fossil fuels over time. Land use changes, primarily deforestation for land clearing, fuel wood, and wood products, were relatively important initially. Up to the early 1910s, land use change was responsible for more than half of total emissions. Land use changes remained significant through 1940, when it represented about 25% of U.S. emissions. After 1940, its share was small.

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

[2] Data on carbon emissions are taken from Ritchie, Rosado and Roser (2023). The Our World in Data website includes detailed information on how estimates are constructed and the carbon emission factors used.

Figure 2 presents annual total energy consumption by fuel type in the U.S. from 1850-2023. This figure shows that coal was the dominant fossil fuel starting around 1880. Coal's dominance continued to 1950, when it was surpassed by petroleum. Energy consumption from all three fossil fuels also exhibit roller coaster patterns, with at least one — and sometimes more — periods of increase, decrease, and then increase.

2.2 Rising Carbon Emissions during the Late Nineteenth and Early Twentieth Centuries

The early development and use of fossil fuels in the United States drove the rapid rise in carbon emissions between 1890 and 1917. Over that period, aggregate emissions from land use change were fairly stable, falling modestly from 1.48 billion tons of CO_2 to 1.23 billion tons. In contrast, aggregate emissions from fossil fuels and industry rose from 400 million tons of CO_2 to 1.67 billion tons. On a per capita basis, emissions increased from 6.5 tons to 16.8 tons.

In 1890, the United States had natural endowments of minerals, including fossil fuels, but so did many other countries. What distinguished the U.S. was early development of its resources through investment in mining education and incentives for discovery provided in federal mining laws (David and Wright, 1997). In the 1910s, the U.S. was also the leading producer of fossil fuels (Wright, 1990). In 1913, it produced 39% of world coal, 65% of world petroleum and 95% of world natural gas. This is despite having about 23% of world endowment in 1989 (reserves + historical cumulative production) of coal and 20% of world endowment in petroleum. The U.S. was also a top producer across a broad range of industrial minerals including iron ore, copper, lead, and zinc, among others.

Coal and other fossil fuels had a wide range of economically important uses including transportation and industrial production. For example, coal represented 90% of railroad fuel in 1880 (Atack, 2024). In 1915, railroads consumed slightly more than a quarter of all

bituminous coal consumed in the U.S. and a smaller share of anthracite coal. Petroleum was initially refined into kerosene for lighting, but became increasingly important as cars, trucks, and other forms of transportation fueled by petroleum products appeared on the scene.

U.S. manufacturing was growing rapidly and harnessing a range of new fossil fuel powered sources, including steam and electricity (Lafortune et al., 2021). Over 1880-1900, manufacturing exhibited modest decreasing returns to scale at the median (0.959). However, during 1910-1930, manufacturing began to exhibit modest increasing returns to scale at the median (1.024). These increasing returns were larger in sectors with greater human capital and energy intensity in 1880. Consistent with this, carbon emissions per dollar of GDP rose up to 1917 and then began to fall (Muller, 2022).

During this era, the U.S. rose to leadership in world industrial production, surpassing the United Kingdom (Wright, 1990). One of the distinctive characteristics of U.S. manufacturing exports between 1880 and 1920 was their high and rising intensity in non-reproducible natural resources (Wright, 1990). Coal was a key input into iron and steel products, and iron and steel products along with petroleum products were increasing shares of American exports. By 1913, these two categories represented 38% of U.S. exports, and the shares would climb above 50% in the 1920s. Petroleum exports were initially kerosene and later included gasoline, aviation gasoline, diesel, and other products. During World War I, petroleum products took on enormous strategic importance as motorcycles, cars, trucks and airplanes played critical roles.

2.3 Decarbonization through Productivity Growth

Estimates show slower growth in total factor productivity (TFP) up to 1920, more rapid growth up to 1970, and slower growth after that (Gordon, 2017; Field, 2018; Bakker, Crafts and Woltjer, 2019). Gordon (2016) highlights the differences across the three periods (p. 73): "The margin of superiority of TFP growth in the 1920–1970 interval is

stunning, being almost triple the growth rate registered in the other two periods." Gordon (2017) also examines labor productivity, decomposing it into the parts attributable to education, capital deepening, and rising TFP. He notes that the contributions of education and capital deepening are relatively constant over the three periods, 1890-1920, 1920-1970, and 1970-2014. Thus changes in TFP were the primary driver of variation in labor productivity over time.

Increased total factor productivity in manufacturing, rail, and electric utilities, all major consumers of coal, contributed to the slower growth in carbon emissions overall and on a per capita basis beginning in the 1920s. Unfortunately, detailed sectoral data are not available over the entire period. Bakker, Crafts and Woltjer (2019), do, however, provide sectoral estimates of TFP for 1899-1941. Manufacturing had TFP growth rates close to zero before 1920, high TFP in the 1920s, and lower TFP in the 1930s for an overall growth rate of 2.0%. Rail experienced steadier growth in TFP over time with an overall growth rate of 2.2%. The electric utility sector was a leader in TFP growth throughout 1899-1941, with a TFP growth rate of 5%.[3]

2.4 Carbon Emissions and the Changing Energy Mix

Figure 2 shows the changes in fuel mix that began around 1920. Coal consumption, which had been rising rapidly, began to flatten and even fall. This continued until about 1960, when coal consumption began to rise again. Coal consumption began its final decline in the early 2000s. Around 1920, consumption of petroleum began to increase rapidly, and in the 1940s natural gas began to increase rapidly as well. Consumption of both petroleum and natural gas fell during and after the oil crises of the 1970s before rising again. In the last 20 years, energy consumption from renewables has begun to rise.

[3]The drivers of TFP across these sectors varied. In manufacturing, it was electrification and the associated organizational changes (Fiszbein et al., 2020), while in electricity, it was economies of scale and improvements in transmission (Kitchens and Jaworski, 2017). In rail, the increase was the result of changes in organization and operations and improvements in locomotives and rolling stock (Field, 2011).

Until quite recently hydropower and wood were the most common renewable energy sources. Recent increases have been driven by wind, solar, and geothermal generation.

The changing fuel mix had implications for CO_2 emissions, because petroleum and natural gas have lower carbon emission factors per unit of energy than coal. What drove these shifts in fuel mix? On the supply side, prospectors had been looking for oil to produce kerosene since the nineteenth century (Yergin, 2011). They and subsequent investors discovered and profitably exploited oil fields in the Appalachian basin. The market for kerosene, while lucrative and sizeable, was finite. Demand soared with the rise of internal combustion engines fueled by petroleum products and their use in cars, trucks, and other forms of transportation. By then, further exploration had led to large discoveries in California, Louisiana, Texas, and Oklahoma. Consumption of petroleum increased rapidly.

In addition to meeting new transportation needs, petroleum replaced coal as a fuel for some applications. For example, locomotives and ships shifted from coal fired engines to diesel engines. Oil also began to replace coal for residential and commercial heating in some parts of the country. In both cases, oil was cleaner burning and easier to transport and store than coal. New electric power plants were powered by oil in some parts of the country, where prices were low.

Natural gas took longer to take off, because it was harder than petroleum to capture and transport (Castaneda, 2018).[4] One problem was that fields tended to be rapidly depleted, so consistent availability of supply was an issue. Things began to change with the discovery and development of natural gas in California and the Southwest, often in conjunction with oil. In the 1920s, firms began constructing long distance natural gas pipelines to major cities including San Francisco, California; Wichita, Kansas; and Denver, Colorado (Castaneda, 2018). Development of pipelines slowed during the Depression and expanded after World War II with the privatization and conversion of oil

[4]Natural gas was used for cooking, heating, and industrial purposes in some places in Appalachia, such as Pittsburgh, quite early (Tarr and Clay, 2015).

pipelines built during the war to natural gas.

Like petroleum, natural gas replaced coal as a fuel for some applications. In particular, natural gas began to replace coal for residential and commercial heating, cooking, and selected industrial uses. Where prices were low and availability was secure, new electric power plants were powered by natural gas.

