Renewable Energy Innovation Policy: A Comparative Institutional Analysis of the European Union and the United States

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Abstract:

To avoid the most catastrophic effects of global climate change, countries around the world need to rapidly decarbonize their energy systems by deploying current renewable energy sources as well as the next generation of low-carbon technologies. Low-carbon energy sources are the products of innovation systems. The United States (US) and European Union (EU) have robust energy innovation systems that contribute to the development and deployment of renewable energy sources. Many of the institutions in the US's energy innovation system date back to the 1970s when ambitions of energy independence were heightened by the energy crises of 1973 and 1979. Today, the US spends more on energy research and development than any other nation in the world. Throughout the decades, the US has developed innovative ways to accelerate the commercialization of renewable energy technologies. However, more still needs to be done to strengthen the ties between public research centers, private industry, and academia to foster a more collaborative and efficient innovation system. The EU's energy innovation system is comparatively modern, having been developed primarily during the previous decade. The EU's challenge has been to develop an innovation system that complements those of its member states. The EU has been able to reconcile this tension in part by making decarbonization a central tenet of its innovation system. Yet, the EU continues to struggle with the development and commercialization of disruptive next-generation technologies. Both the US and the EU should continue to examine how their multi-level governance structures can be better utilized to aid with the innovation of low-carbon energy sources.

Introduction:

In March 2023, the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) announced that global surface temperatures have risen 1.1°C above pre-industrial levels and are on course to reach 1.5°C of warming by the early 2030s. This means the most ambitious goal in the Paris Agreement to limit global warming to 1.5°C is nearly impossible. Furthermore, the overarching goal of limiting global warming to 2.0°C is in jeopardy. Consequently, communities around the world will be disrupted by wildfires, flooding, drought, hurricanes, extreme heat waves, food, water, and vector-borne diseases, ecosystem loss, food and water insecurity, and more frequent conflict (IPCC, 2023). To keep global warming to below 2.0°C, countries around the world will need to rapidly transition to low-carbon energy sources. This energy transition will require the rapid deployment of current technologies as well as the development of new technologies (Mowery et al., 2010). Low-carbon energy sources are the products of innovation systems. To understand the processes that have led to low-carbon technology development and proliferation, it is helpful to understand the actors, actor networks, and institutions that influence technological change (Hekkert et al., 2007).

The United States (US) and the European Union (EU) both have robust innovation systems that have contributed to the development of renewable energy technologies and are imperative for the development of new low-carbon energy sources. Comparing these two systems can help illuminate the strengths and weaknesses of each system and indicate places for improvement. The US outperforms the EU during the research and development (R&D) phase, spending more on renewable energy R&D and distinguishing itself globally for its explicit focus on next-generation energy technologies (Meckling et al., 2022). The EU excels at supporting the deployment of renewable energy sources through the creation of niche markets via policy incentives and ambitious goal-setting (Abolhosseini & Heshmati, 2014; Delreux & Ohler, 2019). Both systems require greater institutional support for technology commercialization to strengthen their renewable energy innovation systems and make the much-needed transition to low-carbon energy sources (Meckling et al., 2022).

Literature Review:

Schot and Steinmueller (2018) propose that three frames for innovation policy have emerged through contemporary innovation policy discourse. These three frames have shaped the rationales of policymakers producing science, technology, and innovation policies during the past century. The first framing was around *Innovation for Growth*, the second around *National Systems of Innovation*, and the third around *Transformative Change.* The first framework was ushered in during the post-WWII era and was characterized by the belief that the state had an active role to play in advancing scientific and technological progress, particularly through investment in R&D. The role that national governments played in mobilizing and conducting the war effort during WWII helped to legitimize state intervention in industry, especially in the US and the United Kingdom. This framing joined with fears about economic instability and unemployment in the post-war years, and fears about the Cold War in later decades, to create an innovation landscape that emphasized a private-public pairing. From WWII through the 1970s, the state's role in innovation was to invest in R&D that would lead to scientific and technological discoveries that could then be mass produced and commercialized by the private sector. As explained by Schot and Steinmueller, the first framework "reflects a modernist confidence in the inevitability of progress and an economic rationale of the benefits of choice across a range of competitively mass produced (and hence relatively inexpensive) goods" (Schot & Steinmueller, 2018, p. 1556). Thus, any shortcoming could be remedied with further research to expand scientific knowledge. This established a relatively straightforward understanding of innovation policy that measured national progress by countries' R&D expenditures and emphasized developing policies to increase R&D funding (Hekkert et al., 2020).

The oil shocks of the 1970s and economic recession of the early 1980s began to expose the growing divide between higher and lower income countries. The anticipated technology transfer from richer countries to poorer countries that largely failed to occur challenged the first frame's linear model of innovation that was believed to be able to be replicated anywhere. The second frame for innovation policy, *National Systems of Innovation*, emerged in the 1980s in response to a growing awareness of the shortcomings of the first frame. A new model was established that drew attention to the national characteristics that supported innovation systems, particularly the configuration of organizations that produced and utilized technological and scientific knowledge (Schot & Steinmueller, 2018). This second framing examined national systems of innovation to determine what made some countries prosper and others fall behind both technologically and economically. In the early 1990s, Lundvall (1992) and Nelson (1993) both published books examining national innovation systems. While Nelson's comparative analysis of national innovation systems discusses R&D spending, this discussion is contextualized within an analysis of the firms and actors supporting R&D. Lundvall's analysis looks further out from organizations to configurations of organizations and the broader socio-economic context in which they sit (Edquist, 2006). These analyses helped usher in a new policy agenda that emphasized strengthening ties between actors to build more robust systems to support innovation in differing national contexts (Edquist, 2006; Hekkert et al., 2020). Notably, both analyze national systems of innovation, substantiating that innovation systems fall within national boundaries.

The third frame rethinks the presumption that the ultimate goal of innovation policy is national economic growth and refocuses the aim of innovation systems on bringing about *Transformative Change*. At the forefront of these transformative changes are achieving the UN's 17 sustainable development goals and reaching the targets set in the Paris Agreement (Schot & Steinmueller, 2018). Mazzucato (2018) asserts that in order to address climate change, a complex and interconnected challenge linking social, economic, and environmental upheaval, we need mission-oriented innovation policies designed to co-create and shape markets, not just fix them. She emphasizes that mission-oriented innovation policies are constructed around a well-defined goal, but do not strive to pick technological winners. Rather the emphasis is on generating wide-ranging innovations from across disciplines and sectors that can bring about much needed social, economic, and environmental change (Mazzucato, 2018).

Mission-oriented framing may be more adept at capturing the complexity of the sustainability problems we are facing than the unpredictability of socio-technical innovation. This is because socio-technical innovations require an element of public participation or buy-in which is often unpredictable and overlooked in the top-down governance strategies endorsed in mission-oriented framing (Kirchherr et al., 2023). Kirchherr et al. (2023) critique mission-oriented innovation policy for its optimistic acceptance of top-down governance. They argue that governments are too often viewed as monoliths and that the relationships between government and non-government actors are too often overlooked. Specifically, they are concerned about instances where incumbents, such as actors from the fossil fuel industry, persuade government actors to stray from the mission. They encourage that the interactions among diverse actors be more widely considered in the sustainability missions literature (Kirchherr et al., 2023). Kirchherr et al. also point out that although sustainability missions may not strive to pick technological winners, they inevitably pick industrial winners through subsidies, trade protectionism, and funding research, an exercise that cannot occur without embedded power dynamics. Finally, Kirchherr et al. assert that many of the examples of successful missions examined in the academic literature do not fully reflect the broad-reaching impacts or long-term timescale of a problem like climate change. Yet, Kirchherr et al. do not advocate for an abandonment of mission-oriented innovation policy, but rather a critical evaluation of it (Kirchherr et al., 2023). Such an evaluation is needed as the mission framework is taken-up by policymakers, most notably the European Commission, which has adopted missions into Horizon Europe, their primary research and innovation program (Hekkert et al., 2020).

Methodology:

This paper takes a historical institutionalism approach to understanding decarbonization policy by comparing the institutions in the US and the EU that have supported renewable energy innovations. Institutions are "sets of common habits, norms, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups, and organizations" (Edquist, 2006). Institutional analysis seeks to explain where institutions come from, why they persist, and how they change over time. Historical institutionalism emphasizes the historical context and processes in which institutions emerged and evolved and typically begins with empirical evidence (Mahoney & Thelen, 2009; Thelen, 1999). My analysis is primarily concerned with formal institutions and takes an inductive approach, drawing on case studies to build conclusions. To contextualize the processes that the relevant institutions play in the US and EU technological innovation systems, I draw on Hekkert et al.'s *functions of innovation systems* framework which breaks the institutions in an innovation system into seven categories: (1) knowledge development; (2) knowledge diffusion through networks; (3) entrepreneurial activities;

(4) guidance of the search; (5) market formation; (6) resources mobilization; and (7) creation of legitimacy/counteract resistance to change (Hekkert et al., 2007).

After reviewing the institutions that fall into each function in both the US and EU, I discuss the policy implications and propose policy recommendations to improve each innovation system. When facing a global problem like climate change, there are a myriad of policy responses from around the world. Comparing the US and EU policy responses side by side can help identify the strengths and weaknesses of each. In terms of population and economic development, the US and EU are comparable in size. The EU is slightly larger with 447.7 million inhabitants compared to the US's 331.9 million. The US has a larger GDP amounting to $26 trillion in 2022 compared to the EU's $16.6 trillion. While this may seem like a significant gap, the EU has the third highest GDP in the world after the US and China ($19 trillion) meaning they have similar economic standings globally (Rao, 2023). Their multi-level governance structures make them compelling comparative case-studies. The US's energy R&D agenda has largely been driven by federal priorities throughout the decades, consistently energy security and more recently climate change. The primary role states have played in the energy innovation process has been in deployment. In contrast, the EU's member states have their own innovation systems, some of which are quite influential in their own regard such as those of Germany, Denmark, and France. Therefore, the EU's challenge has been to carve out its own position around these existing systems. Leading on climate policy is one way the EU has found a way forward, using EU-level interests, specifically addressing climate change, to deepen European political integration (Jordan et al., 2012).

