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Perspective

Innovation and legacy in energy knowledge infrastructures

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A B S T R A C T

We focus on how the concept of knowledge infrastructure can help interrogate both the novelties and continuities in energy transitions. In particular, we turn attention to research, innovation, and knowledge production capacities in renewable energy transitions. We outline the subfield of knowledge infrastructures and introduce concepts relevant to energy research. We especially illustrate the ways that knowledge infrastructures may support or adapt to change, and also the ways that they display 'legacy' properties that inhibit, slow or outright prevent transitions. To ground our investigation, we briefly examine research in Scotland's marine energy sector as the nation pursues a transition from an energy sector heavily reliant on oil and gas, to one based on renewable energy innovation and implementation. Via this case, we illustrate that a great deal of the 'old' knowledge infrastructures for energy research, rather than being wholly swept away, instead persist across energy transitions. The concept of knowledge infrastructures provides a powerful addition to energy social science because they are fundamental to our ability to research and develop renewable energy technologies, and so play an important role in defining possible energy futures.

A 'classic' conception of infrastructure is already well-woven into the conceptual fabric of energy transitions thinking, as discussed in Sovacool et al. [1]. In such investigations the term infrastructure usually refers to civic facilities and capital equipment. For example, approaching energy transitions via the concept of classical infrastructure may prod us to ask: What physical and material resources will be needed to generate energy? How will the energy be transported? Will the infrastructures that currently exist, such as powerlines, vehicle charging stations, plugs, and sockets, be appropriate for the energy transitions that we envision? Or, will we need to redesign and adapt our existing infrastructures to meet renewable energy futures? Yet those involved in energy transitions need to understand how to plan for change, not only at the level of physical infrastructure, but also in the knowledge infrastructures that support these changes. Further, for energy transitions to take place, both shifts in societal perspective *and* shifts in scientific objects must occur. Thus, energy transitions necessitate either support from new knowledge infrastructures, the adaptation of old ones, or some combination of both.

Turning to *knowledge* infrastructure provides an additional facet of insight by focusing on the scientific and knowledge creation enterprises of energy research. The seemingly mundane and often backgrounded [2,3] work on long term data-archives and analytics, instrumentation, technical metrics and testing facilities for energy research are all actually important and concentrated sites for the development of novel energy imaginaries, and act as hubs for deploying global metrological networks of energy use and exchange [4]. While such energy research seeks to push the borders of knowledge and technical capacity, it must also contend with century-long sedimentations of established practices, research institutions, and supporting infrastructure. It is these instances of scientific work that a knowledge infrastructures perspective foregrounds, and it is these same instances that can also enable or constrain transition or change.

We therefore turn to the study of knowledge infrastructure to provide an additional way to think about what makes energy transitions possible by drawing our attention to the facilities and resources that support scientific investigation, evaluation and knowledge production. These infrastructures may include physical spaces and places such as laboratories and testing facilities, or they may include more diffuse, long-term data archives or computational facilities for analysis, modelling or prediction [5]. It is only with and through the use of such facilities that the core questions of energy research are formulated, rendered tractable in practice, and then investigated.

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On the one hand, such knowledge infrastructures seek to push the borders of science and technical capacity, i.e., they can be a vehicle for scientific and technological novelty. But knowledge infrastructures, like their classical cousin of roads and bridges, also face many challenges that in studies of infrastructure are called 'legacy problems': e.g., sedimentations of established and routinized practice and technological architectures that are difficult, if not practically impossible, to shift or overturn. In sum, here we inspect how knowledge infrastructures enable innovation and invention, while also simultaneously inspecting how they may disable or constrain energy transitions. For, without understanding the knowledge infrastructures that support transitions to energy futures, we risk missing important ways that our ability to transition to renewable energy itself is either stifled or supported.

In order to ground these concepts, we outline brief examples of ongoing renewable energy transitions in Scotland. There, knowledge infrastructures which once supported major research programs on offshore oil and gas shifted to instead enable research on offshore renewables. This paradigmatic shift in Scotland is ongoing, and so too are our investigations of that site; here we use this case to illustrate a tangible example of knowledge infrastructure concepts applied to energy research.

2. Knowledge infrastructures

Knowledge infrastructures enable knowledge work to occur. They may include people, organizations, or material infrastructures that support gathering, storing, accessing, and sharing information or data [5]. They can also include policies, metrics, or standards that facilitate collaboration, coordination and communication across networks of experts, fields, or sectors [2]. Knowledge infrastructures are "made of" heterogeneous and interdependent components such as individual experts, technologies, and organizations, as well as relational dynamics with funding sources, regulatory agencies, and other regional, national, or global institutions [3,5]. They consist of complex adaptive systems without bounded edges [6]. This means that knowledge infrastructures are practical, situated, and relational, operating differently depending on context, and holding different meanings for different groups of people [5].