2.5 The Energy Crisis, Regulation, and Carbon Emissions

In the 1960s and early 1970s, there were signs of problems in U.S. oil and gas markets. On the oil side, consumption and imports were rising, since domestic production was too low to meet demand (Akins, 1973; Painter, 2012; Hamilton, 2013). The Nixon Task Force Report on Oil Imports in early 1970 suggested, however, that price increases would be limited and the share of imports would remain small. In early 1973, price controls associated with the end of Bretton Woods and the depreciation of the dollar were causing gasoline shortages. Natural gas was facing significant supply and demand imbalances beginning in 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 vs. Attorney General of Wisconsin. The court ruling led to the price regulation of interstate transfers of natural gas and declining investment in gas production. By 1970, this had begun to lead to curtailment of natural gas deliveries to industrial customers.

These preexisting issues were greatly exacerbated by the Arab-Israeli War in 1973 and the Iranian Revolution in 1978-1979 (Painter, 2012; Hamilton, 2013; Brew, 2019). OPEC had been founded in 1960 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 members of OPEC and some Arab non-members declared an embargo against the U.S. and other countries that supported Israel in the Yom Kippur War and subsequently cut production. The real price of imported oil rose dramatically, from $10.67 per barrel in 1972 (2007 USD) 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 prices to $62.71 in 1980.

Roughly concurrent with the energy crises of the 1970s, there were many nuclear power plant openings and then a high-profile nuclear accident (Joskow, 2006; Davis, 2012). However, there was increasing resistance to nuclear power even beginning in the 1960s. One byproduct of this was construction delays as groups opposed to nuclear power filed legal cases and federal agencies responded with safety related changes and public hearing processes. These drove up costs, in some cases even among plants already under construction. In light of the cost increases, many proposed plants were canceled in the mid to late 1970s. Despite tightening standards, many plants opened in the 1970s, increasing nuclear power's net generation share to around 10%. In 1979, a serious accident at Three Mile Island further highlighted the risks of nuclear power. After Three Mile Island, no new nuclear power plant construction was authorized until 2012.

The pre-existing trends and the energy crisis shifted the mix of fuels consumed in the United States, decreasing the use of petroleum and natural gas. Figure 2 shows that petroleum consumption, which peaked in 1978, would not regain this peak until 2000. Similarly, natural gas consumption, which peaked in 1972, would not regain this peak until 1996. Because nuclear plants displaced coal-fired electricity generation – 1 GWh of nuclear generation resulted in a roughly 0.8 GWh decrease in coal-fired generation historically (Adler, Jha and Severnini, 2020) – the nuclear upheaval increased coal consumption.

Regulation 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 (ESECA), which required that, if feasible, electric power plants burning oil and natural gas would have to convert to coal (Meltz, 1975). ESECA was 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). The legislation covered both electric utilities and major industrial fuel burning installations, although much of the Department of Energy's enforcement effort in practice focused on electric utilities. While the legislation did not induce widespread conversion at existing plants – most utilities delayed due to high cost, even when faced with conversion orders – new plants were almost exclusively coal burning.

3 Carbon Emissions in the Electricity Sector

3.1 Coal intensity during the early development of the power sector, 1882 to 1940

Total coal consumption by electric utilities rose dramatically from 1882 to 1940. The sector remained small in the decades following the opening of Edison's Pearl Street power plant in 1882. By the turn of the century, electric utilities consumed roughly 9 million short tons of coal per year, accounting for just 3 percent of total U.S. consumption. Annual coal consumption by electric utilities rose to 50 million short tons by 1940, with the sector accounting for 11 percent of total U.S. consumption (U.S. Census Bureau, 1976).

The increase in utility coal consumption mirrored a national rise in electricity generation. Between 1900 and 1940, total generation by electric utilities increased from less than 2 billion kWh to more than 140 billion kWh (U.S. 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 manu-

facturing 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 electrified.

Over this same time period, the electricity sector witnessed dramatic *declines* in coal intensity, as measured by the tons of coal burned per megawatthour of generation. Between 1900 and 1940, coal intensity decreased by more than 90 percent. The declines in coal intensity in the electricity sector were driven by both technological innovation in the power sector and changes in federal and state government policy. These two factors had independent and interactive impacts on the national trends.

Technological innovation was a primary driver of the declines in coal intensity. A number of technical developments improved coal combustion, including the use of steam with higher pressure and temperatures as well as pulverized fuel. This allowed for much larger and more thermally-efficient generation (Lovell, 1941).

Appendix Figure A.2 documents the size of the largest generating unit and the average unit size in each year. The early decades of the 20th century witnessed the installation of substantially larger generating units. Over this same time period, the average size of new generating units steadily increased.

At the same time, advances in transmission technology allowed electric utilities to site new plants at better locations. Indeed, local factors such as water temperature played a crucial role in the performance of steam turbines (Lovell, 1941). Meanwhile, the development of an interconnected grid reduced reliance on smaller, less efficient, locally provided power sources, and allowed power plants to operate at greater efficiency levels by smoothing demand across geographically distinct load centers.

New state and federal policies also contributed to the declines in coal intensity in the pre-WWII era. The policies enacted during this period were not designed to target emissions in the electricity sector per se. Instead, the reductions in coal intensity arose indirectly as an unintended consequence of new state and federal legislation.

State-level policies interacted with technological progress in the power sector to reduce coal intensity. Beginning in 1907, states began regulating the electricity sector, establishing rate-of-return legislation and enacting territorial monopolies. These new regulations reduced the borrowing costs for private electric utilities and allowed them to better exploit economies of scale (Hausman and Neufeld, 2002; Knittel, 2006). These policies reinforced the shift away from smaller 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.

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 TVA and Bonneville hydro plants. 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.

This expansion in hydroelectric capacity reduced reliance on coal-fired generation and contributed to the decline in coal intensity over this period. Indeed, absent the new additions of hydroelectric capacity between 1920 and 1940, national-level coal intensity in the electricity sector would have been 28 to 40 percent higher by 1940. This range in estimates reflects uncertainty regarding the extent to which unmet electricity demand was replaced with additions in coal capacity. Assuming that none of the missing hydro capacity was offset by new coal capacity, counterfactual coal intensity would have been 28 percent higher by 1940. Assuming that new investments in coal capacity fully offset the missing hydro capacity, counterfactual coal intensity would have been 40 percent higher.

Despite the significant impact of federal and state policy on national carbon intensity in the electricity sector in the pre-WWII era, there was little direct effort to curb

plant emissions. State and federal air quality regulations were non-existent, and local ordinances aimed at reducing city pollution were largely unenforced.

In summary, the period 1882 to 1940 witnessed a massive expansion in total coal consumption by electric utilities which coincided with rising demand for electricity for commercial, industrial, and residential purposes. At the same time, technological innovations in generation and transmission both contributed to reductions in coal intensity over this time period. State and federal policies complemented these innovations to reinforce the national decline in coal intensity over this period.

3.2 Mid-20th century decarbonization of the electricity sector, 1940-1960

As demand for electricity increased, coal consumption by electric utilities rose throughout the mid-20th century. Figure 3a displays annual total coal consumption by sector from 1940-2020. By 1960, the power sector was the leading source of domestic coal use. In contrast, coal use in other sectors declined over this period, with almost no coal burned for heating or transportation purposes by 1970.

Figure 3b shows the percentage of electricity generation from various energy sources from 1950 to 2000, highlighting the shifts in reliance over time. Coal and hydro were the dominant sources in the earlier decades, but nuclear and natural gas saw significant increases later on. In the 1970s, the share of electricity produced using coal temporarily declined, likely due to the rise of nuclear energy. However, the growth of nuclear energy slowed following the Three Mile Island accident in 1979, leading to a rebound in the share of electricity generation from coal.

The thermal efficiency of power plants also improved substantially between 1940-1960, as illustrated in Figure 4. This figure presents trends in annual total tons of coal burned divided by annual total gigawatt hours (GWh) of electricity produced (termed "coal intensity"). 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. Similar declines – from 14,081 to 9,261 – occurred in the input heat energy (MMBtus) per gigawatt hour. Measuring energy in MMBtus accounts for variation in the energy content of different types of coal, which becomes important later in the twentieth century.