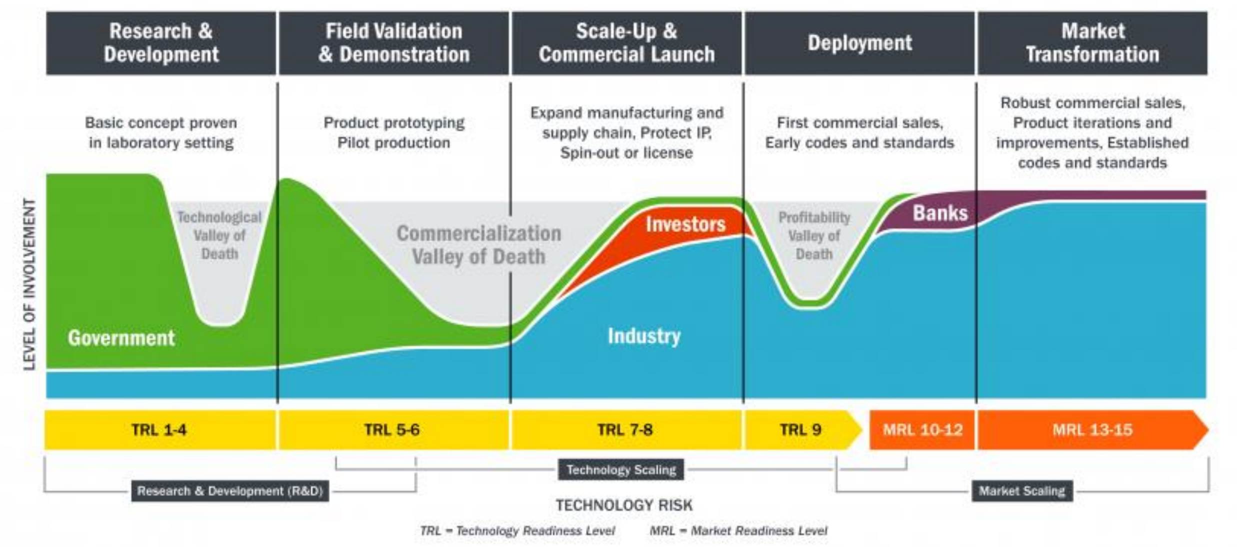
In regards to climate policy, the EU has striven to lead by example and establish itself as an international agenda setter (Jordan et al., 2012). In contrast, the US has often pushed back against international agreements, especially binding ones, never ratifying the Kyoto Protocol and temporarily leaving the Paris Agreement (Bäckstrand & Elgström, 2013; Schiermeier, 2020). Yet, the US has the largest economy in the world, spends more on energy R&D than any other nation, and historically was a leader in global environmental politics in the 1970s and 1980s (e.g., protecting the ozone layer with the Montreal Protocol) (Bäckstrand & Elgström, 2013; IEA, 2020; Rao, 2023). Thus, whether absent or present at international climate negotiations, the US's efforts to decarbonize are noteworthy. Although the EU's and the US's approaches to renewable energy innovation and mitigating climate change differ and some of the approaches may only succeed in a European or American context, there are still lessons for the US to learn from the EU and vice versa.

Functions of Innovation Systems:

The fundamental building block of innovation systems is knowledge. *Knowledge development* is concerned with the processes that lead to learning and how knowledge is created. It is primarily quantified through R&D projects and expenditures. One of the essential steps of turning knowledge into technological innovations is the successful exchange of information through networks, ensuring that scientific breakthroughs and technological advances do not remain in the lab but are able to crossover into the marketplace. *Knowledge diffusion through networks* describes how information is shared through actor networks and is particularly concerned with how R&D is used and interacted with by actors in government and markets (Hekkert et al., 2007).

Entrepreneurial activities refer to the actions taken by entrepreneurs that lead to new knowledge, networks, and markets and the government institutions that support these actions. Central to this function is how new knowledge can be turned into new business opportunities (Hekkert et al., 2007). For an innovation to develop from the research and development stage into something that can transform the market, it must overcome several common failure points known as “valleys of death” (see Figure 1 below). Government and industrial support can help renewable energy entrepreneurs navigate and overcome these valleys of death (Office of Energy Efficiency & Renewable Energy, n.d.).

Figure 1



Source: Office of Energy Efficiency & Renewable Energy (n.d.)

For a technology to develop, it must be perceived as legitimate among technology producers and users. Government targets or long-term goals can create that sense of legitimacy, stimulating resource allocation for the technology. *Guidance of the search* refers to the activities by industry, government, or the market that guide technological investment, e.g., renewable energy targets. New technologies often struggle to compete with embedded technologies, typically offering few advantages over existing technologies during the early stages of development. This can result in low levels of diffusion. To overcome this obstacle, favorable tax regimes and environmental standards can be used to create niche markets that stimulate technological development and improvement. *Market formation* refers to the need for protected spaces or niche markets to allow new technologies to develop (Hekkert et al., 2007).

Resource mobilization differs from knowledge development by asking whether the human capital and financial resources devoted to a technology are sufficient for knowledge production. One way to determine this is by examining whether long-term R&D programs have been established by government or industry to aid with the development of a specific type of technology. For a new technology to overthrow an incumbent regime, it needs to have enough parties with a vested interest in it that lobby and advocate on its behalf. Lobbying and advocacy help place a new technology on the political agenda paving the way for resource allocation, tax regimes, and regulations that are advantageous to the technology. *Creation of legitimacy/counteract resistance to change* traces the creation of advocacy groups that lobby for a new technology (Hekkert et al., 2007).

Below, Table 1 outlines how I operationalized each function and the primary examples of each function in the EU and the US. This overview of how I applied Hekkert et al.'s *functions of innovation systems* framework is followed by descriptions of the institutions supporting each function including their origination, development, and impact. These descriptions do not offer an exhaustive record of the institutions that have supported renewable energy innovation in the US and the EU. However, I strove to select institutions that exemplify the individuality of the US and EU innovation systems.

Table 1

Function	**Operationalization**	**European Union**	**United States**
1. Knowledge development	Public Energy R&D funding as an input metric	Funding from Horizon 2020, Horizon Europe, and the Innovation Fund	Budget requests from the Department of Energy (DOE)
2. Knowledge diffusion through networks	Examples of institutions supporting network formation	The European Institute of Innovation and Technology (EIT) and the European Innovation Council (EIC)	R&D Consortia: Manufacturing USA Institutes, User Facilities, and Energy Innovation Hubs

3. Entrepreneurial activities	Descriptions and assessment of outcomes of institutions supporting innovation development	The European Research Council (ERC)	The Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs and the Advanced Research Projects Agency-Energy (ARPA-E)
4. Guidance of the search	Examples of renewable energy and greenhouse gas emission reduction targets and metrics of success at reaching these targets	20-20-20 Climate Targets and updated 2030 targets	Nationally Determined Contribution (NDC) and national Clean Energy Standard (CES) (not enacted)
5. Market formation	Examples of policies that have supported renewable energy deployment and the outputs of these policies	Feed-in tariffs (FITs) and feed-in premiums (FIPs)	Public Utility Regulatory Policies Act (PURPA), Renewable Portfolio Standards (RPS), production tax credit (PTC), and investment tax credit (ITC)
6. Resource mobilization	Examples of long-term R&D programs supporting new technologies in niche experiments	Joint Research Centre (JRC) labs	DOE National Labs, emphasis on the development of the National Renewable Energy Laboratory (NREL)
7. Creation of legitimacy/counteract resistance to change	Metrics of fossil fuel and renewable energy lobbying	Lobbying amounts from LobbyFacts.eu	Lobbying amounts from OpenSecrets

1. Knowledge development

The European Union:

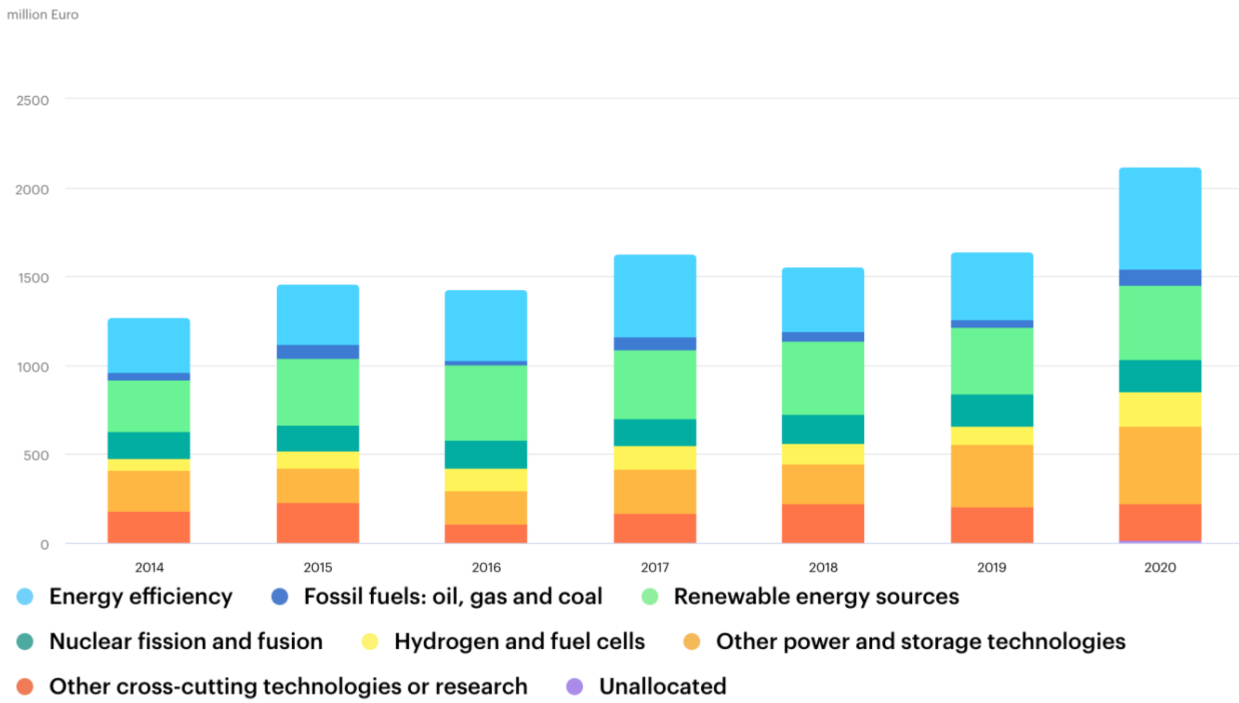
In 2002, the EU devised the Lisbon Strategy, which set the goal of becoming the most competitive knowledge-based economy in the world by committing three percent of GDP to R&D by 2010. While countries within the EU have been supporting renewable energy R&D since the 1970s, the EU did not start funding energy R&D in earnest until 2014 with the launch of Horizon 2020 and the Innovation Fund in 2020 (Veugelers et al., 2015). Horizon 2020 was the EU's research funding program from 2014 to 2020, providing nearly €80 billion to research and innovation projects. It was succeeded by Horizon Europe which will run from 2020 to 2027 and has a budget of €95.5 billion. That said, not all of the funding in Horizon 2020 or Horizon Europe is devoted to decarbonization technology. There is also funding for health research, social science research, protecting biodiversity, food and agriculture, digital technology, and space research. Thirty-five percent of the budget will contribute to climate objectives (Directorate-General for Research and Innovation (European Commission), 2021). Concerns have been raised that this will not be enough to catalyze renewable energy R&D investments from the private sector (Dutton & Pilsner, 2019).