In the field of Science and Technology Studies (STS), knowledge infrastructures have become a powerful concept that has shifted the analytical perspective from the direct activities of knowledge production, to the material and organizational elements that support that knowledge production. This nested recursion deserves some additional explanation. From a knowledge infrastructures perspective, the activities and facilities that support energy production, research, and innovation (such as petroleum transport or research and innovation policy for transitions) are themselves the objects of research for a wide variety of interlocking academic, government, and industrial investigators that stretch from basic science and engineering, to economic and management inquiries, and to the social sciences. "Energy" and "energy transitions" are the object of inquiry for many fields, and each of these fields, via their investigations, also draw along with them vast and nested infrastructures of research.

A vivid and relevant example is Paul Edward's investigation of the knowledge infrastructures that support climate science [4]. Edwards shows how, for instance, one of the ways that scientists have sought to understand climate change has been by relying on the data collected for tracking and predicting weather. But weather is not climate, and there is no easy translation (or 'interoperation') between weather and climate data. Weather data is often short-term, small-scale, and not initially globally standardized – weather data look different all around the world. The activities of commensurating all of this heterogenous data, produced by and for various militaries, newscasts and meteorologists, is the topic of Edward's investigation: knowledge infrastructures that scientists had to assemble and integrate in order investigate and make claims about climate change. Edwards traces decades of scientific, cross-national, and interdisciplinary efforts to bring these data together in order to produce authoritative images of a changing climate. All of this data commensuration had to occur in advance of being able to analyze those data, much less make any global scientific claims about climate with those data. More accurately, commensurating the heterogenous sources of data is *part* of the activity of scientific investigation (even if often backgrounded), or what Karasti et al. have called 'infrastructuring' [7], to emphasize the active and dynamic elements of infrastructural activities. Studies based on knowledge infrastructure approaches, thus, take a step back from those practical activities most closely associated with science and research, and attend to those facilities and resources that make such research possible.

Knowledge infrastructures, therefore, support the work that scientists, and other researchers, do. They are formed to make investigations of particular research objects (such as weather) or to address particular problems (such as climate change) possible, but since infrastructures are often long-lived they are also regularly 'repurposed' [8,9] to new investigative ends (as with weather data being used to understand climate). This means that, not only are "new" knowledge infrastructures needed, but "older" knowledge infrastructures are also regularly redeployed for new purposes. We return to this theme in the next section on infrastructural change and legacy.

While many studies of knowledge infrastructure focus on what makes research possible, a significant theme of the field has also been the ways that they can hinder, limit, or outright preclude certain pathways of investigation. Knowledge infrastructures render certain objects of research less tractable than others, and on occasion make certain research practically impossible. For instance, Michele Murphy's study of environmental toxins and Sick Building Syndrome provides an example of this limiting dynamic with her concept "domain of imperceptibility" [10]. Murphy describes the difficulty of measuring and characterizing the novel disease, Sick Building Syndrome. By tracing the long history of toxicity research, Murphy showed how diseases in the early 20^{th}C such as black lung served as benchmarks for toxicity, and so too instruments, data, and policy were all tuned to such benchmarks. But Sick Building Syndrome typically manifests from much smaller toxic exposures; more characteristic of white-collar office work than the black lung of coal mining. An instrumentarium developed for black lung thus made characterizing the novel disease more difficult because the instruments for toxicity were tuned to another, different, phenomena. Murphy calls this a "domain of imperceptibility," a blind spot for scientific instruments which is created at the margins of the very phenomena those instruments were designed to render measurable and manageable. This is an example of how knowledge infrastructures shape the nature of scientific inquiry in important and material ways.

Methods for investigating knowledge infrastructures in STS have tended to be ethnographic or historical-archival, often both. Ethnographies often focus on what are called "the relational and ecological" aspects of infrastructure, highlighting practical local work, distributed coordination, and the different meanings and uses of infrastructures for different people [3]. Paraphrasing Star [3], one person's infrastructure of support is another person's everyday job of maintenance. Another way of methodologically codifying this insight is by employing what is known as "infrastructural inversion," a method that asks the investigator to attend to backgrounded labor or resources (such as maintenance or data integration) rather than the more usually foregrounded outcomes (such as scientific findings or intergovernmental reports) [11]. Many of these tasks are often overlooked as mundane work that is often "invisible," ignored, or unvalued, but are nevertheless essential to a functioning research program. Infrastructural inversion thus refers to a bevy of methods that can serve to excavate and elevate these more mundane practices and their meanings [3]. Another important methodological insight to come from work in STS is that knowledge infrastructures are often most visible when they break down [2]: e.g., a website that returns a 404 error, a toaster than does not toast. Such breakdowns spur a kind of naturally occurring infrastructural inversion, as actors unearth and seek to repair their usually seamless pathways of support.

