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Challenging Carbon Lock-In: Insights From U.S. Governmental Energy Research and Development Expenditures With Advocacy Recommendations for the Energy Research Community

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The United States relies heavily on fossil and nuclear energy to meet its burgeoning electricity generation demands. The incumbent institutional and industrial power dynamics may support a fossil and nuclear energy status quo and have shown signs of carbon lock-in. Government research and development (R&D) funding can either be a help or hinderance to institutional carbon lock-in. This analysis investigates the link between the Department of Energy's historical funding allocations for energy research programs in the fossil, nuclear, and renewable energy sector, and the federal government's tendency to support entrenched, carbon-based energy systems. While the Department of Energy's renewable energy programs have received more funding in recent years, this investment alone is not enough currently to thwart carbon lock-in. Thus, this article recommends suggestions for researchers to advocate for more renewable energy research and development resources through personal, professional, and institutional strategies to spur decarbonization.

Keywords: carbon lock-in, research and development, energy transition, renewable energy, science policy, advocacy

INTRODUCTION

In 2020 alone, the United States used 92.9 quadrillion British thermal units (BTU) of energy, the majority of energy production coming from petroleum (35%) and natural gas (34%), with renewables (12%) used at a significantly lower rate (EIA, 2020). While the shale gas revolution in the U.S. has led to increased usage of natural gas and historic national carbon emissions reductions, the continued dependence on fossil fuel energy will not help in meeting future climate goals (IEA, 2019). The U.S. remaining on a fossil fuel-based energy trajectory will not achieve the 85–90% emissions reductions by 2050 that are needed to keep global surface temperatures under a warming of 2°C, thus triggering the need for rapid decarbonization at the national level (Rockström et al., 2017; Janipour, et al., 2020; Asayama, 2021). The motivation for this article is to investigate whether U.S. federal government energy research and development spending with the Department of Energy adequately supports rapid decarbonization efforts. However, a significant challenge to rapid decarbonization in the U.S. looms on the horizon: carbon lock-in (Unruh, 2000).

The state of carbon lock-in can be defined as a path dependent process when "industrial economies have become locked into a fossil fuel-based technological system" (Unruh, 2000, p. 817; Seto et al., 2016). This phenomenon arises from the "combined interactions among technological systems and governing institutions" where stakeholders try to maintain the status quo of the current energy system, which consists of inexpensive and reliable energy sources, namely non-renewables (Janipour, et al., 2020, p. 2; Seto et al., 2016). This techno-institutional complex's path toward fossil energies can then pose challenges for alternative paths as the costs of path reversal, in the form of alternative and renewable energy, are high (Janipour, et al., 2020). Further, the system can cement itself so deeply into a certain technology that any changes to that technology can become locked out of the system (Janipour, et al., 2020).

Seto et al. (2016) have discussed in detail how carbon lock-in can manifest in three major categories: infrastructural and technological lock-in, behavioral lock-in, and institutional lock-in. Infrastructural and technological lock in refers to both technologies and infrastructures that can indirectly or directly emit greenhouse gases and influence energy supply (Seto et al., 2016). Behavioral lock-in encompasses the "behaviors, habits, and norms associated with the demand for energy-related goods and services" (Seto et al., 2016, p. 427). Institutional lock-in is defined as institutions, governments, and decision-making processes that set the rules for energy production and consumption and thus influence supply and demand dynamics in the energy sector (Seto et al., 2016). Specifically in this piece, the concept of institutional carbon lock-in will be focused on, primarily through the role of government spending and research and development programs that can either cement carbon lock-in or facilitate its undoing (Seto et al., 2016).