The Innovation Fund is funded by the revenues generated from the EU's Emissions Trading System (carbon market). It has the potential to provide up to €38 billion in funding for low-carbon innovations; however, the exact amount will depend on the price received from the 450 million carbon allowances auctioned off from 2020 to 2030 in the ETS. The Innovation Fund supports large-scale and small-scale projects focusing on energy intensive industries, renewable energy generation, energy storage, and carbon capture utilization and storage (European Commission, n.d.-h). Since the first projects funded by the Innovation Fund are just getting underway, it is too soon to evaluate the impact they will have on the success of the program.

Below in Figure 2 is the breakdown of the EU's total public energy R&D budget per year beginning in 2014 with the launch of Horizon 2020. The largest allotments of the EU's energy innovation funding go to renewables and energy efficiency. Total spending increased from just over €1.6 billion (1.9 billion USD) in 2019 to €2.1 billion (2.5 billion USD) in 2020 with the beginning of Horizon Europe and the Innovation Fund (IEA, 2022b).

Figure 2

EU Total Public Energy R&D Budget Per Year



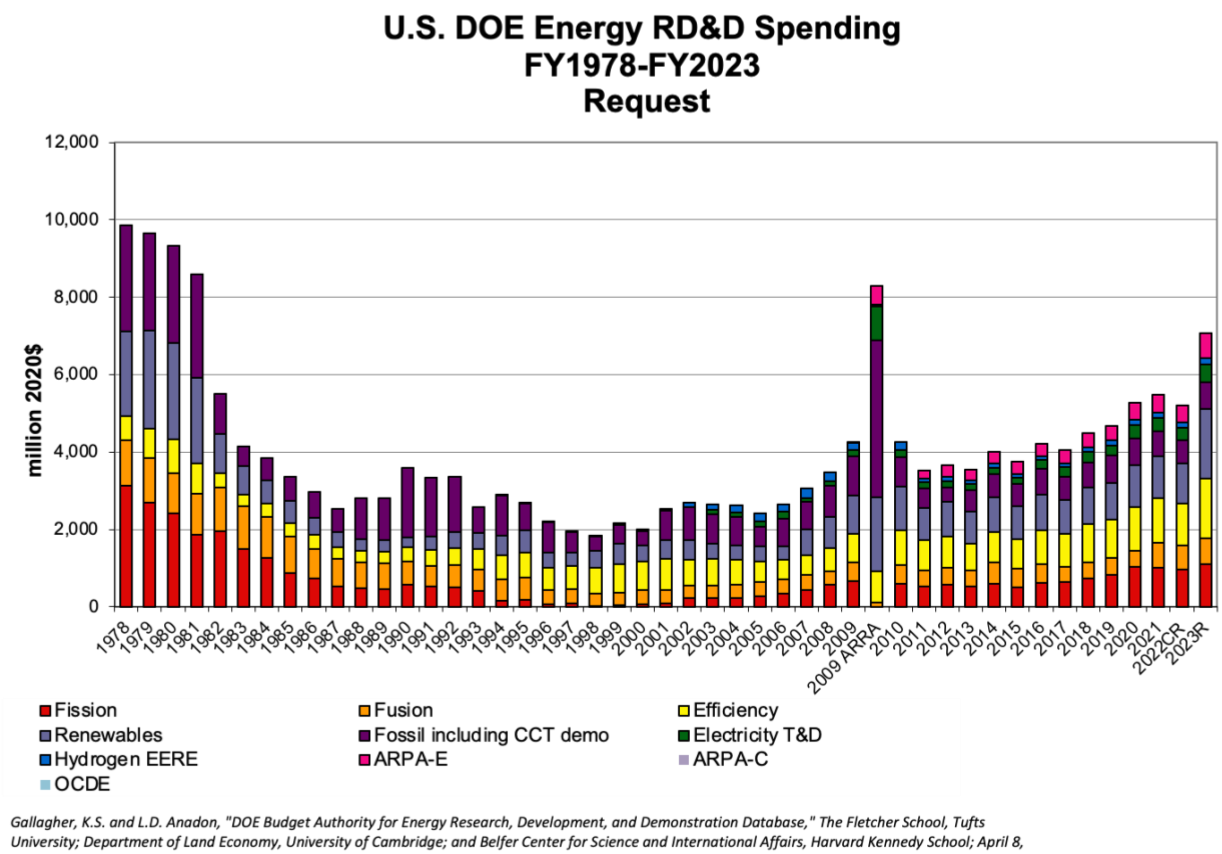
Source: IEA (2022b)

The United States:

In the US, major public investments in energy R&D began in the 1970s in response to the oil crises. In 1973, President Richard Nixon proposed the creation of the Energy Research and Development Administration (ERDA), which would support energy R&D with the goal of reaching 100 percent domestic energy production by 1980. ERDA was created a year later with the passage of the Energy Reorganization Act of 1974. At the start of the Carter Administration, ERDA merged with the Federal Energy Administration to form the Department of Energy (DOE) and a Secretary of Energy position was established in the President's Cabinet. President Jimmy Carter was instrumental in providing resources for solar photovoltaic (PV) development pushing Congress to provide more funding for PV R&D. Under the Reagan Administration, funding for energy R&D was cut dramatically with funding for PV R&D dropping from $130 million per year to $50 million per year. The extensive budget cuts reflected President Ronald Reagan's belief in free enterprise and that government funding should only go to basic research as opposed to applied research. These funding cuts stalled the progress that was being made towards developing an economically competitive PV in the US (Nemet, 2019).

Public energy R&D funding levels have never surpassed the levels seen during the Carter Administration, except in 2009 with the investments from the American Recovery and Reinvestment Act. Energy R&D has trended upward during the past decade with greater proportions going to renewable energy and energy efficiency than in previous decades (see Figure 3 below) (Gallagher & Diaz Anadon, 2022). That said, the proportion of energy R&D funding that goes to fossil fuels has consistently been larger in the US than in the EU as shown in dark purple in Figure 3 and dark blue in Figure 2.

Figure 3



Source: Gallagher & Diaz Anadon (2022)

2. Knowledge diffusion through networks

The European Union:

The European Institute of Innovation and Technology (EIT) and the European Innovation Council (EIC) were created in 2008 as part of Horizon 2020 and expanded as part of Horizon Europe. EIT forms partnerships between actors in industry, research, and higher education to find solutions to a specific global problem. The program is structured around Knowledge and Innovation Communities that each have a central focus, such as climate change, sustainable energy, healthy living, or food. EIT's mission is guided by the principle that connecting innovators and organizations will help turn academic research output into disruptive commercial innovations (European Institute of Innovation & Technology, n.d.). In contrast to EIT, which generally tries to connect actors across sectors for the sake of advancing research, EIC is more focused on connecting basic research to an end use and finding an existing market (Reimagine Europa, 2021).

With a budget of €10.1 billion from 2021 to 2027, the EIC provides grants and investments to startups and small and medium businesses to support innovations throughout the innovation lifecycle from early-stage research to proof of concept to scaling up. The EIC strategy is devised by the EIC Board made up of investors, researchers, and entrepreneurs. EIC funding is actively managed by EIC Programme Managers that serve limited terms no longer than 4 years and oversee the funding in their portfolio areas. Programme Managers primarily work to identify potential challenges that projects in their portfolio areas might face, educate applicants about those challenges, and connect projects with investors and partners (European Innovation Council, 2023). In 2021, a Memorandum of Understanding was signed between the EIT and EIC to strengthen the ties between (1) small and medium businesses and start-ups and (2) academic institutions and research organizations (European Innovation Council, n.d.).

The United States:

The DOE created R&D Consortia that bring together stakeholders from a high-priority technology area that are essential to clean energy manufacturing, industrial efficiency, and decarbonization. The R&D Consortia use federal funding to bring stakeholders together to address the technological and procedural challenges facing advanced manufacturing, resource efficiency, and cybersecurity. Stakeholders include small and medium businesses, researchers, manufacturers, and state and local governments. There are three categories of R&D Consortia: Manufacturing USA Institutes, User Facilities, and Energy Innovation Hubs. The Manufacturing USA Institutes provide shared resources and facilities to its members to help with the development and scaling up of new technologies. The User Facilities specifically provide resources for additive manufacturing and carbon fiber testing and manufacturing at the Oak Ridge National Laboratory (Department of Energy, n.d.-e). The Energy Innovation Hubs were established in 2010. They bring together basic and applied research with engineering to address a single, critical energy issue. These multidisciplinary research centers provide significant resources for early-stage research as well as chart a path for research to lead to deployable technologies by taking guidance from the private sector on the research to commercialization pathway. There are currently five Energy Innovation Hubs focusing on nuclear energy, fuels from sunlight (artificial photosynthesis), batteries and energy storage, critical materials, and energy-water desalination (Department of Energy, n.d.-a).

3. **Entrepreneurial activities**

The European Union:

In 2007, the European Commission reached the conclusion that there was insufficient support for cutting-edge basic research across Europe. As a result, they established the European Research Council (ERC) to support investigator-driven frontier research. The ERC accepts applications from all fields from researchers all over the world; so far, it has provided grants to researchers from 85 countries (European Research Council, n.d.-a; König, 2016). It has five thematic working groups, including one on innovation that specializes in working with industry to design, develop, and implement innovations with socio-economic benefits (European Research Council, n.d.-c).

The ERC was established as part of the 7th Framework Programme, which was the EU's research funding program from 2007 to 2013, and received a budget of €7.5 billion over 7 years. The 7th Framework Programme was succeeded by Horizon 2020, which provided €13.1 billion in funding for the ERC from 2014 to 2020 (König, 2016). Under Horizon Europe, the ERC will receive €16 billion in funding from 2021 to 2027. The ERC is governed by the Scientific Council which consists of 22 scientists and scholars that set the ERC's scientific strategy. This strategy is implemented by the ERC Executive Agency, which is in charge of grant administration and provides support to applicants (European Research Council, n.d.-a). The ERC divides funding opportunities based on where researchers are in their careers to ensure funding is available to those just starting out as well as those who are well-established (König, 2016). Additionally, the ERC has a Proof of Concept grant for previous ERC grant winners who wish to explore the social and commercial potential of their research (European Research Council, n.d.-b).

The ERC is generally considered to be a success, supporting scientific discoveries by providing researchers with the opportunity to pursue riskier ideas. Furthermore, the ERC has been accredited with providing opportunities to young researchers wishing to break free of traditional academic hierarchies and establishing a healthy competition among countries and host institutions over the number of grants received (König, 2016). However, the ERC program does a better job supporting scientific advancements than scientific breakthroughs and does not excel at promoting disruptive technologies (European Research Council, 2021; Reimagine Europa, 2021).

The United States:

The Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs are housed within the Office of Energy Efficiency & Renewable Energy at the DOE. They support the development and commercialization of innovative technologies, including renewable energy technologies, by small businesses. The SBIR program was created in 1982 with the passage of the Small Business Innovation Development Act and supports innovation by providing funding in the form of grants for small businesses conducting R&D (National Academies of Sciences, Engineering, and Medicine, 2020). Projects that receive funding must have the potential for commercialization and must fulfill one of the DOE's missions, such as Energy Production & Use or Energy Storage & Security (Department of Energy, n.d.-b). The STTR program was established in 1992 following the passage of the Small Business Research and Development Enhancement Act and sought to increase the commercialization of innovations receiving federal funding by requiring partnerships between small businesses and research institutions (National Academies of Sciences, Engineering, and Medicine, 2020).