The primary drivers behind the declines in coal intensity in the power sector were technological innovation, economies of scale, and improvements in transmission.[5] Coal-fired power plants generate electricity by heating water into high-pressure steam in order to spin the turbine and ultimately 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 in the production process—with the associated improvements in thermal efficiency. In particular, in the post World War II era, the industry benefited from wartime-related improvements in design and metallurgy that supported larger scale (Rosenberg, 1998). As documented in Hales (1976), electric utilities steadily built larger generating units between 1910-1970 (see Appendix Figure A.2). The associated economies of scale also served to decrease aggregate coal intensity in the industry. In addition, the continued development and interconnection of high-voltage transmission infrastructure also played a crucial role by reducing communities' reliance on small, local power producers. This grid enabled utilities to build larger power plants further away from demand centers (Clay et al., 2021).

As a result of these improvements in thermal efficiency, there was a 34% 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 588 million tons if total coal-fired generation in 1960 was produced at the aggregate carbon emissions per gigawatt hour of electricity in 1940.

[5] As discussed in Bakker, Crafts and Woltjer (2019), this rapid increase in productivity growth beginning in the 1920s was also present in the rail and manufacturing sectors.

[6] Throughout the paper, we translate input heat energy from coal to carbon emissions using a conversion factor of 211.63 tons of CO_2 per MMBtu of coal (U.S. Energy Information Administration, 2024*a*).

Rising coal consumption in the electricity sector brought with it concerns about air pollution, since emissions 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 and the Great Smog of London in 1952. For instance, the estimated negative effects of coal-fired plant openings on local housing values from Clay, Lewis and Severnini (2024) suggest a reversal in the local amenity value associated with coal-fired generation.

Despite these concerns, there was little federal or state action to address air pollution. The Air Pollution Control Act of 1955 allocated 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 the Federal Power Commission's Annual Reports. For example, the 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 socio-economic concern for the electric power industry (FPC, 1967, p.ix). Although experimentation with baghouses and other pollution abatement technologies began in the 1940s, few plants had installed such systems before 1960.

In summary, there was a dramatic decrease in coal intensity within the electricity sector between 1940-1960, driven primarily by technological advancements that improved the efficiency of new boilers built over this period. This greatly reduced carbon emissions in the electricity sector. While air pollution was a source of local concern, utilities did not face significant pressure to curb emissions prior to 1960.

3.3 The emergence of federal local air pollution regulation in the power sector, 1960-2000

The period from 1960 to 2000 witnessed the emergence of the federal government's role in combating local air pollution. This shift began with the 1963 Clean Air Act (CAA), which marked the first instance of federal legislation granting the government authority to regulate air pollution. However, only a small number of abatement conferences were held under this legislation. Abatement conferences 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 CAA resulted in minimal enforcement to reduce air pollution.

The regulatory landscape changed dramatically with the passage of the 1970 Clean Air Act. The 1970 CAA represented the first comprehensive federal effort to address local air pollution on a national scale. The United States saw sharp decreases in local air pollution emissions after 1972 (Cropper et al., 2023).

Although the CAA was primarily aimed at improving air quality, air pollution regulations potentially have indirect effects on global pollutants such as carbon dioxide (CO_2). Whether air pollution regulations increase or decrease unregulated global pollutants is theoretically ambiguous. On the one hand, air pollution regulations provide incentives for innovation in thermal efficiency. On the other hand, coal-fired power plants may reduce local air pollution emissions by installing and operating pollution abatement technologies. The increased energy consumption associated with operating pollution abatement technologies could come with increased global air pollution emissions. Furthermore, policy-induced changes in the types of generation sources built (e.g., coal versus natural gas versus nuclear) and the types of coal burned (i.e., low sulfur versus high sulfur coal) further complicated the relationship between local pollution

regulations and global emissions.

Figure 4 illustrates that the 1970 CAA and subsequent amendments in 1977 coincided with increases in coal intensity and energy intensity within the electricity sector. Aggregate MMBtus per gigawatt hour increased from 8,851 in 1970 to 10,051 in 1990, a 14% increase. To put this in perspective, aggregate energy intensity in 1990 was roughly on par with the aggregate energy intensity in the mid-1950s. The aggregate implications of this increase in energy intensity from 1970 to 1990 are meaningful: annual total carbon emissions in 1990 from coal-fired generation was 1,606 million tons, but would have been 1,414 million tons if the same amount of coal-fired electricity had been generated at 1970 levels of carbon emissions per GWh.

The increase in coal intensity was driven primarily by a combination of two factors. First, after a period of tremendous improvements in technology between 1940-1960, there were limited additional improvements in technology to increase thermal efficiency after 1960. Until then, coal-fired power plants were built with various steam pressure technologies, but were operated at relatively low pressures. Supercritical boilers, developed after 1959, represented a major technological shift, using higher pressures to generate more efficient steam. They offered efficiency gains by generating superheated steam directly, 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).

Second, compliance with environmental regulations came with increases in coal intensity, either due to the increased energy consumption from pollution abatement technology, the switch to lower-sulfur coal with lower heat content, or simply producing at suboptimally low output levels. As discussed in Clay et al. (2021), the patterns in coal intensity also align with historical evidence on the impacts of the 1963 and 1970 CAAs on power plant design and operations. Following the 1963 CAA, utilities anticipated that

future environmental regulation was forthcoming. Consistent with this, we see increases in the installation of pollution abatement technologies, siting of new plants to be further from pollution monitors, and evidence of shifts in the direction of innovation away from thermal efficiency and toward pollution abatement. After the 1970 CAA, older plants responded by reducing operations, burning lower sulfur-content coal, and continuing to install and operate abatement technologies.

Figure 5 further highlights these issues. It displays the changes in coal intensity and energy intensity, measured in tons of coal and MMBtus per gigawatt-hour (GWh) of electricity, for two groups of counties: those that have always met air quality standards ("Always Attainment") and those that have failed to meet them at some point between 1970-1994 ("Ever Nonattainment"), as classified under the 1970 CAA. In the latter group, power plants were subject to potentially costly regulation to meet emission reductions targets.

The figure reveals a general decline in coal and energy intensities prior to the Clean Air Act of 1970, suggesting that technological improvements – such as more efficient boilers and turbines – were already contributing to cleaner energy production. However, after the 1970 CAA, there is a noticeable reversal in the downward trend in these intensities, particularly in "Ever Nonattainment" areas. This divergence in coal intensity across plants in "Ever Nonattainment" versus "Never Nonattainment" counties is consistent with differential exposure to local environmental regulation. In particular, the patterns suggest that the rise in local environmental regulation under the Clean Air Act may have contributed to the upward trend in power plant carbon emissions after 1970.

There are several reasons why greater enforcement of local air quality standards may have increased global emissions. First, in order to comply with the new regulations, many plants shifted towards low-sulfur, low-heat content coal from the Western United States (Clay et al., 2021). This fuel switching may have lowered thermal efficiency, since plants are optimized to burn a particular type of coal (Joskow, 1985).

Second, the adoption of pollution abatement technologies following the 1970 Clean Air Act may have contributed to the rise in coal intensity. These technologies, such as scrubbers, Selective Non Catalytic Reduction (SNCR), Selective Catalytic Reduction (SCR), and electrostatic precipitators, were implemented to control emissions of sulfur dioxide, nitrogen oxides, and particulate matter, respectively. While these devices are effective at reducing harmful local air pollutants, they require non-trivial amounts of energy to operate (termed "parasitic load"). Since 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 increases in coal consumption per GWh of electricity *sold*.

Third, in an effort to meet emission reduction targets following a county Non Attainment designation, power plants reduced annual output (Clay et al., 2021). These reductions in operations may have contributed to the rise in coal intensity resulting from plants operating at suboptimal efficiency levels.

Together, the adoption of pollution control technologies, the substitution to lower-sulfur coal, and the decreases in plant generation likely led to the reversal in the downward trend of emissions intensity in "Ever Nonattainment" areas. This highlights a significant trade-off. While the Clean Air Act effectively reduced local pollution, it may have inadvertently led to an increase in carbon emissions. The higher carbon emissions per GWh in "Ever Nonattainment" counties underscore the challenge of balancing local air quality improvements with broader environmental impacts.