In terms of institutional lock-in, the government and its actions play a key role. The government's power to make institutional policy has the potential to influence market forces and once these policies are established, they can resist change and remain in their original form for an extended amount of time (Unruh, 2000). Institutional lock-in is unique, as it is an "intended feature of institutional design" rather than an indirect effect of the system, which more aptly describes behavioral lock-in and infrastructural and technological lock-in (Seto et al., 2016, p. 433). Stakeholders within the system have a myriad of power dynamics which they use in coordinated efforts to support a trajectory within their personal interests (Seto et al., 2016; Trencher et al., 2020). Strong political resistance from incumbent coalitions of fossil fuel-based energy industries can effectively block changes to the status quo (Kim and Tang, 2020). The existing power imbalances favoring carbon-based energy have been seen in the U.S., such as providing support systems for established technologies and increasing business risk and transaction costs for innovative technologies (Brown et al., 2008). Subsides supporting fossil fuel-based energies can be an example of a supporting structure for conventional fuels through lowered consumption prices and tax breaks and other production-based financial incentives (Brown et al., 2008; Skovgaard and van Asselt, 2019). In 2020, fossil fuel subsidies internationally totaled \$5.9 trillion, with China (\$2.2 trillion), the U.S. (\$660 billion), and Russia (\$520 billion) as the top three countries with the most contributions to fossil fuel subsidies (Parry et al., 2021). Fossil fuel subsidies backed by strong interests can become embedded into the established structural power relationships and bolster these power dynamics by favoring certain actors and activities over others, potentially becoming one symptom of institutional carbon lock-in (Seto et al., 2016; Skovgaard and van Asselt, 2019). Surmounting institutional lock-in can be possible but propitious circumstances and exogenous shocks are needed to create a window of opportunity for change to occur (Seto et al., 2016). Since these circumstances and shocks can be few and far between, examining other ways to surmount carbon lock-in is necessary, such as through government spending.

Government research and development programs can demonstrate that new technologies are sustainable and financially beneficial, encouraging investments needed to overcome system transition costs and shift the current trajectory (Seto et al., 2016). However, the intellectual capital that is gathered in the form of knowledge from research and development programs can potentially facilitate carbon lock-in (Trencher et al., 2020). When introducing new technologies to usher in a transition, current research institutions may have limited competencies, knowledge and/or human resources required for this shift (Trencher et al., 2020). Thus, it is important to investigate if competencies in renewable energies to support the energy transition are being built in the United States, specifically through the Department of Energy's (DOE) research programs and associated spending that will be discussed in the following section.

The DOE operates the greatest number of national renewable energy and energy efficiency incentive programs in the U.S., providing significant amounts of research, development, demonstration, and deployment (RDD&D) contracts and grants (Cunningham and Eck, 2021). The DOE also maintains an extensive network of national laboratories located in 14 states, with 50 major project installations in 35 states (Sovacool, 2009). Although other agencies such as the U.S. Department of Agriculture (USDA), the Department of the Treasury, and the Department of the Interior (DOI)—along with many others—administer incentives for renewable energy programs, the DOE is the largest public funding provider for clean energy research and development in the U.S. (Shah and Krishnaswami, 2019; Cunningham and Eck, 2021), and hence the focus of this article. Though funding in renewable energies within the DOE has grown since the 1970's, the associated programs have not been accelerating at the pace needed to facilitate an energy transition and combat climate change (Seto et al., 2016; Clark, 2018; Shah and Krishnaswami, 2019).

The work of scientists in government agencies is crucial to policy and the decision making process, emerging in importance likened to a fifth branch of the federal government (Jasanoff, 1998). The scientific inquires that are mandated by governments to inform the policymaking process are inherently different from research taking place in academic institutions, as they are molded by certain values and interests in the form of science policy (Jasanoff, 1998). The research that is produced from governmental institutions can then be used as political ammunition by stakeholders who find the conclusions favorable to their interests (Desmarais and Hird, 2014; Cairney, 2016). Even researchers themselves are not separate from this process and have made individual job choices to support these research objectives undertaken from the government (Jasanoff, 1998; Pielke, 2007; Seto et al., 2016).

With greenhouse gas emissions climbing and public research funding for renewable energy dwindling: what can renewable energy researchers do to spur energy research innovation and funding in renewables amid carbon lock-in (Unruh, 2000; Morgan, 2017)? Based on a review of current literature on ways scientists and engineers can get involved in policy, this article highlights suggestions for researchers to raise awareness and funding for renewable energy research programs. These recommendations will be outlined in the third section using a typology of three pathways for advocacy—personal, professional, and institutional—and their associated risks and benefits.

U.S. DEPARTMENT OF ENERGY SPENDING IN ENERGY RESEARCH AND DEVELOPMENT

In the United States, all energy research and development programs are under the administration of the Department of Energy (DOE) (Clark, 2018). The DOE was established in 1977 through the Department of Energy Organization Act, incorporating the activities of the Federal Energy Administration (FEA) and the Energy Research and Development Administration (ERDA), established in 1974 and 1975 respectively (Clark, 2018). The DOE's mission includes scientific research that encompasses broad topics, through its system of national laboratories, on basic and applied research and development (Sovacool, 2009; Sargent, 2021).