While the SBIR-STTR programs have successfully led to technological innovations that have supported DOE missions, some of the other goals of the programs have been less successful. Some projects have led to significant commercialization efforts; however, this has not been the case for the majority of awardees indicating the need for more support for commercialization efforts or shifts in strategy to emphasize commercialization. Furthermore, one of the stated goals of the programs is to increase participation of minority-owned small businesses and women-owned small businesses in technological innovation. Yet, minority-owned small businesses and women-owned small businesses each accounted for less than 10 percent of the awardees of the program from 2005 to 2015 (National Academies of Sciences, Engineering, and Medicine, 2017a). For reference, 20 percent of businesses were minority-owned and 21 percent of businesses were woman-owned in 2020 (US Census Bureau, 2022).

The other major institution at the DOE tasked with supporting entrepreneurial activities is ARPA-E. The Advanced Research Projects Agency-Energy was created by Congress in 2007 to develop energy technologies that reduce reliance on foreign energy sources, reduce greenhouse gas emissions, and maintain US technological leadership in developing and deploying energy technologies (National Academies of Sciences, Engineering, and Medicine, 2017b). It was formally launched two years later in 2009 with $400 million in funding from the American Reinvestment and Recovery Act (Tollefson, 2021). Funding levels for ARPA-E declined after its initial launch and in 2011, it had a budget of only $180 million. However, its funding levels steadily increased over the next decade reaching a budget of $427 million in 2021 (ARPA-E, n.d.).

ARPA-E follows the Defense Advanced Research Projects Agency or DARPA model. DARPA was established in 1958 amidst Cold War tensions to fund research of breakthrough technologies with potential for military applications. The DARPA model does not rely on a single research lab but is instead built around program directors who are given a high level of autonomy to determine which projects in outside research laboratories should receive funding. Technical R&D experts with extensive experience at a university, national laboratory, or in industry can apply to be program directors at ARPA-E and if selected serve for only three to five years. Program directors are granted the freedom to assemble research teams and actively engage with these teams on projects. Directors set demanding deadlines for projects, and if they feel that a project is not performing as desired, the funding is terminated and redirected towards other more promising projects. An innovation in the ARPA-E system is that Program Directors help grant applicants develop commercialization plans from the outset of the project (Bonvillian & Van Atta, 2011; Tollefson, 2021).

Assessments of ARPA-E indicate that, although it is too soon to see evidence of the widespread deployment of funded technologies, there is preliminary evidence that the agency is making progress towards its goals thanks to the technical and leadership skills of its Program Directors and the autonomy they are granted. The allowance given to Program Directors to take risks has led to investments in revolutionary technologies while their active project management leads to modifications in the development process to ensure projects continue to advance. It has been suggested that other programs at the DOE emulate the ARPA model (National Academies of Sciences, Engineering, and Medicine, 2017b).

4. **Guidance of the search**

The European Union:

The EU is an international leader on setting long-term goals for decarbonization technologies. In the lead up to COP15 held in Copenhagen, the European Council passed the 20-20-20 climate targets which committed the EU to reducing greenhouse gas (GHG) emissions by 20 percent from 1990 levels, increasing the share of energy consumption coming from renewable energy sources to 20 percent, and reducing energy consumption by 20 percent through energy efficiency all by 2020 (Delreux & Ohler, 2019). The EU surpassed its GHG emissions goal, decreasing emissions by 24 percent from 1990 levels, and cleared its renewable energy goal with renewables generating 22 percent of final energy consumption in 2020. The EU was not on track to meet its energy consumption targets, but with the lockdowns during the COVID-19 pandemic, energy consumption declined, and the EU managed to reach a 20 percent reduction in 2020 (European Commission, n.d.-g; European Environment Agency, 2023). The EU continues to update its targets; it is now aiming to decrease emissions by 55 percent, reach 45 percent renewable energy generation, and decrease energy consumption by 9 percent from the 2020 reference scenario by 2030 (European Commission, n.d.-g, n.d.-a).

The United States:

On the national level, the US has been unable to pass the same sort of legally binding targets as those seen in the EU. In 2021, the US rejoined the Paris Agreement and submitted a nationally determined contribution (NDC) committing the US to reducing greenhouse gas emissions by 50 to 52 percent from 2005 levels by 2030 (Kerry & McCarthy, 2021). The enactment of national legislation such as the Infrastructure Investment and Jobs Act and the Inflation Reduction Act will help reach this target, but there is no national law codifying this commitment. There have been attempts to set a national clean energy standard (CES), which would legally require a minimum percentage of electricity generation from clean energy sources, dating back to 1997; but these attempts have never passed through Congress (Lawson, 2021). Despite not having a national target, renewable energy sources provided 13 percent of the US's total primary energy consumption and 22 percent of total utility-scale electricity generation in 2022 (U.S. Energy Information Administration, 2022).

5. Market formation

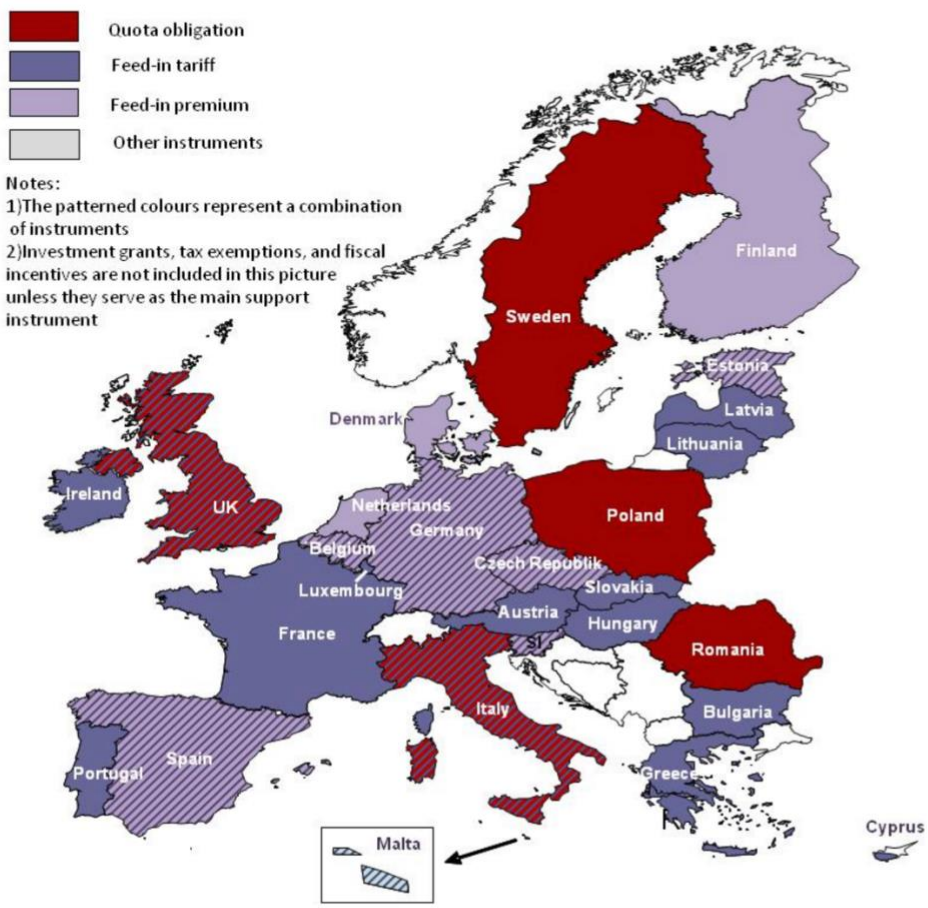
For this function, I included policies enacted by EU member states because they have been an integral part of forming niche markets for renewable energy technologies and there is a lack of policies that serve the same function at the EU level. Additionally, most of the countries within the EU have enacted very similar policies meaning though feed-in tariffs (FITs) and feed-in premiums (FIPs) are technically implemented at the national level, they are nearly EU wide. Figure 4 below illustrates just how wide-spread FITs and FIPs are throughout the EU. I also discuss state implemented Renewable Portfolio Standards (RPS) because they cover the majority of the US's electricity retail sales and there is no national equivalent.

The European Union:

Countries in the EU have tended to favor FITs and more recently, FIPs to promote renewable energy development (IEA, 2022a). FITs support the development of new renewable energy projects by: (1) guaranteeing grid access; (2) providing long-term contracts to project developers; and (3) offering a purchase price based on the cost of energy production (Abolhosseini & Heshmati, 2014). FIPs offer a premium above the market price to transition renewable energy technologies to the market while continuing to incentivize renewable developers (IEA, 2022a).

Figure 4

EU Renewable Energy Support Schemes



Source: Ragwitz (2013)

Germany and Denmark were two of the early adopters of FITs. In the 1980's, a Danish utility entered into a voluntary agreement with the Danish Wind Turbine Association where they agreed to purchase its output at 85 percent of retail electricity rates. In 1991, Germany passed a FIT modeled after the Danish agreement where utilities were required to purchase renewable energy at 90 percent of the retail electricity rate. Following the decline of German retail rates and thus decreased incentives for renewable energy, Germany modified the FIT in 2000 to use fixed rates that have been periodically updated since then (Rickerson et al., 2007). Evidence from across Europe indicates that FITs are an effective instrument for incentivizing renewable energy deployment and have helped the EU reach its renewable energy targets. In 2011, Germany installed its one-millionth PV system reaching a cumulative installed capacity of 24.8 GW, a milestone that was largely attributed to its FIT policies. In 2010, Italy installed 9.3 GW of PV capacity following policies supporting advantageous rates for renewables (Abolhosseini & Heshmati, 2014).

In 2012, Germany introduced a sliding FIP for renewables with a floor price. This means that renewables can be entered in the spot market and will receive a premium in addition to the market price until the spot market price rises above the minimum payment guarantee (the floor price), at which point they will only receive the market price. Other European countries have followed suit to encourage market integration of renewable energy sources as the technology has matured (IEA, 2022a).

