POLICY FORUM

Advance planning can help communities adjust to fossil fuel–fired power plant closures, as with the 2019 shutdown of the Bruce Mansfield Power Plant in Shippingport, Pennsylvania.

PHOTO: ROBERT NICKELSBERG/GETTY IMAGES

ENERGY AND CLIMATE

Fossil electricity retirement deadlines for a just transition

A 2035 deadline for decarbonizing U.S. electricity would strand only about 15% of fossil capacity-years

By **Emily Grubert**

Decarbonizing the electricity sector is critical for addressing climate change, particularly given the expected role of an expanded clean electricity system for home heating, transportation, and industry (*1*). This will require vast investment in new infrastructure such as renewable-energy power plants and batteries. Absent major investment in carbon-capture equipment or fuel switching, it will also require the retirement of carbon-based power plants. Both motivate explicit attention to a "just transition" (*2*) that ensures material well-being and distributional justice for individuals and communities affected by a transition from fossil to nonfossil electricity systems (*3*). Determining which assets are "stranded," or required to close earlier than expected absent policy, is vital for managing compensation for remaining debt and/or lost revenue (*4*, *5*). Here, I introduce a generator-level model to show that in the United States, a 2035 electricity decarbonization deadline, as proposed by President-elect Biden and the 2020 Democratic party platform (*6*, *7*), would strand only about 15% of fossil capacity-years and 20% of job-years, which is unusually low from a global perspective [see supplementary materials (SM)] (*4*). Such insights into the location and timing of potential plant closures are critical for informing specific, coordinated, and locally grounded planning, which can substantially improve transition outcomes but is neither widespread nor supported by a national framework (*8*).

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In 2018, 10,435 fossil fuel–fired generators produced 63% of U.S. electricity with 841 GW of capacity. They also emitted 1.9 billion tonnes (Gt) of carbon dioxide ($GtCO_2$), 1.3 Mt of nitrogen oxides ($MtNO_x$), and 1.4 Mt of sulfur dioxide ($MtSO_2$), while consuming 3.2 billion m^3 of water for plant operations and fuel extraction. These facilities operated in 1248 of 3141 counties, directly employed about 157,000 people at generators and fuel-extraction facilities, and paid sometimes locally meaningful taxes (see SM) (*8*).

Retirements are already under way: 126 GW of fossil generator capacity was retired between 2009 and 2018, including 33 GW in 2017 and 2018 alone (see data S1). But simply understanding that a closure is coming in some indeterminate future does not prevent economic shock when closures are announced with layoffs (*9*). We have seen before what happens without adequate planning and preparation, such as with the collapse of the U.S. steel industry in the 1970s and 1980s. Policy interventions for a just transition might include planning, training, and funding to stabilize local conditions (*8*) or political efforts to address broad social costs of transition (*3*). Effective just transition planning is participatory and government supported, with emphasis on stabilizing revenue, context-specific consideration of existing strengths and needs, fostering a willingness to change, and ensuring environmental remediation (*8*). All of these are much easier to achieve if the location and timing of step changes such as plant closures are known, which is a key focus of the work described below.