In summary, the period from 1960 to 2000 was marked by substantial changes in the regulatory framework governing the energy sector, particularly in relation to local air pollution. These regulations successfully reduced local air pollution emissions. However, many compliance methods such as operating pollution abatement technology or

burning lower-sulfur coal resulted in increases in the emissions of unregulated global pollutants like carbon dioxide.

3.4 The Natural Gas Fracking Revolution, 2000-2020

Figure 3 highlights a sharp decline in U.S. coal consumption for electricity generation starting around 2008. 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, by the 2010s coal consumption saw a dramatic drop, falling by almost half by the early 2020s.

The "fracking revolution" played a pivotal role in accelerating this decline in coal use. Hydraulic fracturing (fracking) unlocked vast reserves of natural gas in the United States. Fracking led to a drop in U.S. gas prices by over 60% between 2008 and 2015. As natural gas became more accessible, it quickly displaced coal as the primary fuel for electricity generation. This switch reduced carbon emissions, as natural gas emits about 50-60% less carbon than coal when burned for energy. The switch to gas also contributed to the overall decline in fossil fuel consumption in the electricity sector.

Using an integrated assessment model, Holland et al. (2020) found a significant reduction in air pollution damages caused by U.S. power plants from 2010 to 2017. Over this period, annual damages dropped from $245 billion to $133 billion. This major improvement was driven primarily by changes in how power plants operate and the shift from coal to cleaner natural gas. New technologies that reduced emissions at coal plants, such as advanced sulfur dioxide (SO_2) controls, accounted for a $63 billion reduction in damages. Additionally, many coal plants either reduced their output or shut down, contributing another $60 billion in benefits. These factors contributed more to the decline in aggregate pollution from the power sector than the increase in renewable energy or changes in electricity consumption.

The rise of renewable energy sources like wind and solar still contributed to the re-

duction in the use of coal for electricity generation in the United States. Between 2010 and 2017, wind and solar accounted for only a small percentage of total electricity generation, though their share has grown significantly in recent years. Wind power accounted for about 12% of electricity generation in June 2024, over double its contribution from a decade earlier. Solar power account for about 7% of electricity generation, reflecting a 17-fold increase over the same period. As these technologies became more efficient and affordable, they offered a cleaner, more cost-effective alternative to coal. Government policies, including tax incentives and state-level renewable portfolio standards, further encouraged the shift to renewables. As a result, coal plants faced greater competition, leading to a significant decline in coal consumption and its share of the U.S. energy mix.

4 Concluding Remarks

Our analysis highlighted three key points that have implications for economies working to reduce carbon emissions. In the United States, increases in productivity played an important role in reducing carbon emissions until the 1960s, playing a limited role thereafter. In many developed economies, ongoing decarbonization may not be driven by large productivity gains. In some developing economies, however, productivity improvements in the electricity sector and the broader economy may play a more important role in decarbonization.

In the U.S., the energy crisis of the 1970s and regulations related to the crisis reinforced the use of coal, which results in higher carbon emissions when burned than alternative fuels. Developed and developing countries should be attentive to events that directly or indirectly reinforce the use of higher carbon emitting fuels. The rapid movement away from nuclear power in the United States, Germany, and other countries in response to nuclear accidents is one example (Severnini, 2017; Jarvis, Deschenes and Jha, 2022).

In the United States, the Clean Air Act of 1970 and the Clean Air Act Amendments of 1977 reduced local air pollution per unit of electricity at the expense of increased carbon emissions. Many developed economies are moving quickly towards the use of renewable energy sources, which do not emit either local or global air pollutants. Some other economies, however, are heavily reliant on fossil fuels, including coal, and so may face the same trade-off between local pollution and carbon emissions faced by the historical United States. Global cooperation on climate action, coupled with locally adapted solutions, will be key to ensuring that all nations can reduce both carbon emissions and local air pollution while meeting their energy needs.

Moving forward, researchers and policymakers should closely monitor the evolving impacts of emerging energy technologies – such as carbon capture, utilization, and storage (CCUS) and hydrogen production – and assess how different policy frameworks shape decarbonization outcomes. For example, recent work documents that CCUS technology designed to reduce carbon emissions results in increased ammonia emissions, highlighting again the potential trade-off between reducing global and local air pollution (Waxman, Huber-Rodriguez and Olmstead, 2023). By learning from past regulatory experiences and adapting in light of emerging technology, policymakers can meet the urgent challenges posed by climate change and local air pollution.

References

Adler, David B., Akshaya Jha, and Edson Severnini. 2020. "Considering the nuclear option: Hidden benefits and social costs of nuclear power in the U.S. since 1970." *Resource and Energy Economics*, 59: 101127.

Akins, James E. 1973. "The oil crisis: this time the wolf is here." *Foreign Affairs*, 51(3): 462–490.

Atack, Jeremy. 2024. "Railroads." In *Handbook of Cliometrics*, ed. Claude Diebolt and Michael Haupert, 2329–2357. Springer.

Bakker, Gerben, Nicholas Crafts, and Pieter Woltjer. 2019. "The sources of growth in a technologically progressive economy: the United States, 1899–1941." *The Economic Journal*, 129(622): 2267–2294.

Brew, Gregory. 2019. "OPEC, international oil, and the United States." In *Oxford Research Encyclopedia of American History.*

Castaneda, CJ. 2018. "Historical Overview of the Natural Gas Industry." In *Encyclopedia of the Anthropocene*, ed. Dominick DellaSala and Michael Goldstein, 63–73. Elsevier Inc.

Cintron, Lizette, ed. 1995. *Historical Statistics of the Electric Utility Industry through 1992.* Washington, DC:Edison Electric Institute.

Clay, Karen, Akshaya Jha, Joshua A Lewis, and Edson R Severnini. 2021. "Impacts of the Clean Air Act on the Power Sector from 1938-1994: Anticipation and Adaptation." National Bureau of Economic Research Working Paper 28962.

Clay, Karen, Joshua Lewis, and Edson Severnini. 2024. "Canary in a coal mine: infant mortality and tradeoffs associated with mid-20th century air pollution." *Review of Economics and Statistics*, 106(3): 698–711.

Cropper, Maureen, Nicholas Muller, Yongjoon Park, and Victoria Perez-Zetune. 2023. "The impact of the clean air act on particulate matter in the 1970s." *Journal of Environmental Economics and Management*, 121: 102867.

David, A Paul, and Gavin Wright. 1997. "Increasing returns and the genesis of American resource abundance." *Industrial and Corporate Change*, 6(2): 203–245.

Davis, Lucas W. 2012. "Prospects for nuclear power." *Journal of Economic Perspectives*, 26(1): 49–66.

Davis, Lucas W, and Lutz Kilian. 2011. "The allocative cost of price ceilings in the US residential market for natural gas." *Journal of Political Economy*, 119(2): 212–241.

Devine, Warren D. 1983. "From Shafts to Wires: Historical Perspectives on Electrification." *Journal of Economic History*.

Field, Alexander J. 2011. "The Adversity/Hysteresis Effect: Depression-Era Productivity Growth in the US Railroad Sector." In *The Rate and Direction of Inventive Activity Revisited*, ed. Joshua Lerner and Scott Stern, 579–606. University of Chicago Press.

Field, Alexander J. 2018. "Manufacturing Productivity and US Economic Growth." In *Oxford Handbook of American Economic History*, ed. Louis Cain and Paul Rhode, 213–234. Oxford University Press.

Fiszbein, Martin, Jeanne Lafortune, Ethan G Lewis, and José Tessada. 2020. "Powering Up Productivity: The Effects of Electrification on U.S. Manufacturing." National Bureau of Economic Research Working Paper 28076.

FPC, Federal Power Commission. 1967. "Steam-Electric Plant Construction Cost and Annual Production Expenses: 1966." Washington, DC: U.S. Government Printing Office.

Gordon, Robert. 2017. *The Rise and Fall of American Frowth: The US Standard of Living since the Civil War.* Princeton University Press.

Gordon, Robert J. 2016. "Perspectives on the rise and fall of American growth." *American Economic Review*, 106(5): 72–76.