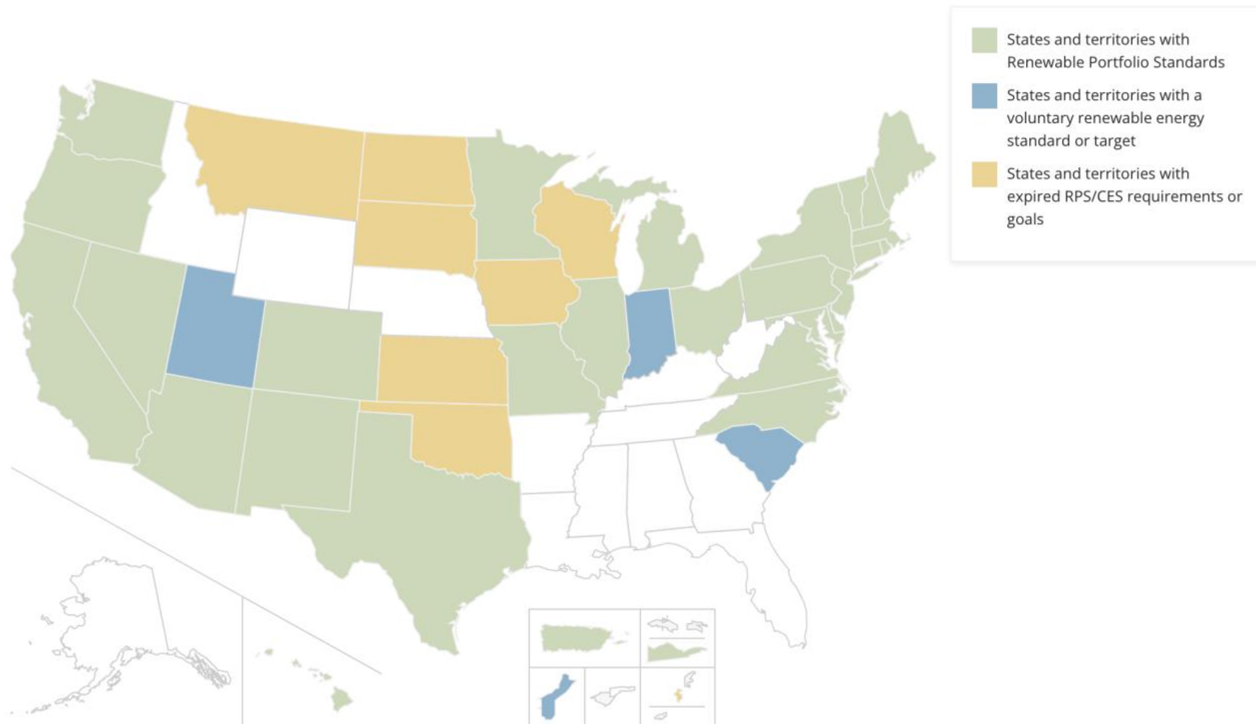
The United States:

The US was an early leader in FITs with the passage of the Public Utility Regulatory Policies Act or PURPA in 1978 in response to the energy crises of the 1970s. PURPA was designed to incentivize cogeneration plants and renewables by requiring utilities to purchase the electricity these independent producers generated. In the US, PURPA has a controversial reputation for raising costs for utilities that were then passed on to ratepayers. However, this has more to do with the ways it was implemented and incorrect assumptions than with FITs as a policy (Abolhosseini & Heshmati, 2014; Rickerson et al., 2007). Rates paid to independent power producers were based on avoided costs for utilities, or the amount it would have cost them to produce that power. Avoided cost rates were left up to individual states. The assumption in the late 1970s was that generating costs would continue to rise, leading some states, such as California and New York, to create long-term contracts with high avoided cost rates. However, avoided costs rates dropped precipitously as many utilities switched from oil to natural gas. The long-term contacts with high avoided cost rates attracted a lot of renewable energy producers (mostly wind) to those states. However, it also created a large discrepancy between what the independent power producers were being paid and the cost of the energy they were producing as the cost of wind was also on the decline (Rickerson et al., 2007). Although further FITs have not been popular at the federal level, California, Indiana, New York, Washington, and Vermont have enacted them at the state level (DSIRE, 2023).

Other state policies encouraging renewable energy deployment include CESs and RPSs. There is no single agreed-upon standard for what constitutes clean energy, with some including nuclear energy or fossil fuel plants with carbon capture and storage. RPSs only count renewable energy sources (Lawson, 2021). In 2021, 31 states plus Washington, D.C. had enacted either a CES or an RPS (see Figure 5 below). These standards account for 67 percent of the US's total electricity retail sales. Additionally, seven states have non-binding goals for renewable energy (Bowers, 2021).

Figure 5

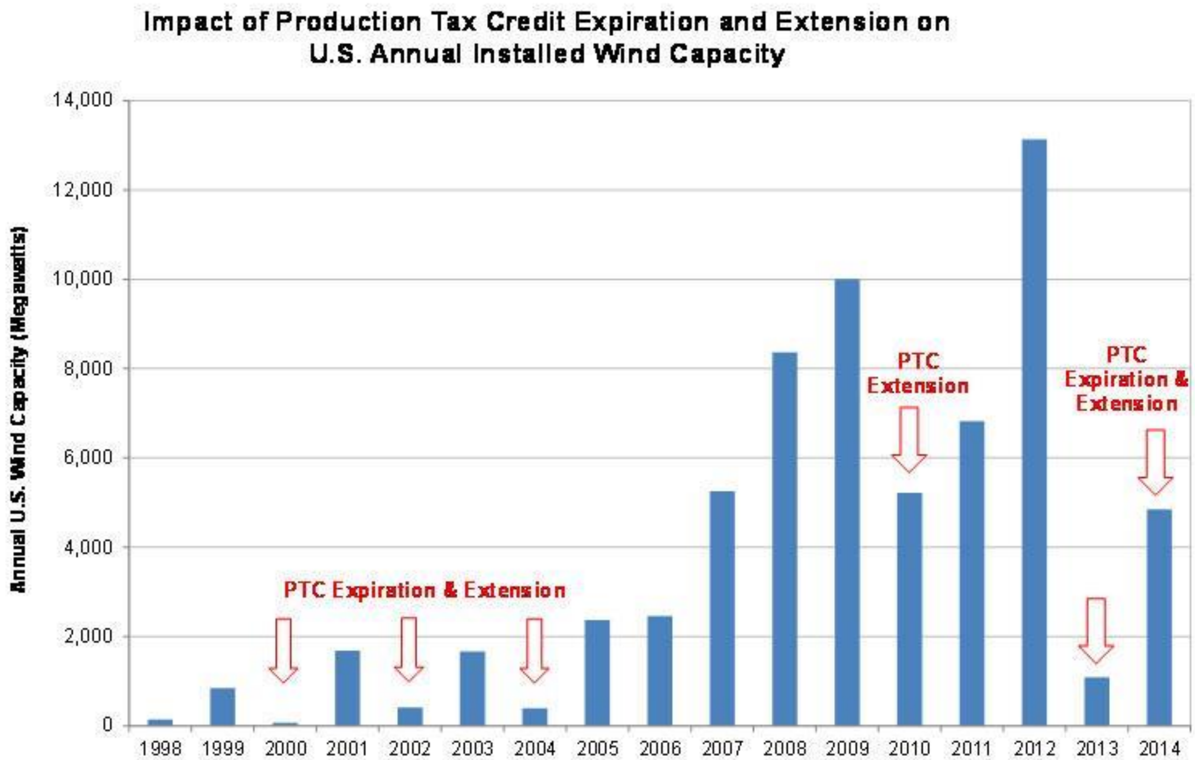
Renewable Portfolio Standards or Voluntary Targets



Source: National Conference of State Legislatures (2021)

At the federal level, the US has favored tax credits to encourage the development of renewable energy sources. The production tax credit (PTC) was first passed as part of the Energy Policy Act of 1992. It provided a 2.3 cent per kilowatt hour produced tax credit for the first ten years of a renewable energy project's operation. Although this credit was available for wind, geothermal, and bioenergy, it was primarily used for wind and is considered to be a major driver of the industry (Novogradac, 2016; Union of Concerned Scientists, 2015). The PTC was repeatedly allowed to expire before being extended by Congress leading to boom-and-bust cycles in wind project development. While this pattern created uncertainty in the industry, it also clearly illustrates the effectiveness of the tax credit at stimulating the creation of new projects (see Figure 6 below) (Union of Concerned Scientists, 2015).

Figure 6



Source: Union of Concerned Scientists (2015)

The investment tax credit (ITC) provides a one-time credit based on the expenses invested in the renewable energy project. It is most often used for solar developments. The Inflation Reduction Act (IRA) extends the ITC providing a 30 percent tax credit on qualified expenditures until 2032 followed by declining percent credits during the following two years (Novogradac, 2016). The IRA also extends the PTC through 2024 with additional wage and apprenticeship requirements (WINDExchange, n.d.). The IRA is projected to more than triple annual installations for wind, solar, and energy storage capacity from 28 gigawatts (GW) installed in 2022 to 90 GW in 2030. Added together, this would result in 40 percent of the US's electricity coming from utility scale wind, solar, and energy storage by 2030 (Hensley, 2022).

6. Resources mobilization

The European Union:

The Joint Research Centre (JRC) is the European Commission's research service which works to provide "independent, evidence-based knowledge and science, supporting EU policies to positively impact society" (European Commission, n.d.-b). It began as a nuclear research organization. Its inaugural lab and nuclear reactor were constructed in Ispra, Italy in 1959. Two more nuclear research centers were built in Karlsruhe, Germany and Petten, the Netherlands in 1960 and 1961 respectively. In 1971, the European Commission decided to expand the scope of the JRC beyond nuclear research to other types of technologies including solar energy, constructing a solar house in Ispra in 1976 (Pakalin, 2017).

Today, the JRC has six research sites, with two in Belgium and one in Spain, in addition to the three original sites. Much of the energy related research is conducted at the Petten lab, with projects on low carbon energy systems, energy storage, energy efficiency, and nuclear safety. In addition to conducting research on nuclear safety and security, the Ispra lab conducts research on energy efficiency, sustainable resources, and transport (European Commission, n.d.-d). There are smart grid interoperability labs at both the Ispra and Petten sites, as well as a battery testing lab in Petten. The European Solar Test Installation lab located in Ispra dates back to the 1970s and conducts research on the electrical performance and reliability of PV products (European Commission, n.d.-e).

In recent years, the JRC has reorganized its structure around six European Commission priorities, including the "European Green Deal" and "A Europe fit for the digital age" with 33 portfolios grouped within these six priorities. The hope is that this will better integrate science and knowledge into EU policy (European Commission, n.d.-c). Assessments of the JRC labs find that they are doing a good job of collecting scientific and technical evidence supporting EU policies and that more of their publications have shown up in the world's top-cited literature in recent years. Yet, there have been critiques that their findings have often failed to reach public attention. For instance, a JRC lab determined that car makers were manipulating diesel-emissions data years before the Volkswagen scandal drew public attention in 2015. Even then, the European Commission and the EU member states failed to act on the finding until crackdowns occurred in the US. Another critique is that the JRC labs spend insufficient resources on exploratory research, with only 3.5 percent of JRC staff working on exploratory projects. This limits the innovative power of the JRC labs and could potentially lead to holes in the knowledge of policymakers ("Europe's Joint Research Centre, Although Improving, Must Think Bigger," 2017).