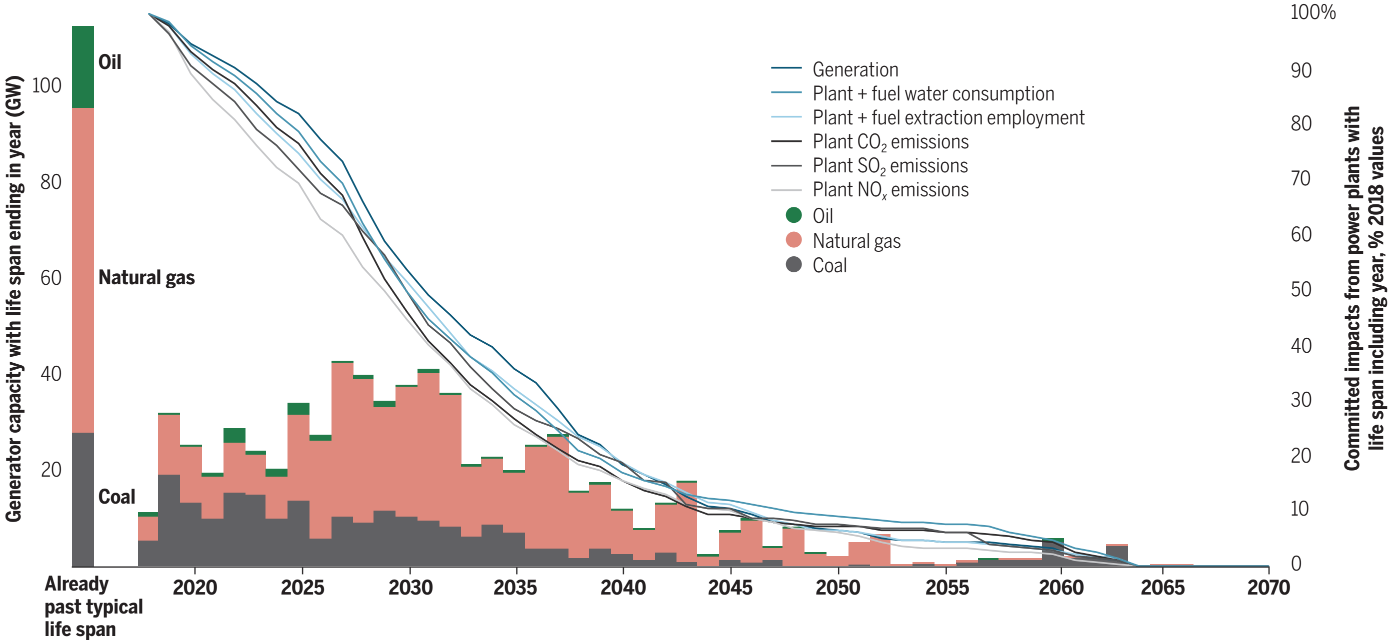
By establishing a deadline, a 2035 electricity decarbonization target represents a major opportunity to facilitate a just transition. Relevant locations are already known: The facilities that need to close exist. Policy can ensure that timing is also known—for example, through closure deadlines that are consistent with overall decarbonization targets. This new model supports such steps and extends committed climate emissions work (*10*, *11*) to inform just transition–oriented industrial policy by evaluating spatially and temporally explicit implications of explicit plant closure deadlines for climate pollution, air pollution, water use, and plant and fuel extraction labor.

THE 2035 CHALLENGE

Understanding which generators would have completed their reasonably anticipated life span before decarbonization deadlines can clarify where policy is stranding an asset (recognizing that financial liability depends on conditions such as ownership, regulatory setting, and depreciation status). To contextualize the impact of a 2035 electricity decarbonization target in the United States, this work assumes that all fossil fuel–fired electricity generators that were operational as of 2018 maintain their 2018 outputs until retiring at the capacity-weighted mean age on retirement observed for generators with the same pri-

Most capacity reaches the end of its life span by 2035

U.S. fossil fuel–fired power plant capacity by fuel and date generator reaches fuel- and technology-specific life span (left axis), and system characteristics (generation, water consumption, employment, CO_2 emissions, SO_2 emissions, and NO_x emissions) as percentage of 2018 value (right axis), 2018–2070. Most capacity reaches the end of its life span by 2035, and all by 2066. Leftmost stacked bar shows capacity that has already reached the end of its life span as of 2018.



mary fuel and technology (prime mover) between 2002 and 2018 (see table S2). Observed mean age on retirement is an aggregate outcome variable that depends on a combination of physical, economic, policy, and other factors. This age is consistent across regions and time, at about 50 years for steam turbine–based generators and about 30 years for other generators (*11*).

This work assumes that generators achieve a typical life span if they (i) retire at the end of their fuel- and prime mover–specific typical life spans and (ii) maintain constant 2018 outputs through retirement (see SM). The goal is to illustrate conditions that are consistent with what interested parties might reasonably expect at the asset level. For example, investor compensation would not generally be considered necessary if a generator maintains historical outputs and retires at a typical age, and a host community or employee would not be unusually burdened by closure under such conditions.

Given these assumptions, this work shows a plausible, generator-level future for fossil fuel–fired electricity generation in the United States, with details on how requiring each generator to close at the end of its fuel- and prime mover–specific life span (see table S2) would affect generation, CO_2 emissions, NO_x emissions, SO_2 emissions, water consumption, and labor associated with both the plant and its fuel extraction (see the first figure, data S1, and SM).