Hales, Jeremy M. 1976. "Tall Stacks and the Atmospheric Environment." EPA Publication, No. EPA-450/3-76-007.

Hamilton, James D. 2013. "Historical oil shocks." In *Routledge handbook of major events in economic history*, ed. Randall Parker and Robert Whaples, 239–265. Routledge.

Hausman, William J., and John L. Neufeld. 2002. "The Market for Capital and the Origins of State Regulation of Electric Utilities in the United States." *Journal of Economic History*.

Henriques, Sofia Teives, and Karol J Borowiecki. 2017. "The drivers of long-run CO2 emissions in Europe, North America and Japan since 1800." *Energy Policy*, 101: 537–549.

Holland, Stephen P., Erin T. Mansur, Nicholas Z. Muller, and Andrew J. Yates. 2020. "Decompositions and Policy Consequences of an Extraordinary Decline in Air Pollution from Electricity Generation." *American Economic Journal: Economic Policy*, 12(4): 244–74.

Jarvis, Stephen, Olivier Deschenes, and Akshaya Jha. 2022. "The private and external costs of Germany's nuclear phase-out." *Journal of the European Economic Association*, 20(3): 1311–1346.

Joskow, Paul L. 1985. "Vertical integration and long-term contracts: The case of coal-burning electric generating plants." *The Journal of Law, Economics, and Organization*, 1(1): 33–80.

Joskow, Paul L. 2006. "The future of nuclear power in the United States: economic and regulatory challenges." MIT Center for Energy and Environmental Policy Research.

Joskow, Paul L., and Nancy L. Rose. 1985. "The Effects of Technological Change, Experience, and Environmental Regulation on the Construction Cost of Coal-Burning Generating Units." *The RAND Journal of Economics*, 16(1): 1–27.

Kitchens, Carl T, and Taylor Jaworski. 2017. "Ownership and the price of residential electricity: evidence from the United States, 1935–1940." *Explorations in Economic History*, 64: 53–61.

Knittel, Christopher R. 2006. "The Adoption of State Electricity Regulation: The Role of Interest Groups." *Journal of Economic History*.

Lafortune, Jeanne, Ethan G Lewis, José Pablo Martínez, and José Tessada. 2021. "Changing Returns to Scale in Manufacturing 1880-1930: The Rise of (Skilled) Labor?" National Bureau of Economic Research Working Paper 28633.

Lebergott, Stanley. 1976. *The American Economy: Income, Wealth and Want.* Princeton NJ:Princeton University Press.

Lovell, Alfred. 1941. *Generating Stations: Economic Elements of Electrical Design.* New York NY:McGraw-Hill Book Company.

Lublin, Edward L. 1981. "The Future of the Department of Energy's Coal Conversion Program." *Energy Law Journal*, 2: 355.

Meltz, Robert. 1975. "The ESECA Coal Conversion Program: Saving Oil the Hard Way." *Environmental Law Reporter*, 5: 50146.

Muller, Nicholas Z. 2022. "War, Influenza, and U.S. Carbon Intensity." National Bureau of Economic Research Working Paper 30522.

Painter, David S. 2012. "Oil and the American century." *The Journal of American History*, 99(1): 24–39.

Ritchie, Hannah, Pablo Rosado, and Max Roser. 2023. "CO_2 and Greenhouse Gas Emissions." *Our World in Data*. https://ourworldindata.org/co2-and-greenhouse-gas-emissions.

Rosenberg, Nathan. 1998. "The role of electricity in industrial development." *The Energy Journal*, 19(2): 7–24.

Schurr, Sam H., and Bruce C. Netschert. 1960. *Energy in the American Economy, 1850-1975: An Economic History of its History and Prospects.* Baltimore:Johns Hopkins University Press.

Seiferlein, Katherine E. 2007. *Annual Energy Review 2006.* Energy Information Administration.

Severnini, Edson. 2017. "Impacts of nuclear plant shutdown on coal-fired power generation and infant health in the Tennessee Valley in the 1980s." *Nature Energy*, 2(4): 1–9.

Shahbaz, Muhammad, and Avik Sinha. 2019. "Environmental Kuznets curve for CO2 emissions: a literature survey." *Journal of Economic Studies*, 46(1): 106–168.

Tarr, Joel A, and Karen Clay. 2015. "Boom and bust in Pittsburgh natural gas history: Development, policy, and environmental effects, 1878–1920." *Pennsylvania Magazine of History and Biography*, 139(3): 323–342.

Tol, Richard SJ, Stephen W Pacala, and Robert H Socolow. 2009. "Understanding long-term energy use and carbon dioxide emissions in the USA." *Journal of Policy Modeling*, 31(3): 425–445.

U.S. Census Bureau. 1976. "Historical Statistics of the United States, Colonial Times to Present." U.S. Census Bureau, Washington, D.C.

U.S. Energy Information Administration. 2024*a*. "Carbon Dioxide Emissions Coefficients." https://www.eia.gov/environment/emissions/co2_vol_mass.php.

U.S. Energy Information Administration. 2024*b*. "Monthly Energy Review August 2024." U.S. Department of Energy.

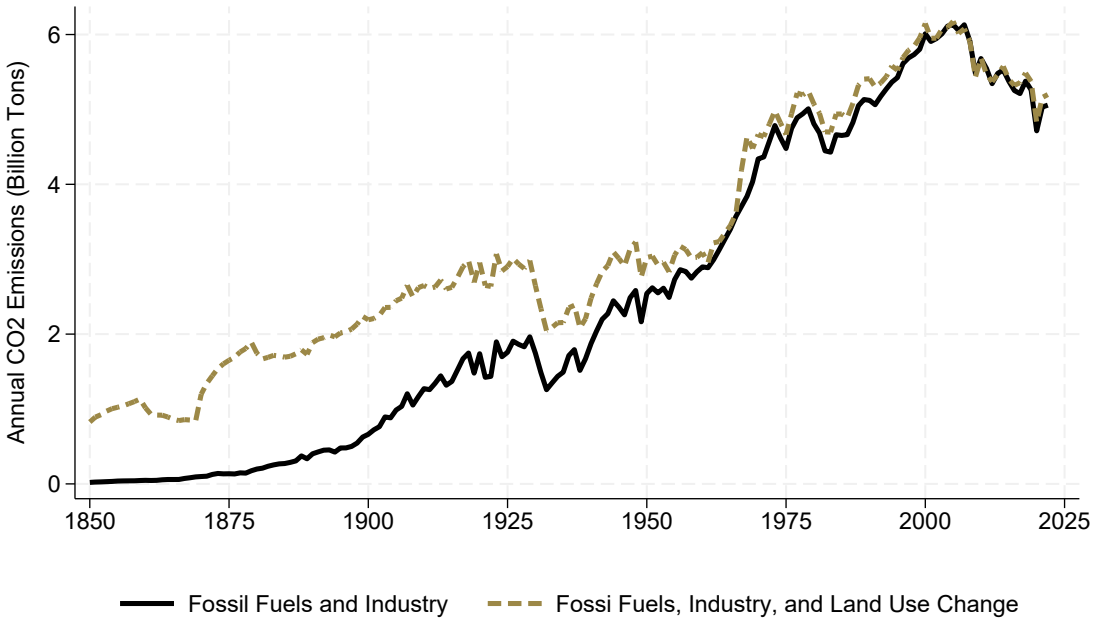
U.S. Geological Survey. Various Years. "Minerals Yearbook." Washington, DC: U.S. Government Printing Office.

Waxman, Andrew, HR Huber-Rodriguez, and Sheila M Olmstead. 2023. "What are the likely air pollution impacts of carbon capture and storage?" *Available at SSRN*.