The United States:

The advent of US national laboratories can be traced back to the Manhattan Project and the US's effort to build the first nuclear weapon. To house the classified and wide-ranging research being done, the first national laboratories were established during WWII. After the war, nuclear research continued with a broader focus on basic nuclear processes, nuclear energy, and medical applications for nuclear materials. This led to the creation of a network of national laboratories throughout the 1940s and 1950s. The oil embargoes of the 1970s increased motivation to develop national laboratories for other forms of energy beyond nuclear (Department of Energy, n.d.-d). President Gerald Ford signed the Solar Energy Research, Development, and Demonstration Act, which created the Solar Energy Research Institute (SERI) in 1974. This was a notable change in US renewable energy policy as this was the first time the US devoted resources to establish a center of innovation with the purpose of creating and marketing renewable energy technologies as opposed to only using policy for this purpose. SERI officially opened its doors four years later in Golden, Colorado (NREL, n.d.).

President Carter was a strong proponent of SERI and encouraged Congress to pass the Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978 allocating $1.5 billion dollars for PV R&D to reach near-term solar PV commercialization and set the goals of reducing the average cost of solar PV systems to $1 per watt by 1988 and deploying 50 GW of solar by 2000 (Nemet, 2019; NREL, n.d.). Under the Carter administration, SERI’s budget and capabilities continued to grow, reaching a budget of $130 million and a staff of nearly 1,000 people in 1980. President Reagan slashed SERI’s budget to $30 million and reduced its staff to 450 people in 1981. Yet, SERI was able to continue to compete for other federal grants and expanded its research into other forms of renewable energy including wind, biomass, hydrogen, and ocean energy. In 1991, President George H.W. Bush turned SERI into a national laboratory and renamed it the National Renewable Energy Laboratory (NREL) to reflect the expanded scope of its work. NREL played a critical role in bringing down the cost of solar, developing a technology that enables mass production of thin-film solar modules, producing some of the lowest-price-per watt PV modules in the world (NREL, n.d.).

Today, there are 17 national laboratories as part of the DOE that work on renewable energy and nuclear energy technology (Department of Energy, n.d.-c). These labs follow the model developed during the Manhattan Project where they are owned by the government but operated by a contractor. While this model offers greater flexibility, it has been advised that to ensure the DOE’s goals are being met, particularly energy innovation, the DOE should play a more active role in setting lab priorities. Furthermore, while basic research is an essential function of the national laboratories, there should be more resources devoted to building private sector partnerships to aid with commercialization of innovations (Bin-Nun et al., 2017).

7. **Creation of legitimacy/counteract resistance to change**

The European Union:

Traditionally, fossil fuel lobbyists have had an oversized influence on energy politics in the EU. From 2010 to 2018, the five largest oil and gas companies spent €251 million lobbying to shape EU climate policies with some success (Laville, 2019). They have been able to delay conversations and influence debates in their favor. For instance, the EU Taxonomy for green investment includes some natural gas investments. Recently, the fossil fuel lobby has been able to capitalize on Russia's invasion of Ukraine and consequent energy disruptions to push through more conservative energy policies. REPowerEU, a set of emergency measures in response to the war in Ukraine, includes significant funding for new oil and gas infrastructure (Ferris, 2022b).

The renewable energy lobby has increased in size and influence during the past decade. In 2022, WindEuope spent €1 million on lobbying, up from €670,000 in 2012. SolarPower Europe also spent €1 million in 2022, representing an even greater increase from the €275,000 they spent in 2012 (LobbyFacts.eu, n.d.). While the renewable energy lobby's spending still does not come close to that of the fossil fuel lobby (Shell alone spent €5.5 million in 2022), it carries a disproportionate influence thanks to the media's, the public's, and many EU politicians' favorable views of renewable energy and the renewable energy lobby (Ferris, 2022b; LobbyFacts.eu, n.d.). Data from EU Integrity Watch indicates that "three of the ten organizations with the most high-level meetings in 2021 can be considered 'green', compared with two that represent traditional industrial players, and zero fossil fuel companies" (Ferris, 2022b). Additionally, the increasing number of jobs in the renewable energy industry have strengthened the public support they receive and their lobbying power (Ferris, 2022b).

The United States:

The fossil fuel lobby has shaped the dialogue around climate change in the US, particularly on the right, for the past three decades. Despite rapid growth of the renewable energy industry in politically conservative states such as Iowa, Kansas, Oklahoma and Texas, Republican lawmakers have been unwilling to cross the fossil fuel lobby and vocally support renewable energy policies in recent years (The Economist, 2021). Until recently, the renewable energy industry has been too small and disparate to effectively lobby against the fossil fuel industry. In 2022, $22 million were spent on renewable energy lobbying. In comparison, $124 million were spent on oil and gas lobbying, nearly six times as much as renewable energy lobbying (OpenSecrets, 2022). That said, as the renewable energy industry has grown, so has the money it spends on lobbying Congress, increasing from $1.48 million in 2000 (OpenSecrets, 2022). Renewable energy lobbyists have successfully advocated for the extension of renewable energy tax credits and the passage of the IRA (Ferris, 2022a; Geng, 2020).

Discussion:

Jordan et al. argue that the EU's climate policy is influenced by the paradox of aiming to lead the world on climate change mitigation targets and policies while remaining a relatively leaderless system of governance. The European Commission, the European Parliament, and greener member states have sought to lead in international negotiations and on setting ambitious EU-level policies. Yet, the EU has a relatively open and pluralistic governance structure without a single central governing entity. Thus, leadership on climate policy has emerged from many places within the EU. This has served as an asset, helping to avoid the policy gridlock that has characterized US climate politics (Jordan et al., 2012). Rather than finding unity by rallying behind a single leader, the EU is often brought together by a shared vision of what is best for the member states. Underlying the continuation of the EU is the belief of its members that together they wield more economic and governance power which will ultimately benefit the member states' citizenry (Hooghe & Marks, 2001). Such a governance structure has made mission-oriented innovation policies well suited to the EU. Furthermore, the EU's innovation system has developed during the past two decades corresponding with the emergence of mission-oriented innovation policy discourse. Therefore, to understand the character of the EU's innovation institutions it is helpful to trace what the EU has expressed as its mission.

In 2002, the EU's foremost innovation goal was becoming the most competitive knowledge-based economy in the world (Veugelers et al., 2015). Today, their stated goal is "relating EU's research and innovation better to society and citizens' needs" and their top priority is tackling climate change followed by achieving the UN's Sustainable Development Goals (European Commission, 2021). Decarbonization and sustainability are incorporated throughout the EU's innovation institutions. For example, the EU's EIT and EIC build networks to support wide-ranging types of innovations but find focus by addressing specific EU goals that emphasize sustainability. In contrast, the DOE's R&D Consortia and Energy Innovation Hubs are focused on making the connections needed to support specific energy R&D challenges. By my assessment, the US's network building is too confined to certain objectives failing to foster the linkages seen in the EU's system that encourage R&D agendas to be updated as norms and values change.

However, in regard to supporting entrepreneurial activities, the EU would benefit from taking a more targeted approach to renewable energy innovation. The ERC has struggled to support the high-risk innovation strategies needed to develop and commercialize groundbreaking technologies like those emerging from ARPA-E. The substantial investment of resources needed for the ARPA model to prosper makes it challenging for a single European country to support such a project on its own leading to a further gap on the European side. The EU may be best positioned to put together an ARPA-E like program (Reimagine Europa, 2021).

Furthermore, the JRC labs have struggled to support cutting edge research. The researchers at the JRC labs tend to prioritize conducting research that informs current EU policies. While this can help improve the lives of people in the EU, it also creates a disconnect between the scientists at the JRC labs and the those at universities and research institutes. This type of siloed research may be impeding faster innovation on next generation technologies ("Europe's Joint Research Centre, Although Improving, Must Think Bigger," 2017). The US national laboratories have taken active steps to break down silos to increase technology transfer. They have made a concerted effort to ensure that public energy R&D is put into practice by establishing formal programs to increase collaboration with private sector energy entrepreneurs (Chan et al., 2017). The EU would benefit from taking a more active roll in incorporating technology transfer programs into the JRC labs.

For the past century, the US has been an innovation powerhouse. During the decades following WWII, the US's national investment in R&D was greater than all other OECD nations combined. A high priority on the US's innovation agenda was and continues to be national security as is reflected by the US's military R&D budget. In 1960, defense research received roughly 80 percent of federal R&D funding (Nelson, 1993). The oil crises of the 1970s made energy independence a national security concern. Consequently, energy innovation funding increased dramatically during the 1970s (Nemet, 2019). Notably, many of the US's innovation system's institutions emerged during the first frame of innovation policy in the post war years where state investment in R&D followed by commercialization by the private sector was emphasized.

Although the US energy R&D budget has fluctuated throughout the decades, the US outspends the EU on energy R&D both in terms of absolute dollar amount as well percentage of GDP (IEA, 2022b). Additionally, the US's innovation system utilizes the roll of small startup firms in developing and diffusing new technologies more than nearly any other national innovation system (Nelson, 1993).

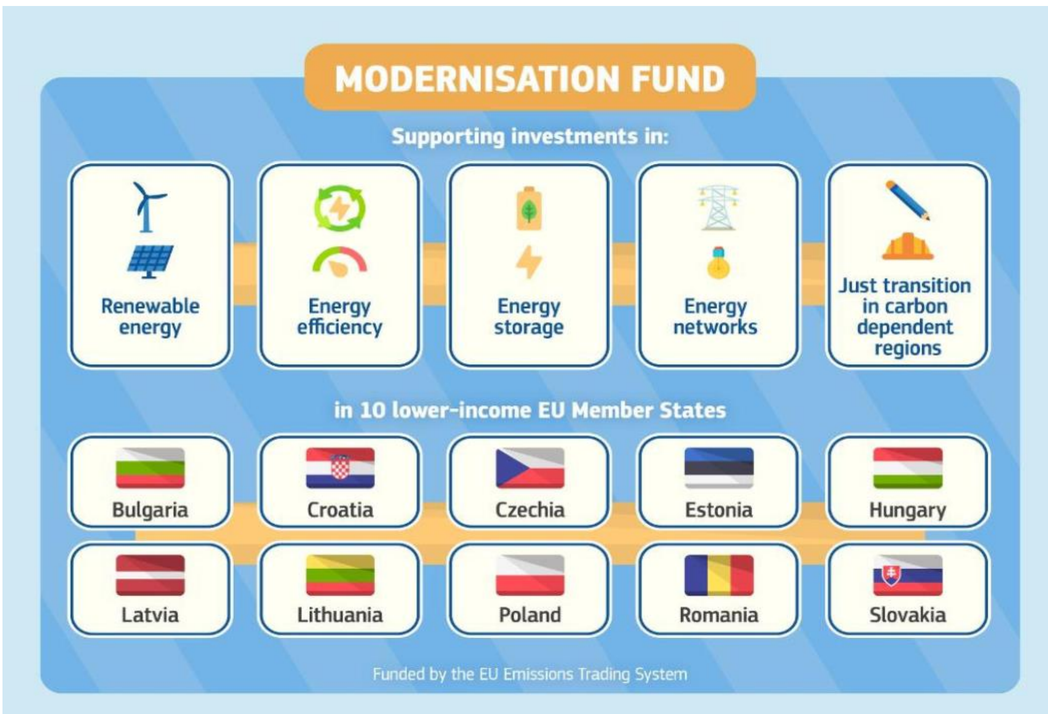
However, the historic origins of the US's innovation system may be hindering its ability to address 21st century problems. The US's R&D programs are highly fragmented with financing and administration falling under both Congress and the executive branch. Such a system has led to a high degree of pluralism in US R&D programs (Nelson, 1993). While such a system can be beneficial with regards to supporting a wide diversity of R&D projects, addressing a broad societal challenge that requires transformative systems change will require a more focused approach (Hekkert et al., 2020). Decarbonization requires not just the rise of renewables but also the fall of fossil fuels. The US spends more on renewable energy R&D than the EU. However, the proportion of the EU's total energy R&D budget going to renewable energy R&D is greater than the US's. Furthermore, in 2020, the US spent five times as much on fossil fuel R&D as the EU (Gallagher & Diaz Anadon, 2022; IEA, 2022b).