Under these conditions, committed combustion CO_2 emissions from existing U.S. fossil electricity generators account for an estimated 25 Gt of CO_2 (see SM). Of operable U.S. fossil fuel–fired generation capacity (630 out of 840 GW), 73% reaches the end of its typical life span by 2035 (810 GW, or 96%, by 2050; 100% by 2066). About 13% of U.S. fossil fuel–fired generation capacity (110 GW) operating in 2018 had already exceeded its typical life span. The remaining 27% would need to close or convert earlier than a typical life span to meet a 2035 decarbonization deadline (see the second figure, data S1, figures S3 to S15, and movie S1).

Because typical life spans are averages, some generators run longer. Simply allowing facilities to run until they retire is thus likely insufficient for a 2035 decarbonization deadline. Closure deadlines that strand assets relative to reasonable life span expectations, however, could create financial liability for debts and other costs that can no longer be paid because of policy action. A key finding of this research is that a 2035 deadline for completely retiring fossil-based electricity generators would strand only about 15% (1700 GW-years) of fossil fuel–fired capacity life, alongside about 20% (380,000 job-years) of direct power plant and fuel extraction jobs remaining as of 2018. This is unusually low from a global perspective (largely because U.S. infrastructure is older than average) (*4*), limiting the scope of potential financial liabilities while enabling important, no-cost local benefits of closure deadlines, such as certainty regarding timelines.

POLICY ACTION FOR A JUST TRANSITION

U.S. policy to decarbonize the electricity sector by 2035 can facilitate a just transition by establishing explicit retirement deadlines for fossil fuel–fired electricity generators. In the large majority of cases (73%), such deadlines could be at or later than the reasonably expected end of life for a given generator and still comply with the 2035 target, allowing for years of advance planning grounded in the specific assets and needs of a community, enabling development of concrete and shared visions of the future (*12*). Facilities that would be partly stranded by a 2035 deadline would have more than a decade for transition planning if policy were enacted in the early- to mid-2020s. Advance planning is particularly important because utility-owned facilities that would be stranded by a 2035 deadline, leaving rate payers responsible for debts, are disproportionately in states with higher poverty rates (see figure S16), possibly indicating a role for federal support.

Even when financial aid is not expected, knowing when and where a facility closure will happen can enable targeted deployment of training resources for people who need them, long-term budgeting that accounts for tax revenue losses, and advance planning for transitioning individuals to local jobs in environmental remediation of fossil facilities. Clear expectations about when and where generator retirements will occur can also facilitate synergistic behavior in support industries, such as by allowing

GRAPHIC: N. DESAI/*SCIENCE* FROM E. GRUBERT coal mines to operate at efficient scales to stockpile fuel to close out existing contracts.

Closure deadlines could be implemented in multiple ways. One option is to require generators to close by fuel- and prime mover–based typical end of life (see table S2) or 2035, whichever is first. Under the assumptions described here, this approach results in cumulative emissions of 20 Gt of CO_2, 12 Mt of NO_x, and 13 Mt of SO_2, supporting 1.7 million fossil job-years. Extending the retirement deadline to 5 years past typical life span or 2035, whichever is first, supports 26% more fossil job-years but also commits 30% more CO_2, 32% more NO_x, and 29% more SO_2. Using U.S. Bureau of Labor Statistics wage data and federal guidelines for emissions costs, these differences are worth an estimated additional $55 billion in direct wages (in high-paying industries that support, on average, about three indirect jobs/direct jobs, for people who could potentially seek alternative employment), at the cost of an estimated $250 billion in air pollution costs and $400 billion in CO_2 costs (excluding methane emissions) (2018 dollars) (see SM).

Decarbonizing the electricity system cannot occur through plant closures alone. Large amounts of infrastructure will need to be built, with associated issues related to community identity and the just transition (*13*). However, large amounts of infrastructure will need to not be built. A commitment to a just transition away from fossil fuels also demands that we minimize new liabilities in the form of new-build power plants that will require transition before the end of their useful lives (*14*). The federal Energy Information Administration's 2020 "Reference Case" for electricity through 2050, which assumes static policy conditions, includes more than 50 Gt of CO_2 of potential committed emissions from not-yet-built fossil fuel–fired electricity capacity. Proscribing construction of new fossil fuel–fired generators is likely the simplest available action toward a just transition, particularly because proposed new utility fossil assets (which would be paid for by rate payers) are also disproportionately in states with higher poverty rates (see SM and figure S17).