Spurred by energy crises of the 1970's, federal energy research and development expanded to include renewable energies, such as biomass, geothermal, hydropower, solar, and wind (Clark, 2018). In 1978, the National Energy Act established the Office of Conservation and Solar Energy (CSE) which would later become the Office of Energy Efficiency and Renewable Energy (EERE) in 1992 (EERE, n.d.). Through their initiatives in renewable energy, the DOE and EERE have reduced the costs of wind and solar power, as well as cutting prices on batteries and LED (light emitting diode) light bulbs, along with many other notable achievements (Shah and Krishnaswami, 2019).

However, as the DOE's organization expanded, its management structure became rigid and layers of stove-piping between the agency and its national laboratories began to surface (Sovacool, 2009). The lack of communication between the agency and its installations led to an arising concern that rapid, innovative energy research in the U.S. would stall (Sovacool, 2009). From a 2006 National Research Council report, the Advanced Research Projects Agency-Energy (ARPA-E) was presented as a potential solution to the DOE's stagnation (Sovacool, 2009; National Academies, 2017). Modeled after the Department of Defense's (DOD) successful Defense Advanced Research Projects Agency (DARPA), ARPA-E was tasked with funding high-risk, transformative energy research (National Academies, 2017). Beginning operation in 2009, ARPA-E was deliberately constructed to be more flexible and autonomous from the DOE's hierarchy with separate program funding and organizational structure (National Academies, 2017).

Since 2009, ARPA-E has provided approximately \$3 billion in funding for innovative energy research and development projects to researchers in universities, industry, and national labs, as well as providing technical and business advice (Goldstein et al., 2020). ARPA-E has supplied funding to over 1,270 projects, producing 4,871 peer-reviewed journal articles and 789 patents (ARPA-E, n.d.). Despite these achievements, both ARPA-E and the DOE's national laboratories have struggled in getting innovative technologies to the commercialization stages (Anadon et al., 2016; Chan et al., 2017; Goldstein et al., 2020). For ARPA-E, it has been recommended that the agency "reconceptualize its 'tech-to-market' program" to advise funding recipients of supplementary funding possibilities and nontechnical aspects that could influence the project's financial performance, such as regulatory barriers (National Academies, 2017, p. 8; Goldstein et al., 2020).

Perhaps a critical underpinning to ARPA-E's commercialization challenges is that the agency has never received the full amount of funding originally outlined in the National Research Council's report (National Academies, 2017). Federal investments in energy research and development have been declining since the 1980's, with the DOE's research and development funding being increased incrementally from \$4.2 billion in 2001 to \$4.99 billion in 2011 (Schuelke-Leech, 2014). Political shifts from 1990 to 2017 have resulted in an average annual increase or decrease of over 30% in a fifth of the DOE's technical area's budgets, resulting in a high level of budget volatility (Schuelke-Leech, 2014; Chan et al., 2017). While budget volatility affects the total amount of funding, its consistency and allocation are also influenced which impact project timelines, cost-effectiveness, and retention of critical staff (Schuelke-Leech, 2014; Chan et al., 2017). Thus, it is important to examine not only the funding totals given to the DOE but how this funding is allocated between its programs amid decreasing federal research and development investments (National Academies, 2017; Nemet and Kammen, 2007). It has been found that allocation of research funding in the DOE's energy programs does not necessarily align with the national distribution of greenhouse gas emissions' sources, with 56% of the agency's 2016 fiscal year funding being directed toward electricity research and development projects while greenhouse gas emissions from the electricity sector only comprised an estimated 28% of emissions in 2017 (Shah and Krishnaswami, 2019). Missing from the current DOE research and development literature is an overview of how the DOE's funding is allocated to its various programs, especially renewable energy, and ways for energy researchers to incentivize federal funding through participation and advocacy in the science-policy interface.