Two of the EU's innovation program strengths are its focus and its longevity. Horizon Europe is structured around five missions and will run from 2021 to 2027, creating a guaranteed funding scheme for seven years (European Commission, 2021). The US innovation system lacks that type of institutional structure and predictability. Admittedly, the EU was able to craft such an innovation program by gathering collective support for its missions including addressing climate change. The fact that climate change has been politicized in the US makes it challenging to construct a national innovation mission emphasizing decarbonization especially for a sustained period of time as the political party in power changes. The politicization of climate change is compounded by the outsized roll lobbying plays in American politics. While the renewable energy lobby spent nearly ten times as much on lobbying in the US than in the EU in 2022, this reflects how much more is spent on lobbying in general in the US than in the EU rather than the strength of the renewable energy lobby itself (LobbyFacts.eu, n.d.; OpenSecrets, 2022).

Furthermore, energy lobbying in the US is highly partisan, with only three of the top 20 recipients of oil and gas lobbying belonging to the Democratic Party and only 2 of the top 20 recipients of renewable energy lobbying belonging to the Republican Party (OpenSecrets, 2022). Stokes (2015) argues that the expansion or retraction of renewable energy policies is influenced by the balance of power between supportive and opponent interest groups, thus when renewable energy advocates possess proportionally more power than their opponents, policies favoring renewable energy increase. Exactly what the Republican Party's position on the energy transition during the coming decades will be is still unclear, but the ever-larger renewable energy industry could create new power dynamics in politics and potentially influence the Republican Party position in a way that is more pro-renewable. That said, the comparative lack of politicization of climate change and renewable energy in the EU has likely improved the EU's ability to incentivize renewable energy. Even after the passage of the IRA, subsidies for renewable energy production remain larger in the EU than in the US (Kleimann et al., 2023).

To reach their decarbonization goals, the US government must take a more active role in shaping renewable energy and other low-carbon technology markets. With respect to deployment of renewable energy sources, the EU surpasses the US getting 22 percent of its energy from renewable sources in comparison to the US's 13 percent (European Commission, n.d.; U.S. Energy Information Administration, 2022). This is in part due to the legally binding renewable and decarbonization targets passed at the EU level and in part due to the policies enacted by member states that created niche markets for renewables with generous incentives. Furthermore, in recent years, the EU created support mechanisms, most notably the Modernisation Fund, to ensure that all member states are able to make the energy transition. The Modernisation Fund provides financial support to modernize energy systems in lower-income member states by funding renewable energy, energy storage, and energy efficiency projects (Delreux & Ohler, 2019). Figure 7 below indicates the components of and countries supported by the Modernisation Fund.

Figure 7



Source: European Commission (2022)

The IRA's recent investment in renewable energy and other low carbon technology is likely to dramatically increase deployment, increasing utility scale renewables and storage to provide 40 percent of the US's electricity by 2030 (Hensley, 2022). Yet, it was met with mixed reviews in Europe because of the protectionist nature of some of the provisions. While many European officials recognize that the IRA will make a significant impact on reducing greenhouse gas emissions, some worry that the domestic manufacturing provisions and local-content requirements will reduce European competitiveness and induce protectionism in other countries (Kleimann et al., 2023). It is too soon to say with certainty what the impacts of the IRA will be globally, however, it does point to the growing need for coopetition in clean energy innovation. Meckling et al. call for policymakers to advance global coopetition which is "the managed interplay of cooperation and competition, through both domestic and international measures", to improve energy innovation governance. While competition can help strengthen national energy innovation efforts, protectionism and unfair competition can trigger conflict that undermines cooperation on energy R&D (Meckling et al., 2022).

Policy Recommendations:

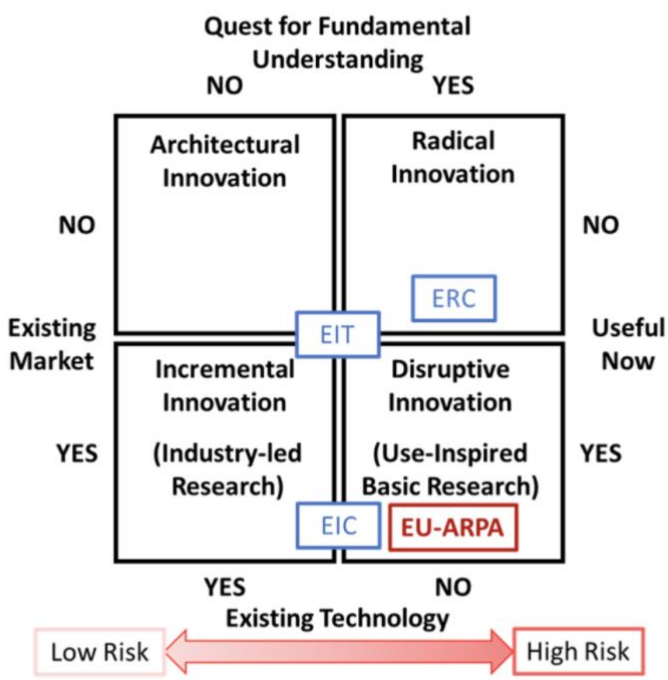
A New ARPA:

There are inherent risks in frontier research with the potential for both scientific breakthroughs leading to transformative innovations as well as failure leading to lost investments. As such, public funding plays an important role in supporting those areas of research deemed too risky by the private sector for major investment. The ERC provides a strong base for supporting frontier research. Its working group on innovation plays an important role in funding the R&D needed for transformative innovations (European Research Council, n.d.-c). However, if the EU wants to support the types of disruptive innovations coming out of the US's ARPA-E program, it will need to direct more funding explicitly to high-risk energy technologies and do a better job linking the institutions that support innovations from the R&D phase to the commercialization phase.

A non-partisan European think-tank suggests that the EU should create an ARPA of its own since the EIC, EIT, and ERC do not stimulate the types of innovations that address an immediate and specific need but require high risk investments, the types of innovations the ARPA model specializes in (see Figure 7 below) (Reimagine Europa, 2021). Yet, it should be noted that a key to the ARPA model's success is that the scope of the research is clearly defined. DARPA and ARPA-E have succeeded in part because they both had well defined missions. There are concerns that ARPA-Health proposed by the Biden Administration or the United Kingdom's recently developed Advanced Research and Invention Agency (ARIA) have too broad of scopes (Tollefson, 2021). Therefore, if the EU is to launch its own ARPA, it should not be an EU-ARPA that broadly aims to support innovation; it should be an EU-ARPA-E that aims to support energy innovation to help the EU meet its ambitious decarbonization goals.

Figure 7

Innovation Quadrant Concerning Markets and Technology



Source: Reimagine Europa (2021)

Concerns have been raised that the EU is not investing enough in energy R&D to reach climate neutrality and that private financing of innovation is insufficient in the EU (Dutton &

Pilsner, 2019; González Fernández et al., 2019). The creation of an EU-ARPA-E could help address both of these concerns. ARPA-E's annual budget of $427 million (€388 million) in 2021 is roughly one-sixth of what the EU spends on the ERC in a year. While this is not insignificant, it is also not so large a figure as to be impossible. Furthermore, the new agency could begin with a smaller budget; for instance, ARPA-E had a budget of $180 million (€163 million) in 2011 (ARPA-E, n.d.). The ARPA model has proven itself to be an efficient allocation of resources for technology development and an effective tool for attracting private-sector investments. As of 2021, ARPA-E had invested $2.8 million in 1,200 projects, but had attracted an additional $5.4 billion in private-sector investments. This has led to the creation of 92 companies, many of which are highly successful. A solar manufacturing company that received $4 million from an ARPA-E grant in 2009 built a $300 million facility to manufacture solar cells in 2021 (Tollefson, 2021).

If launching a new agency is too large a step for the EU to take in the near term, they should at least work to incorporate new ways to incentivize disruptive innovations into their existing institutions. The ERC could create a grant category in partnership with the EIC and EIT that requests proposals for transformative energy innovations. Awardees would then receive support on pathways to commercialization from Programme Managers at the EIC and help finding partners in industry, academia, and research organizations from experts in EIT's InnoEnergy Knowledge and Innovation Community. JRC labs should devote more funding and personnel to exploratory research, setting up labs to research the next generation of renewable energy technologies. The JRC set a goal for itself to have 10 percent of researchers working on exploratory research, well above the current 3.5 percent ("Europe's Joint Research Centre, Although Improving, Must Think Bigger," 2017). The JRC should put more resources into reaching this goal, especially with regards to energy technologies.

A New Institute of Innovation:

Award recipients of the SBIR-STTR programs have generally done a good job supporting the DOE's R&D needs. However, few of these firms have produced products that have made it to the commercialization phase indicating a need for greater commercialization assistance. Moreover, Bin-Nun et al. (2017) suggest that the US's energy innovation system would benefit from greater technology transfer from the R&D being done at DOE National Labs to the private sector, leading to the commercialization of new technologies and subsequent societal benefits. The DOE's Energy Innovation Hubs and R&D Consortia have tried to create networks of actors to improve the US energy innovation system. However, the Energy Innovation Hubs are narrowly focused on five highly specific energy issues and the R&D Consortia specialize in bringing actors together to overcome challenges in the R&D phase rather than the transfer of R&D to the commercial market.

The US would benefit from having its own Institute of Innovation and Technology like the one in the EU which brings together actors from higher education, industry, and research to help with the adoption of new technologies. The EIT has partnerships with companies, including small and medium businesses, cities, NGOs, research centers, and universities and supports innovation by providing education courses to entrepreneurs, providing business creation and acceleration services, and conducting innovation-driven research projects (European Institute of Innovation & Technology, n.d.). The DOE would benefit from having an office that performs a similar function that could help find private partners for public R&D and help provide support and training for current entrepreneurs.