Other methodological insights to emerge from the field include a sensitization to issues of scale and temporality, both central to the concept of infrastructure. Knowledge infrastructure studies have focused on the development of both long-term and large-scale research endeavors. Ribes, for instance, has called for *scalar devices*, or the techniques and technologies that actors use for "knowing and managing large-scale research enterprises" [12]. These studies have highlighted how the development of standard practices and metadata [7], data interoperability [13], and classification systems [11] are important, practical forms of work that are often taken for granted but are actually complex and consequential, both conceptually and materially. Through these studies and many others, STS scholars have brought attention to the important ways that knowledge infrastructures shape not only the knowledge being produced today, but by "installing a base," these infrastructures can also affect scientific work well into the future [11]. Methods like these could prove useful for energy researchers, whose studies often encompasses large-scale research enterprises and sociotechnical systems that are, or will be, wide-reaching in geographic and temporal scope. This body of work shows that while knowledge infrastructures are but one part of a sociotechnical system, they play a supporting, and thus fundamental, role in their ability to exist as systems.

3. Change to knowledge infrastructures

As much of the world comes face-to-face with the consequences of unbridled use of carbon-intensive energy, energy research is undergoing fundamental and, in some cases rapid, transformation. Energy transitions therefore require both shifts in societal perspective and in scientific objects. Thus, energy transitions necessitate support from new knowledge infrastructures and the adaptation of old ones. As we will briefly illustrate below, some of the knowledge infrastructures for energy transitions are 'old', drawing on the research traditions and machineries that predate interests in energy transitions, such as those developed to investigate fossil fuel use. There are also 'new' infrastructures, developed specifically for novel energy investigations, such as those for ocean energy, that we examine below. But even these novel infrastructures are often highly indebted to those that came before. In studies of infrastructure this phenomena is called 'legacy', 'the installed base', or 'technical debt', each term hinting at how novel infrastructures are built on top of the old [2,13]. Depending on how they were built and sustained, legacy infrastructures make adapting to change easier, harder or practically impossible.

Any knowledge infrastructure will need to change or adapt in order to sustain its utility, but in energy research, transition and change are fundamental features of both the industrial sector and the scientific fields that study and/or support them. These changes can be in response to technoscientific changes (research objects, methods, or instruments); sociotechnical changes (tools or expectations for coordination or collaboration); or institutional changes (funding or regulatory change) [8]. A renewable energy transition would most often mean changes in object of research, for example from petroleum or nuclear-based energy research to renewable energy research. All of these changes are also influenced by ongoing sociotechnical and institutional changes at multiple scales.

Knowledge infrastructures have no doubt changed in dramatic ways over the past thirty years [8]. Examples abound, but obvious things to include in a list of changes would be the introduction of "big data" and computational technologies, virtual collaboration platforms, and participatory or citizen science – none of these are new, per se, but newly inflected. The inertia introduced by these large-scale changes has strained many knowledge infrastructures as people try to adapt them [6]. Often, knowledge infrastructures are, therefore, adapted in a retrospective way, for example when software updates are required, pressing new technology becomes available, or data become unwieldy [5]. Because this can be a cumbersome process, or even ignored, this has consequences for the research that is possible, and can affect larger efforts to adapt or transition to new technologies. This is why infrastructure studies scholars provide an alternative perspective that takes social and technical organizations and systems into account, offering a long-term vision of knowledge infrastructures and change [5,7]. Through this understanding, knowledge infrastructures are not always "just there" and "ready to hand," but, instead, need to be identified and actively understood and engaged with, to ensure that they remain useful through changing research landscapes [5], or in other words, "sociotechnical transitions."