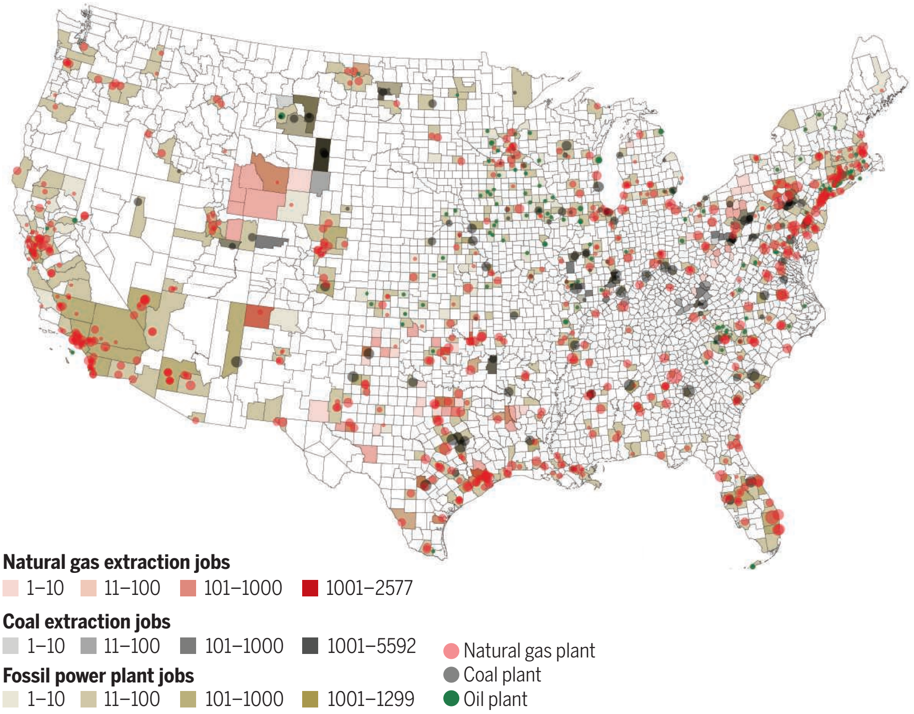
Transition policy is political (*3*), and success relies on political support. Transition policy that includes not only implementation details such as retirement deadlines but also universal social and economic programs that address transition impacts both in and beyond fossil fuel host communities—such as affordable housing, a $15 minimum wage, and job guarantees—can advance normative ideals of a just transition while also increasing political support (*1*, *3*, *15*). Emphasizing universal programs recognizes that a transition focused solely on fossil fuel workers and communities is not just and that support is also badly needed for the many people who lose jobs or more as a result of climate change, as well as those likely to be affected by zero-carbon industrialization.

CONCLUSIONS

Policy proposals to decarbonize the U.S. electricity sector require not only the addition of zero-carbon electricity generation but also the subtraction of carbon-intensive generation. Requiring fossil generators to close by 2035 would result in limited, although sometimes locally impactful, asset stranding relative to typical life spans. Actions such as Clean Energy Standards to set explicit retirement deadlines or New Source Performance Standards to restrict new fossil fuel–fired generation capacity, combined with universal social programs, can support a just transition. ■

Mapping plants whose life spans extend beyond 2035

Shown are U.S. fossil fuel–fired generators with estimated fuel- and technology-specific life span extending past 2035, operable as of 2018, with capacity aggregated to plant level and labels based on largest fuel share burned at combined generators in 2018. Larger circle size indicates larger capacity. Direct employment (at plants, coal mines, and natural gas extraction facilities) associated with plants with life span extending past 2035 are shown by county. County locations for plant employment match plant locations; county locations for coal mining employment match the location of the known or assumed mine responsible for the largest share of coal supply for a given plant; and county locations for natural gas extraction employment are approximated based on spatial distribution of natural gas extraction employment in the U.S. overall.



GRAPHIC: N. DESAI/*SCIENCE* FROM E. GRUBERT

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SUPPLEMENTARY MATERIALS

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