From 2009 to 2018, U.S. funding in renewable energy programs has increased, comprising 19.5% of total DOE spending, while nuclear and fossil energy programs utilize 28.6% and 20.8% respectively of total energy technology funding in this time span (Clark, 2018). In fiscal year 2021, energy efficiency and renewable energy programs received \$2.5 billion, while nuclear energy received \$1.5 billion and fossil energy received \$750 million (Sargent, 2021). While it may seem that renewable energy is receiving more funding, these resources have been coupled with energy efficiency initiatives such as electric vehicles research and building and manufacturing processes energy efficiency research within the DOE's Energy Efficiency and Renewable Energy (EERE) office (Holt and Clark, 2021). From 2009 to 2018, renewable energy programs have received 19.5% of total funding with energy efficiency programs receiving 17.1% (Clark, 2018). Additionally, energy program funding, totaling \$5.47 billion, is dwarfed by the combined spending for science and national security programs, totaling \$12.2 billion for fiscal year 2021 (Sargent, 2021). A breakdown of the share of DOE spending by the three main categories of science, national security, and energy in fiscal year 2021 can be seen in **Figure 1**, while the funding for energy programs by department in the same year can be seen in **Figure 2**.

While renewable energy enjoys a large share of fiscal year 2021 funding, it is concerning to see that ARPA-E only received \$427 million and the proposed ARPA-Climate (ARPA-C) program received no funding (Sargent, 2021). For fiscal year 2022 as proposed by the House of Representatives, ARPA-E's funding has increased to \$600 million, but the proposed ARPA-C still has no resources, though the DOE requested it receive \$200 million (Sargent, 2021). While ARPA-E's funding has increased, it is not a good sign that ARPA-C, which would focus on a transdisciplinary, public-private partnership approach to climate research has not received funding (Badia et al., 2021). While the Biden administration supports the creation of the novel ARPA-C, the current outlook in Congress is dim (Badia et al., 2021).

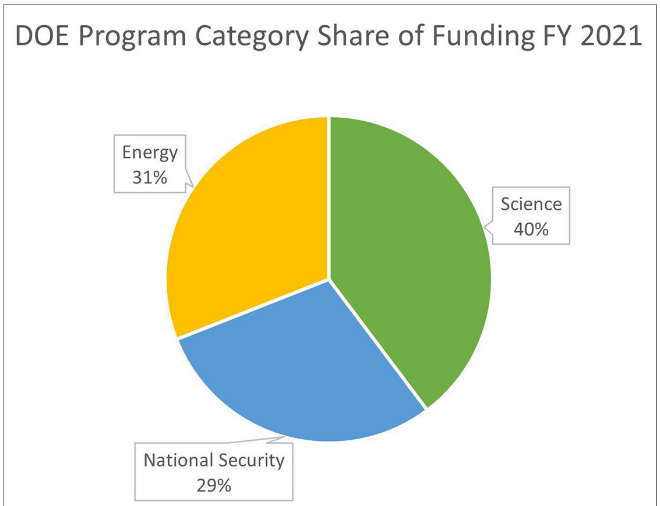

FIGURE 1 | The share of funding for U.S. Department of Energy (DOE)'s spending for fiscal year (FY) 2021 between the three main categories of programs in science, energy and national security. Percentages generated from data retrieved from Congressional Research Service's Federal Research and Development Funding: FY2022 report, R46869 (Sargent, 2021).

From another perspective, the budget for fiscal year 2021 of the U.S. Department of Defense's (DOD)—the home of DARPA, upon which ARPA-E was modeled—was a staggering \$703.7 billion, with an expected increase to \$715 billion for fiscal year 2022 (Bonvillian, 2018; Department of Defense, 2021). Despite the considerably large gap in funding between the Department of Defense and the Department of Energy, the two agencies' research and development spending find origins in similar areas of nuclear research (Clark, 2018; Cunliff, 2020; Sargent and Gallo, 2021). One of the DOD's first research agencies established in 1951, the Air Force Office of Scientific Research (AFOSR), contributed to researching atomic weapons within the Manhattan Project (Sargent and Gallo, 2021). Many national laboratories also found their roots within nuclear energy and weapons research, such as the Department of Energy's Oak Ridge National Laboratory and Argonne National Laboratory (Sargent and Gallo, 2021). In the landmark article *Science—The Endless Frontier,* Vannevar Bush's argument for establishing national scientific research systems was influenced by his work on atomic weapons and their contribution to national security (Pielke, 2010; Thorp, 2020).

Understanding how government scientific research and development originated demonstrates that institutional power imbalances favoring incumbent, often non-renewable technologies may exist within the federal government (Brown et al., 2008). These power dynamics favoring conventional energies could contribute to alternative technologies being locked-out or stalled, via reduced government energy research and development funding (Brown et al., 2008; Seto et al., 2016; Janipour, et al., 2020). With lagging investments in renewable energy research and development from both the private sector and the government, tackling the global climate crisis and institutional carbon lock-in may appear insurmountable (Seto et al., 2016; Shah and Krishnaswami, 2019; Goldstein et al., 2020). However, energy researchers themselves can get involved to galvanize federal investment in renewable energy and zero-carbon technologies in the dearth of federal and private investment.