Atkinson (2021) argues that the US would be strengthened by an institutional home for innovation policy that would support firms and other organizations in their innovative activities. Fifty countries around the world have created some sort of national innovation foundation that catalyzes industry-university research partnerships, expands regional innovation efforts, encourages technology adoption, ensures performance and accountability, and provides guidance on innovation policy (Global Trade and Innovation Policy Alliance, 2019). While creating a national innovation foundation with the same budget as the National Science Foundation, as Atkinson advocates for, may not be realistic, creating an office that performs these functions for energy innovations within the DOE could be more feasible. Furthermore, given that the US already houses almost all of its energy innovation functions within the DOE, keeping this additional function located within the DOE may improve coordination with other DOE Offices and initiatives.

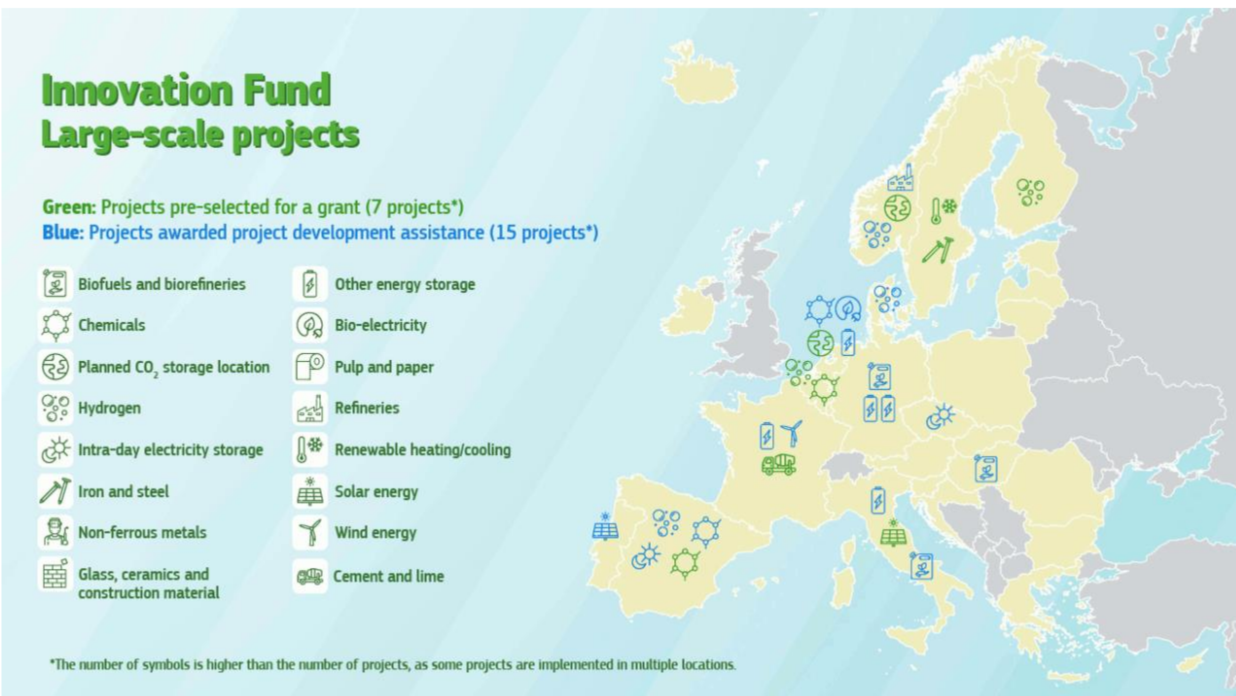
Supporting Multi-Level Governance Functions:

Pires (2022) critiques the EU for overlooking the regional innovation systems of its member states when implementing innovation policies and the US for struggling to connect federal policies to state and local innovation initiatives. Both the US and the EU should do a better job supporting and coordinating with the energy innovation institutions of the states and member states. Despite this commonality, the US's and EU's differing forms of multi-level governance offer insight into how multi-level governance can both help and hinder progress. The EU has at times struggled to get all member states to agree to EU wide policies. During the early years of international climate negotiations, many EU member states did not want the European Commission to have the power to negotiate in international discussions on their behalf, wanting to maintain their autonomy. To get around this obstacle, considerable negotiation went on within the EU to achieve greater unity among EU member states allowing the EU to present as a united force at later international negotiations (Jordan et al., 2012). Additionally, the EU has had to make concessions to ensure the continued compliance of certain member states. For example, the

Modernisation Fund was established in 2018 to get several of the central and eastern European member states to agree to reforms made to the Emissions Trading System that will dramatically shrink the emissions cap during the next decade (Delreux & Ohler, 2019).

Many of the more robust European innovation systems are located in either Western Europe or Scandinavia. Eastern and Southern Europe tend to have fewer institutions focusing on innovation and more small and medium enterprises in traditional sectors (Pires, 2022) Consequently, the competitive innovation funding opportunities often end up going to projects in western and northern European countries. See the map below showing the projects that were granted funding during the Innovation Fund's first call for large-scale projects in 2020.

Figure 8



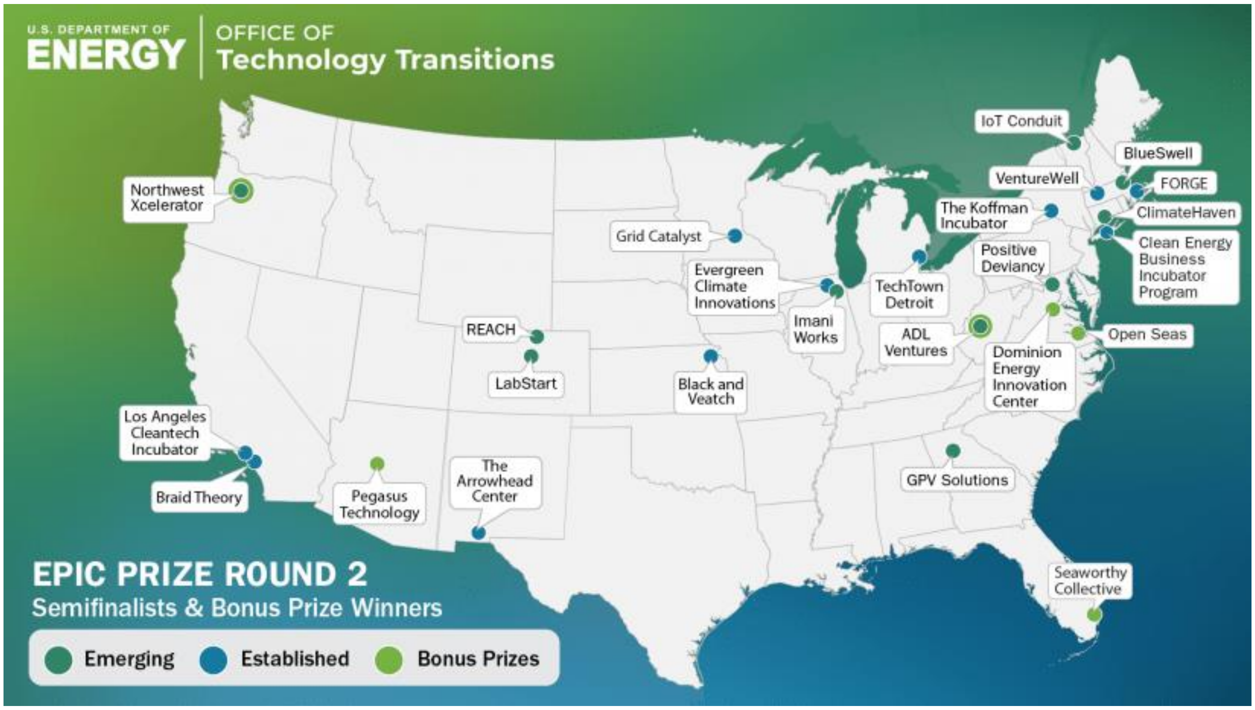
Source: European Commission (2023)

If EU wide funding opportunities are seen as only benefitting certain members, there is a danger that nonbeneficiaries will withdraw their support for such policies. Ideally, the EU should consider the economic structure of each EU member states and provide complementary policies and funding opportunities. Policies that help strengthen the innovation systems of central and eastern European countries, such as providing grants for starting research labs and energy incubators and accelerators, may be one way to ensure all member states continue to comply with the EU's ever more ambitious climate goals.

While the greater autonomy of EU member states can make negotiations challenging, when it comes time for ratification and implementation, it is generally more straightforward in the EU than in the US (Jordan et al., 2012). Having a central figure lead on the climate negotiations and federal climate action has at times prevented progress in the US, such as when the president is out of step with Congress, as was the case with President Clinton and the Kyoto Protocol, or out of step with the populace, as was the case with President Trump and the Paris Agreement. During periods when progress towards decarbonization has stalled at the federal level, states have stepped up and enacted some of the most ambitious climate policies. Due to the impact that changing presidential administrations and congressional makeup can have on innovation funding, it would be wise for Democrats to invest more in region-based energy innovation initiatives when they have the political opportunity to do so.

In 2020, the Office of Technology Transitions at the DOE launched the Energy Program for Innovation Clusters (EPIC) Prize for incubators and accelerators that support regional energy innovation. Incubators and accelerators submitted proposals on how they would assist energy start-ups and entrepreneurs. Twenty applicants were selected based on these proposals and awarded $50,000. In 2022, they conducted a second round of the competition, splitting applicants into two categories: emerging and established, as well as awarding several bonus prizes (American-Made Challenges, n.d.). Below is a map of the Round 2 winners.

Figure 10



Source: American-Made Challenges (n.d.)

The EPIC Prize is a good start to supporting regional energy innovation. Yet, the DOE needs to build off this program to do more to support local incubators and accelerators. The DOE should consider increasing the amount of funding awarded to applicants, increasing the number of applicants that win awards, and creating sustained funding opportunities. Additionally, they should support incubators and accelerators with other resources such as providing training and educational materials to them and hosting conferences to bring the people working in this field together.

Conclusion:

The US is a major contributor to the development of renewable energy innovations. The US outspends the EU on total energy and renewable energy R&D. The US national labs are major sources of energy R&D and have adopted innovative ways to increase commercialization of public R&D. The ARPA model is being emulated around the world as countries try to bring high impact innovations to market quickly. However, the size and strength of the fossil fuel lobby and the politicization of climate change in the US has at times hindered the deployment of renewable energy sources in comparison to the EU. The generous subsidies of EU member states and ambitious EU-wide renewable energy and decarbonization targets have encouraged some of the most rapid deployment of renewable energy sources anywhere in the world. While the EU lacks the financial resources of the US's innovation system, it has created an innovation program centered around the betterment of society and decarbonization. The EU's innovation system is still in its early years; however, its clear focus and mission-oriented structure may result in it having an outsized impact on the development of low-carbon technologies. The EU's history is rooted in building cooperation among its members. The US has often sought to outcompete other nations to maintain its global standing as the largest economy in the world. As countries race to innovate the next generation of low-carbon technologies, both cooperation and competition will be necessary to maintain productive innovation systems.

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