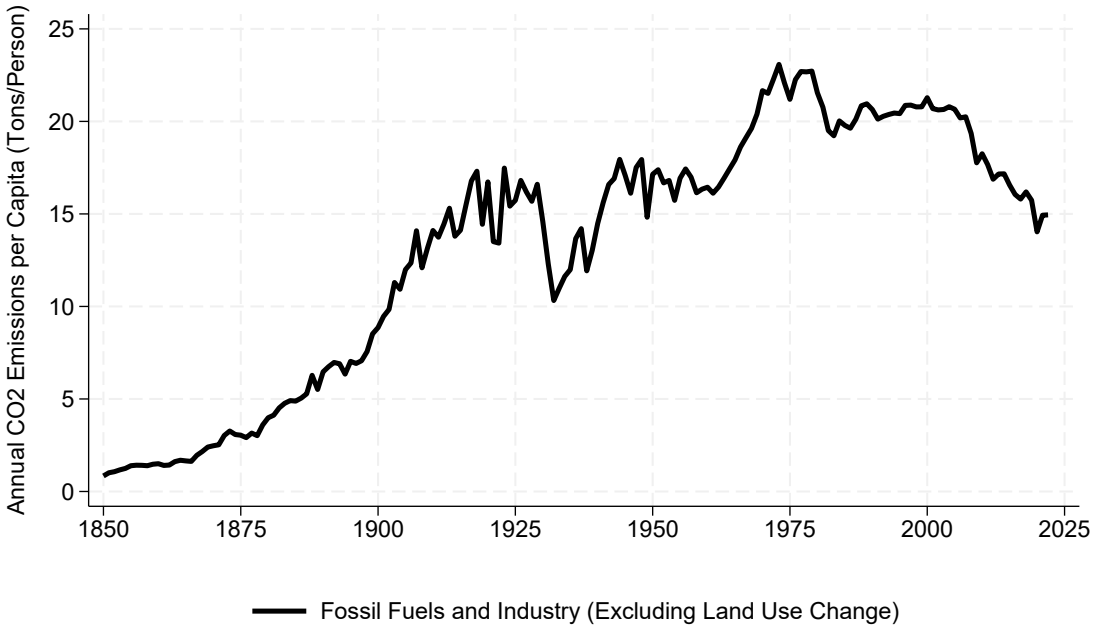
Wright, Gavin. 1990. "The origins of American industrial success, 1879-1940." *The American Economic Review*, 651–668.

Yergin, Daniel. 2011. *The prize: The epic quest for oil, money & power.* Simon and Schuster.

Figure 1: United States CO_2 Emissions and Per Capita CO_2 Emissions



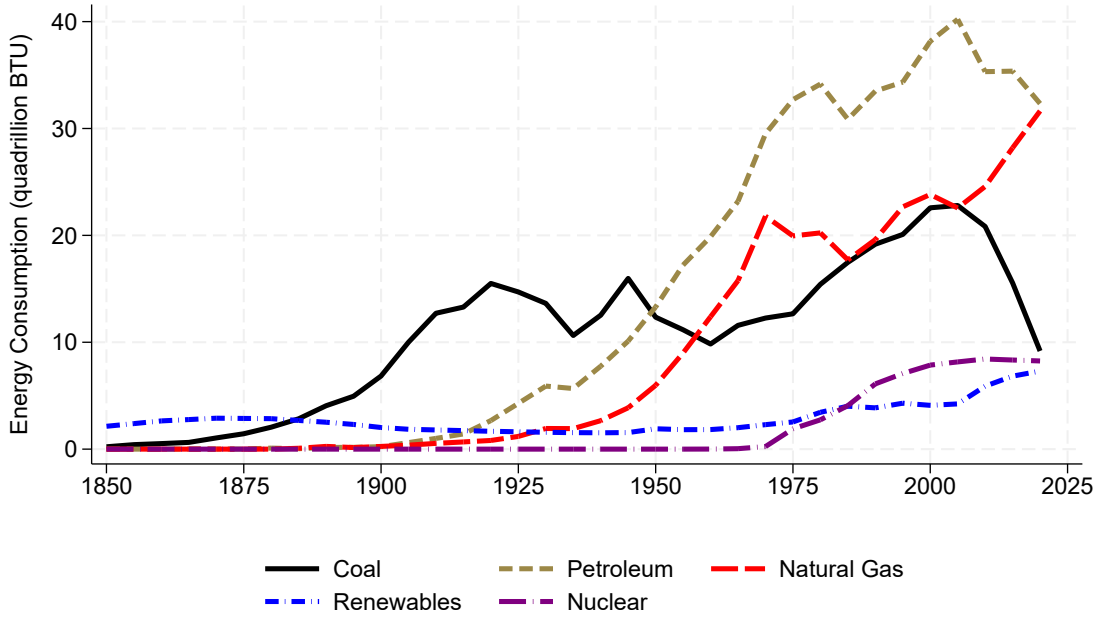
(a) Annual carbon dioxide emissions



(b) Annual carbon dioxide emissions per capita

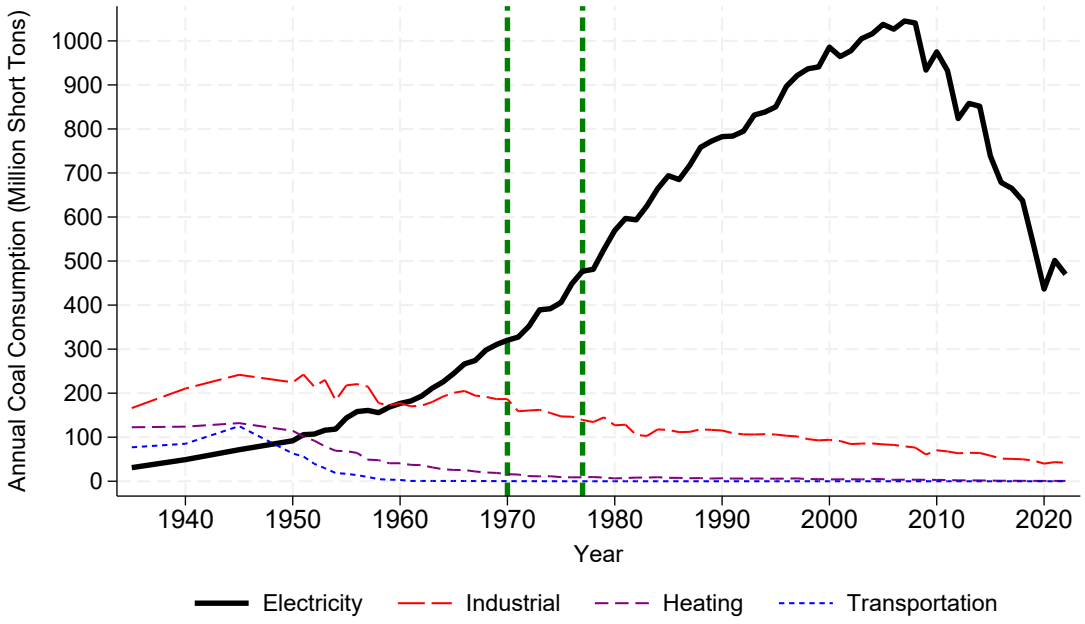
Notes: The top panel of this figure plots annual total carbon dioxide emissions in the United States from fossil fuels and industry as well as from fossil fuels, industry, and land use change. The bottom panel of this figure plot annual carbon dioxide emissions per capita. The data underlying this figure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