ADVOCACY RECOMMENDATIONS FOR ENERGY RESEARCH COMMUNITY

Relying only on political activists and interest groups to further affronts to carbon lock-in is not feasible. Scientists and researchers themselves can take action to decarbonize the nation through technological innovation and secure additional funding. While there is a stigma within the academic community for scientists participating in policy, there is an increased need for scientists' participation in policy discussions coupled with a dearth of public science funding to combat climate change (Bushana et al., 2019). Scientific advocacy will be assessed from the three lenses of personal, professional, and institutional potential pathways for increasing awareness and funding for renewable and zero-carbon energy research and development.

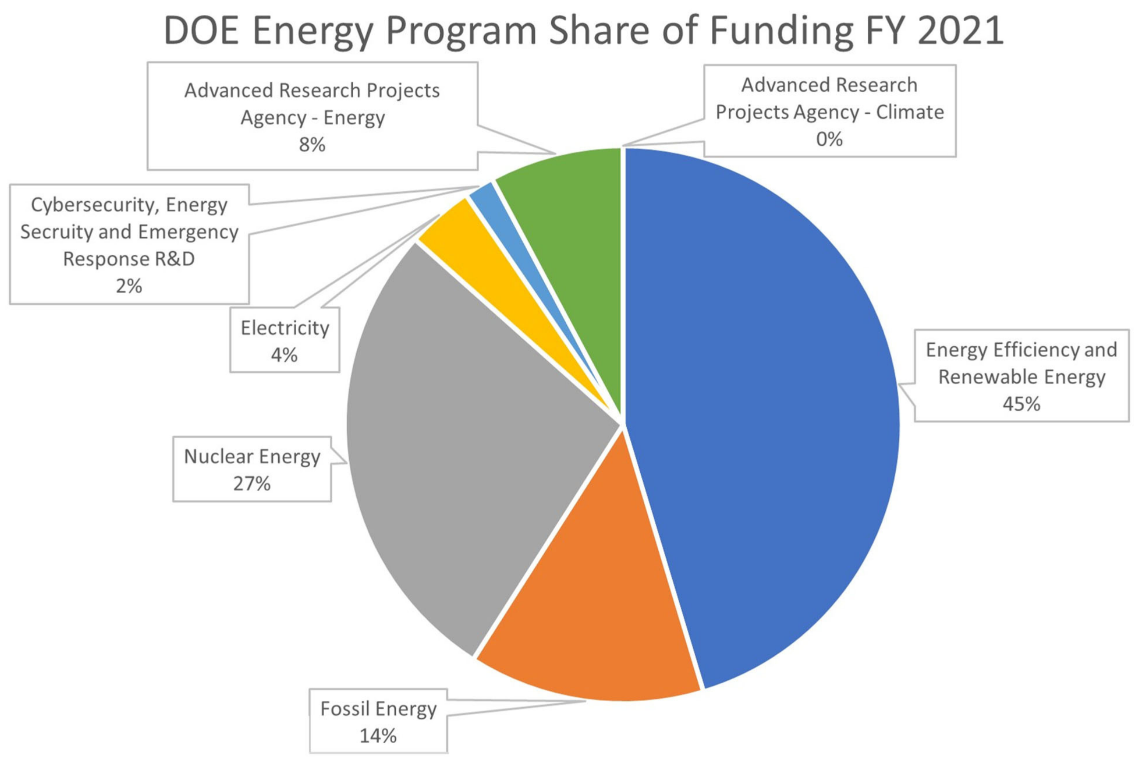

FIGURE 2 | The share of funding for the U.S. Department of Energy's (DOE) spending for fiscal year (FY) 2021 in energy research and development programs. Percentages generated from data retrieved from Congressional Research Service's Federal Research and Development Funding: FY2022 report, R46869 (Sargent, 2021).