Moving, then, from a focus on *understanding change* in knowledge infrastructures to *organizing for change*, Ribes and Polk [9] ask whether it is "possible to prepare and plan for" such changes. This question is especially pertinent to energy transitions research, a field which is often normatively aimed at facilitating and directing the emergence of renewable technologies. Ribes and Polk investigated the Multicenter AIDS Cohort Study (MACS), a research infrastructure founded in 1984 and continuing to present. Across that time, however, the sciences of HIV/AIDS changed dramatically: for instance, in 1984 the MACS was founded before the discovery of HIV, while today the MACS investigates 'aging with HIV', something wholly impossible to consider in 1984. And yet, despite these dramatic changes in the objects of investigation and knowledge of HIV, Ribes and Polk [9] found that, in many senses, the MACS remained "the same" across decades: continuing to collect the same data and specimens as they had been collecting at their founding. They point to what they call the "kernel of research infrastructure" that consists of a stable set of resources for scientists that could be deployed anew in their novel investigations. Researchers "repurposed," "elaborated," and "extended" the kernel through adapting their work, technologies, and the techniques used to deal with the changes in research object. Data that were once collected to find the cause of AIDS (e.g., drug use, smoking or sexual behaviors) were repurposed decades later to investigate aging with HIV. They call this form of resilience a "bounded technoscientific flexibility" which involves organizing for anticipated changes and responding to unanticipated changes in research objects and methods [9].

Studies that have looked at other fields such as computational science [14], ecology [15], environmental monitoring in oil and gas [16,17], and ecological restoration [18] have also found that researchers draw on different resources to adapt their knowledge infrastructures as their scientific tools, objects of research, and physical environments change. Researchers have thus developed concepts such as "infrastructure time" that highlight an orientation to continual design of infrastructure to support long-term research [7]. Similarly, Ribes and Finholt [19] studied a long-term environmental science cyberinfrastructure project, finding that participants in the project were often caught in a tension between designing for the future, or "long now" and maintaining present work. The tensions that the participants articulated often spanned multiple "scales of infrastructure," complicating their ability to address long-term design factors [19]. All of these examples point to the dynamic nature of knowledge infrastructures and the many ways that their stability, or their flexibility, become integral to the functioning of a scientific enterprise.

These findings also provide insights about the adaptation of knowledge infrastructures that may have implications for energy research, especially research on energy transitions and research and innovation policy to support these transitions. Planning for change in knowledge infrastructures surfaces the politics of design and standards in policy found in energy research [20]. There is a tension found in knowledge infrastructures between the need to be flexible but also stable: a tension between "the desire for universality and the need for change" [6]. This tension also echoes a commonly cited dynamic in energy transitions: the relationship between lock-in and stasis in sociotechnical systems [21]. This inertia and strain is felt when knowledge infrastructures no longer support the research paradigms necessary for change. Yet, while this strain can prevent change, knowledge infrastructures can also be incredibly adaptive, drawing on the kernel of research infrastructure, or other legacies to support changes in research objects and sociotechnical paradigms. We briefly turn to the example of Scotland's energy transition to explore this dynamism.

4. A brief example from Scotland

Drawing on the concepts explored earlier, we can ask, for example, how does a knowledge infrastructure remain useful through change by repurposing, elaborating, or extending the kernel of research? We can also ask how a legacy knowledge infrastructure might stifle transition and change. These questions hold practical importance for the field of energy research, which is often focused on, not only understanding transitions, but also facilitating and supporting them—not only understanding change, but reorganizing for it. Understanding the relationships between novelty, change, and persistence in knowledge infrastructures—in other words, their legacy—is therefore an important place to start in using the conceptual tools of knowledge infrastructures to understand energy research.

These relationships can all be seen in the example of Scotland, where a shift in research focus has followed a concerted effort by the Scottish Government to organize for change as they have sought to transition their energy production and supply from oil and gas to renewables [22]. This has been a long-term transition spanning from the first oil and gas finds in the North Sea in 1969 through to the creation of the Scottish Parliament in 1999, through to subsequent Scottish Energy Strategies that have all called for increasing reliance on onshore and offshore wind, solar, and marine renewable technologies in order to phase out reliance on oil, gas, coal, and nuclear power [22,23]. In 2008, the Scottish Government's energy policy stated: "Scotland is rich in energy resources and we must be ambitious in their exploitation. We are planning now for the huge export potential of renewable energy and clean energy technology" [24]. This shift to renewable energy is a purposeful effort by the Scottish Government, and it is supported, in part, by publicly-funded research facilities and programs as well as supportive innovation policy aimed at innovating breakthrough technologies, particularly in wave and tidal energy [22]. Yet the transition of Scotland's energy production from oil and gas to renewables is not only an infrastructural, political, and institutional one—it is also founded on the idea that Scotland will become a producer of renewable energy technology and renewable energy *knowledge*. This means that the shift in research object (from oil and gas to renewables) necessitates a transition in knowledge infrastructure.