Figure 2: Energy Consumption by Fuel Type in the United States

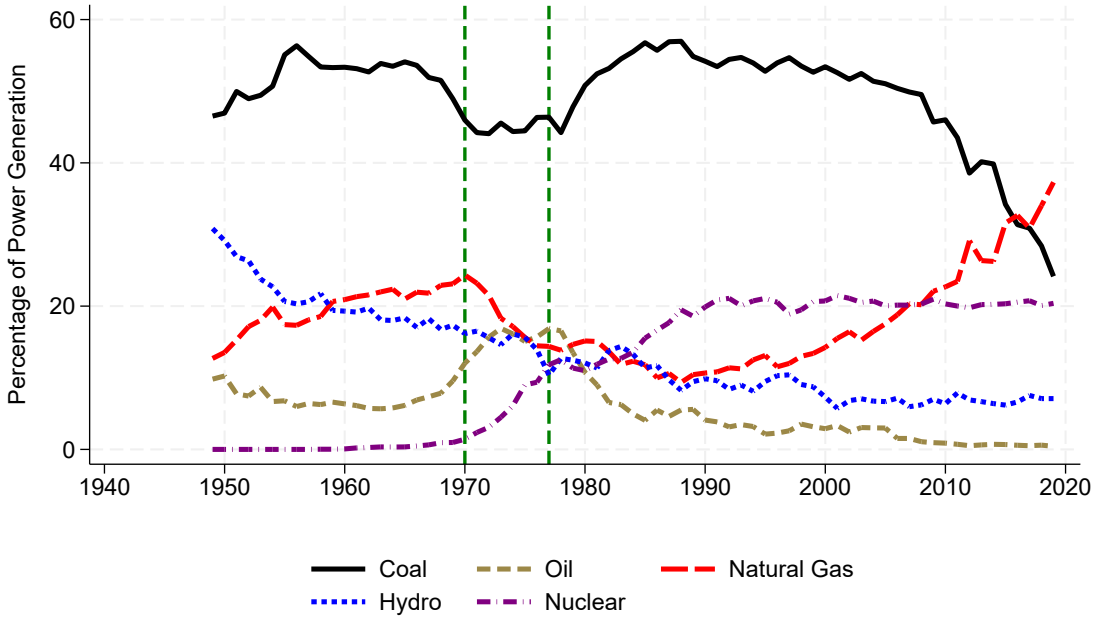


Notes: This figure plots annual total primary energy consumption (in quadrillion BTU) by source. The data underlying this figure are from U.S. Energy Information Administration (2024*b*). Renewables include wood, hydropower, and more recently wind and solar power.

Figure 3: U.S. Fossil Fuel Consumption



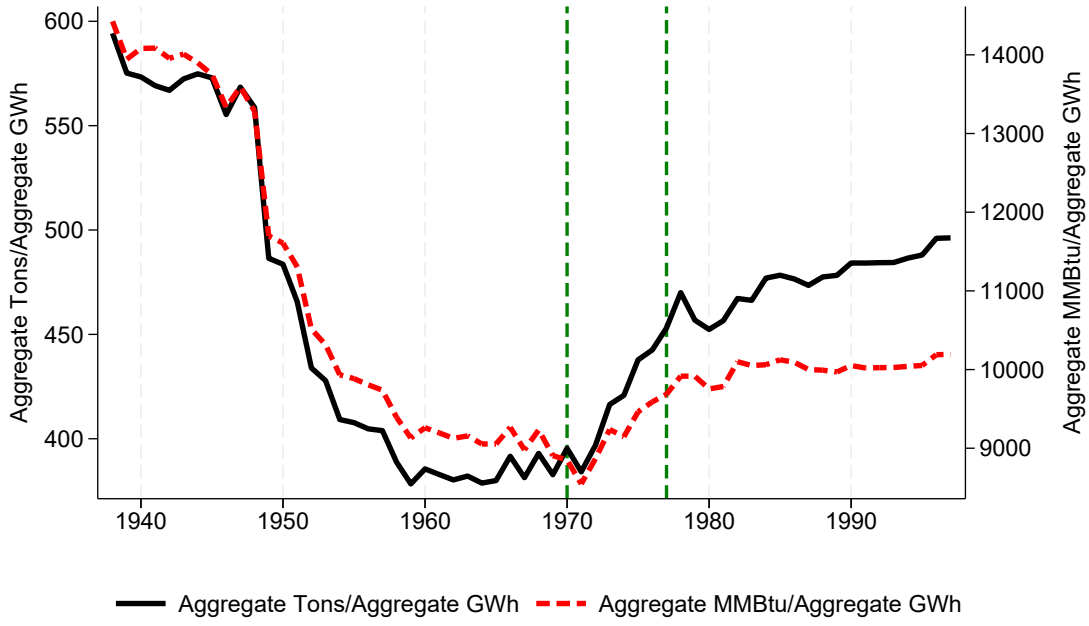
(a) Coal consumption by sector



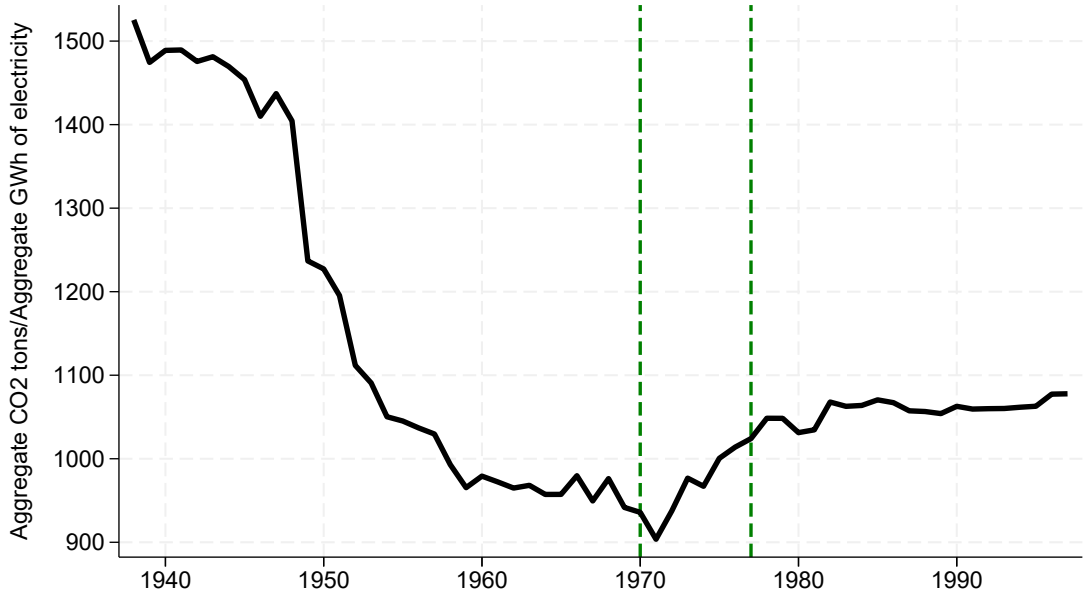
(b) Net electricity production by fuel source

Notes: Panel (a) of this figure plots annual total coal consumption (in million short tons) by sector. Panel (b) of this figure plots annual total net electricity production by source. Panel (a) is based on data from the U.S. Energy Information Administration (EIA) and Schurr and Netschert (1960). Panel (b) is based on data from the U.S. Geological Survey (Various Years) and Cintron (1995). Data for panel (b) are only available beginning in 1949.

Figure 4: Coal, BTUs and Carbon per GWh



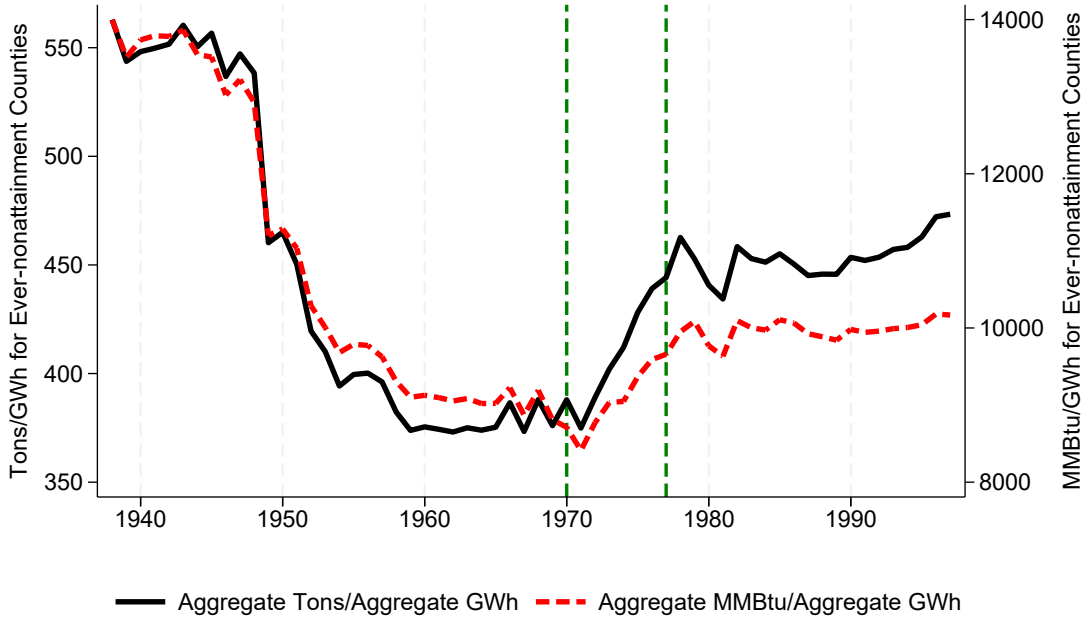
(a) Coal consumption per GWh of electricity