Personal

Individual issue advocacy by researchers has been historically discouraged, with assertions that this advocacy will compromise the credibility of both the researcher and the scientific community (Pielke, 2007; Kotcher et al., 2017; Schmidt and Donner, 2017; Cologna et al., 2021; Garber, 2021). While the general public and scientists believe that researchers should be more involved in policy, there are barriers, such as the skills and time required, and risks, such as loss of access to funding and resources, to this engagement (Pew Research Center, 2015; Schmidt and Donner, 2017; Cologna et al., 2021). However, not engaging at all on policy issues of great public concern has consequences, such as damaging a researcher's reputation among colleagues and the public (Schmidt and Donner, 2017). Balancing the risks and barriers with the external push to engage, researchers can conduct a self-assessment of their personal risk tolerances, motivations, and potential audiences prior to participating in scientific advocacy efforts (Schmidt and Donner, 2017).

Personally, researchers in renewable and zero-carbon energy research and development can make conscious efforts at varying risk levels to spread the availability and awareness of their work. From a publishing angle, receiving scientific information is often difficult for policymakers as most of this information is in dense academic journals (Hetherington and Phillips, 2020). Publishing in open access journals can allow publications to reach a wider audience as well as writing policy briefs that are designed to be more understandable to decisionmakers (Scott et al., 2008; Hetherington and Phillips, 2020). Advocating for increased science literacy and education in the public and awareness of scientific issues in the aforementioned publication types has a lower level of risk in public policy engagement (Schmidt and Donner, 2017). Another common goal of scientific advocacy is to increase research funding, though this form of advocacy comes with the risk of conflict amongst colleagues who are applying for similar funding within limited public budgets (Schmidt and Donner, 2017). Nevertheless, advocating for additional funding can increase the attention and resources given to research projects (Schmidt and Donner, 2017; Gaieck et al., 2020; Hetherington and Phillips, 2020). Researchers may feel they do not have the adequate background to broach this subject with policymakers, however (Gaieck et al., 2020). Training in communicating with decisionmakers is provided by professional societies and legislative action committees, such as the American Association for the Advancement of Science (AAAS) and the Union of Concerned Scientists (UCS) (Gaieck et al., 2020). Further, the creation of short policy "one pagers" that address relevant scientific information and elucidates one's request of a policymaker can be a tool to raise awareness and resources for specific legislation and/or research topics (Hetherington and Phillips, 2020, p. 3). Additionally, there are numerous fellowships that are involved in science policy and communication which can help build a researcher's ability to communicate with policymakers and make their research more policy relevant (Hetherington and Phillips, 2020). However, researchers may not have the time or energy to engage in science policy through intensive personal commitments.

Professional

Researchers can utilize their existing membership(s) in professional scientific societies to participate in the science policy interface. Professional scientific societies represent the collective knowledge of thousands of scientists, which may lessen the risk of credibility damage to a single scientist engaging in advocacy (Scott et al., 2008). These societies, such as AAAS, have historically participated in science policy as evidenced by the inclusion of advocacy in mission statements, hiring policy personnel, and establishing public affairs or policy offices (Scott et al., 2008; Garber, 2021). Professional scientific associations also have more tools available than individual researchers to contribute to science policy through congressional visits, news releases, testimonies for decisionmakers, and policy position statements via their policy offices and forums (Delicado et al., 2014). Professional conferences can facilitate discussion on policy-oriented topics within one's discipline and invite decisionmakers to be a part of the discussion (Hetherington and Phillips, 2020). Supporting these initiatives within a professional scientific society, such as participating in steering committees and workshops for science policy, can be a method to engage in policy and advocate for increased research funding without the risks to an individual's credibility.

Institutional

The final pathway researchers can use to become engaged in science policy and increase research funding is through their institutional affiliations. Universities and research centers are the "producers" of climate change research and are intrinsically involved in the policy and political processes that are associated with research and its funding (Morgan, 2017, p. 118; Stephan, 2012). With government funding decreasing, universities have been forced to secure funding elsewhere by building collaborations between the government and industry to create alternative funding opportunities (Morgan, 2017). In this regard, universities are becoming boundary spanning organizations that can bridge the gap between the policy and science communities (Hart et al., 2015; Morgan, 2017; Bednarek et al., 2018). Universities participating in research are uniquely equipped to be boundary organizations as their departments cover vast areas of expertise required to investigate the causes and consequences of sustainability problems, such as climate change and renewable energy (Hart et al., 2015; Morgan, 2017). Yet, this potential can be difficult to tap into with disciplinary silos within universities and the lack of balance between societal demand for and research-generated supply of scientific information (Hart et al., 2015). To spur boundary spanning at their institution, researchers can form advocacy groups at the university or department level to discuss science policy and incorporate students and faculty in its scope (Bushana et al., 2019). Supporting specific legislation through these advocacy groups can be done by coordinating efforts with a policymaker to introduce new policy or to support policy already in deliberation, though this may not be feasible given individual researchers' time constraints (Gaieck et al., 2020; Cologna et al., 2021). Inviting decisionmakers to policy-focused departmental seminars is another way to facilitate the science policy interface at the institutional level, along with supporting early career researchers and professors to engage with policy activities and attend relevant conferences (Evans and Cvitanovic, 2018; Hetherington and Phillips, 2020). Including decisionmakers and local stakeholders in research projects, known as co-production, can be beneficial in finding actionable policy solutions and securing access to funding and resources (Morgan, 2017). Leading policy initiatives at the department or university level can strengthen researchers' abilities to raise awareness about critical scientific issues, connect with policymakers and stakeholders, and increase funding for energy research and development.

Utilizing personal, professional, and institutional methods, researchers can become more engaged in science policy and advocate for increased renewable energy research and development funding to challenge the effects of carbon lock-in (Seto et al., 2016). Issue advocacy in this realm has been done by Badia et al. (2021) to garner support for the previously discussed Advanced Research Projects Agency-Climate (ARPA-C), through working with former Colorado Governor Bill Ritter to propose the creation of the new agency to the Biden campaign (Badia et al., 2021). In April of 2021, President Biden issued the proposed budget that had a combined $1 billion in resources toward ARPA-E and ARPA-C (Badia et al., 2021). However, this has not been reflected in the House of Representative's budget for fiscal year 2021 as ARPA-C was allocated $0 (Sargent, 2021). Despite this setback, the fight for the creation of ARPA-C can be expanded through the continued collaboration between researchers and policymakers. Renewable and zero-carbon energy researchers can utilize their personal, professional, and institutional capacities to engage in science policy and advocate for increased research and development funding for innovative energy technologies.

DISCUSSION

In summary, this article has evaluated trends in the Department of Energy's (DOE) energy research and development programs' funding allocations and provided recommendations for energy researchers to advocate for increased funding. As government research and development spending is a crucial method to challenge carbon lock-in, evaluating how the Department of Energy utilizes its funding to support renewable energy programs and advanced research programs, such as ARPA-E, can be a link to evaluate if enough is being done to support alternative technology development (Seto et al., 2016). While renewable energy program spending in the DOE has increased significantly since 2009, it is not enough to resist the embedded nature of currently locked-in fossil and nuclear technologies (Seto et al., 2016; Clark, 2018).

The incumbent power structures in place in the United States may support a fossil and nuclear energy future. Institutional carbon lock-in is evident through the imbalance in political and industrial power dynamics in favor of carbon-related energies and non-renewables, such as nuclear (Seto et al., 2016). While the DOE is able to conduct research on renewable energies, the fact that ARPA-C has not become a funded division of their energy programs shows the impact of the power dynamics favoring carbon lock-in and resisting alterations to the status quo (Unruh, 2000; Seto et al., 2016; Sargent, 2021). Challenging power imbalances from entrenched support systems and technologies through renewable and zero-carbon energy research and development can both combat carbon lock-in and catalyze decarbonization needed in the U.S. (Brown et al., 2008; Seto et al., 2016; Rockström et al., 2017). With current decreasing levels of federal funding in energy research, alternative energy technologies are less likely to break through (Schuelke-Leech, 2014; Chan et al., 2017).

As a result of a power imbalance favoring carbon lock-in, this article has suggested actionable recommendations for scientific researchers to advocate for more renewable energy program funding and connect with the science policy interface. This can be done through personal, professional, and institutional strategies, such as communication training, policy-oriented and open access publications, and institutional support for researchers engaging in relevant policy topics (Evans and Cvitanovic, 2018; Bushana et al., 2019; Gaieck et al., 2020; Hetherington and Phillips, 2020). Researchers can engage stakeholders and policymakers in their project topics through the conduits of co-production and institutional boundary spanning (Morgan, 2017). As a researcher is never truly separate from their work and science is an inherently value-laden endeavor, it is imperative that scientists and researchers advocate for the use of science to inform the policy process along with research and development funding that can support the creation of this knowledge to address carbon lock-in the United States (Jasanoff, 1998; Pielke, 2007; Seto et al., 2016; Schmidt and Donner, 2017).

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://crsreports.congress.gov/product/pdf/R/R46869.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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