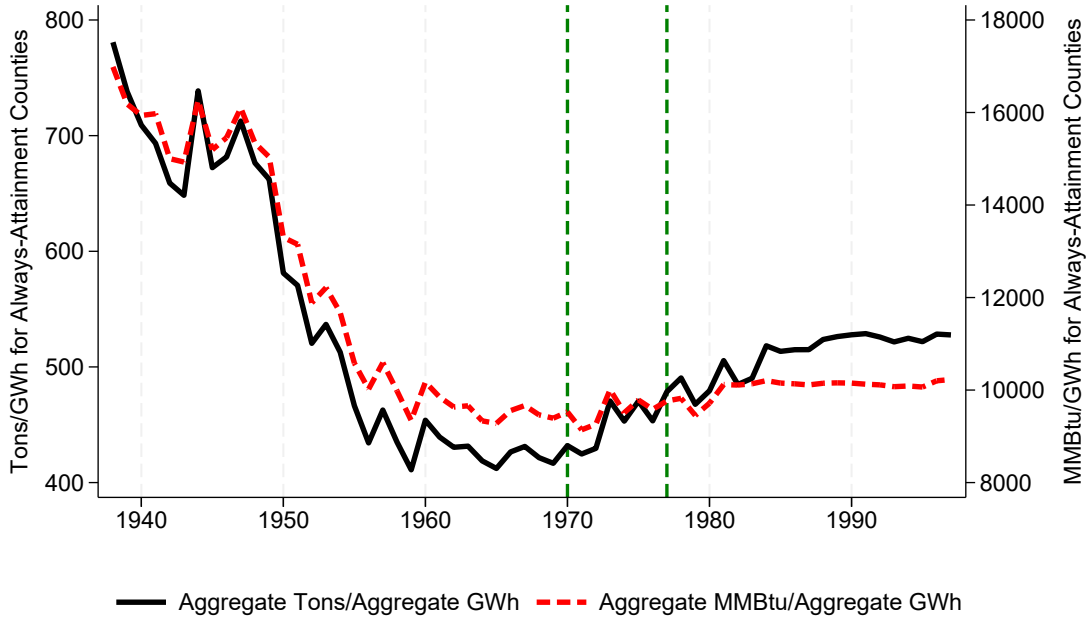
(b) Tons of carbon dioxide emissions per GWh of electricity

Notes: The left y-axis of Panel (a) considers annual total tons of input coal divided by annual total electricity production from coal-fired plants (in GWh). The right y-axis focuses on annual total coal consumption (in MMBtu) divided by coal-fired electricity production. In Panel (b), we plot annual total carbon emissions (CO_2) in tons divided by coal-fired electricity production. We translate input heat energy from coal to carbon emissions using a conversion factor of 211.47 tons of CO_2 per pound of coal (EIA (2014)). This figure is based on data on power plant operations from 1938-1994 from Clay et al. (2021).

Figure 5: Tons of Coal and BTUs per GWh by County Attainment Status



(a) Ever-Nonattainment Counties

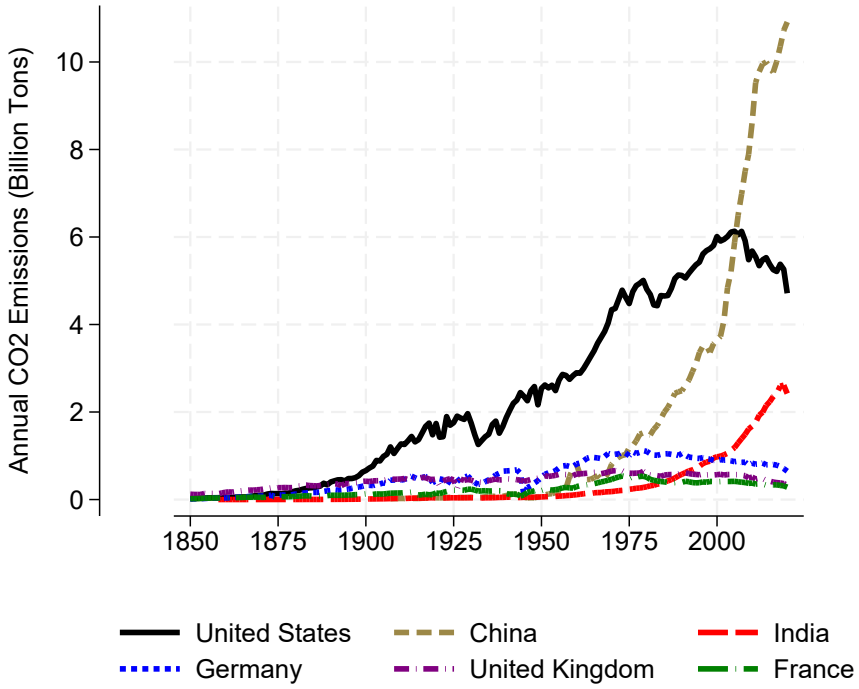


(b) Always-Attainment Counties

Notes: The left y-axis of both panels considers annual total tons of input coal divided by annual total electricity production from coal-fired plants (in GWh). The right y-axis of both panels focuses on annual total coal consumption (in MMBtu) divided by coal-fired electricity production. We plot annual aggregate coal and energy intensities separately for plants in counties that faced nonattainment at least once between 1972-1994 ("ever-nonattainment counties", plotted in panel (a)) versus plants in counties that never faced nonattainment between 1972-1994 ("always-attainment counties", plotted in panel (b)). 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. (2021).

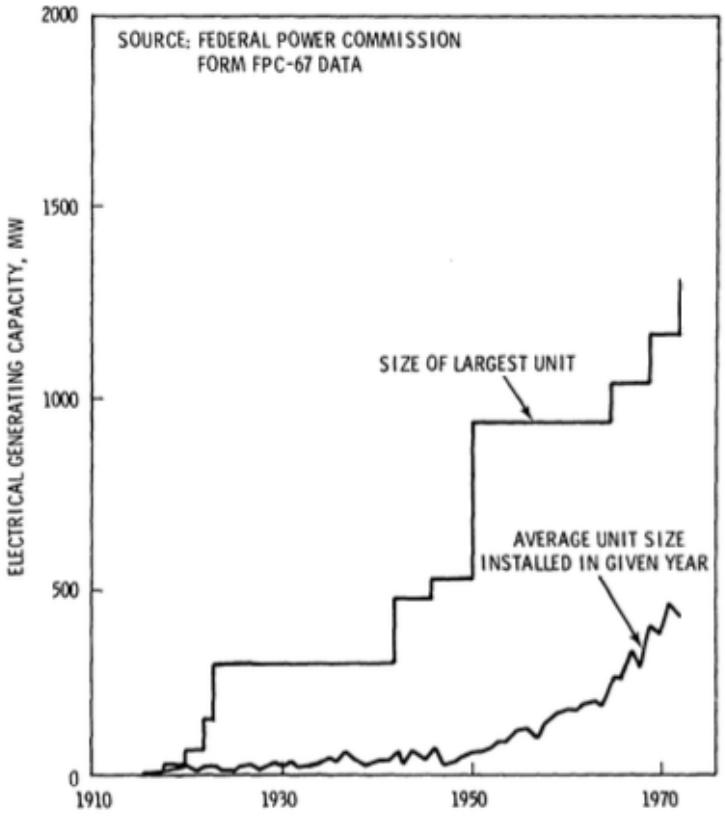
A Online Appendix

Figure A.1: CO_2 Emissions for Selected Countries



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

Figure A.2: 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).