Over the past twenty years, the Scottish Government have succeeded in re-framing their nation's role as a leader in renewable energy research and development, especially in the field of marine energy. While such energy research seeks to push the borders of knowledge and technical capacity in energy engineering, researchers in this field must also contend with century-long sedimentations of established practices and sedimented knowledge infrastructure that has long focused on science to support oil and gas. Since the first offshore oil developments in the late 1960′s, Scotland has been known for its cutting-edge offshore oil and gas expertise and technology. Networks of expertise on the topic span the globe, with strong connections between Aberdeen, "the oil capital" of Europe, to Norway, Saudi Arabia, and Texas [25]. The knowledge infrastructures in Scotland, including training and testing centers to support offshore oil and gas research and development, are complemented by physical infrastructures of pipes and ships to export the North Sea hydrocarbons across the globe. The infrastructure that Scotland built to support its global position as a forerunner of offshore oil and gas research and development has helped sediment its reputation as a place for energy innovation [26]. Even if these pipes are no longer carrying hydrocarbons, the locations of innovation are still buoyed by a repurposed knowledge infrastructure.

We might assume that such long standing research infrastructures, finely tuned to offshore oil and gas energy production, would be so 'locked in' [21] so as to wholly hinder energy transitions research. Yet we find a more complex, nested outcome with 'old' infrastructures in some ways greatly facilitating transition research and in others slowing or even wholly preventing such research. Drawing on work on knowledge infrastructures in STS [9], we can see a reliance on previous resources in the knowledge infrastructure, while at the same time adapting them to the new research object – renewable energy – and simultaneously dealing with the resistance from an earlier knowledge infrastructure that was developed to support cutting-edge research in oil and gas.

Some parts of the knowledge infrastructure were "repurposed," for the study of new objects. For example, research networks, university programs, conferences, journals, and R&D programs that were created to support technology development for offshore oil and gas, such as the Oil and Gas Technology Centre in Aberdeen are now being used to investigate and test marine energy devices. Or, SubseaUK, whose annual expo now envisions the future as "blue and green," referring to ocean renewables. All of these knowledge infrastructures have been repurposed from supporting research and development for offshore oil and gas to support the broader category of "offshore energy." Oil and gas can of course be mined 'offshore', the initial driver for extending the focus of the oil and gas center, but thereafter this also provided an opening for considering 'offshore' wind and marine energy production under the same research header and organizational units. The field was thus extended from the more specific "oil and gas" to the more general, "offshore," and was conceptually broadened to include both offshore wind and marine energy. Along with this conceptual shift, the knowledge infrastructures to support this shift in research and development were also changed. Networks of experts developed new collaborations to address offshore renewable energy technology, data, and instrumentation needs for moorings, grid connectors, and environmental monitoring. Science and engineering programs in offshore oil and gas that were considered world-class were thus re-aligned, for example, through the Energy Technology Partnership (ETP), with a new research object: marine energy. As stated in a 2008 report by the Scottish Government, these developments "draw[s] on technology and skills from the oil and gas industry: this wider infrastructure which gives Scotland a competitive advantage in driving forward projects," this time, in renewables [27].

Less conceptually and more materially, the physical infrastructures and instruments used by offshore oil and gas, such as subsea robotics, oceanographic monitoring systems, and cabling technologies, have been repurposed for wave and tidal energy research. This shift has extended to their research infrastructures, including the formation of new research institutes to study the environmental effects of renewable technologies, employing and training experts across these fields. There has been especially intense development in marine energy testing sites [28], most of this in port locations that once supported the offshore oil industry, but also at universities such as those in Aberdeen, which were once viewed as central to knowledge production for offshore oil and gas development. Today these same universities are recognized for their expertise in offshore energy, but now in the growing wind energy sector.

Knowledge infrastructrures were not only "repurposed," but other dynamics were also in play. Simultaneously, some parts of the offshore oil and gas knowledge infrastructures were "elaborated" as new categories of subsea research, ocean sensing, and environmental monitoring data that were relevant to tidal and wave energy were added to knowledge infrastructures used for renewable ocean energy. We can also find an "extension" of the earlier research infrastructure, whereby new resources such as the development of a world-class multi-scale indoor and open-watertesting infrastructure that could be used for offshore oil platforms *and* offshore renewable devices.

The shift from oil and gas to renewables could easily be seen as a 'classic' infrastructural one: pipelines and ships used for offshore oil and gas are also useful to wave and tidal energy developers. These infrastructures are no doubt important in any energy system. But if knowledge infrastructures are not in view, some foundational dynamics that support this energy transition could easily be overlooked. To produce renewable (in this case, offshore marine and wind) energy, knowledge about and for renewable energy must also be supported. These shifts must occur, including conceptual understandings of the research object (in this case, 'the offshore'). But these shifts also occur through material extension of the monitoring instruments and the data they produce, once intended to study oil and gas production, and the creation of an infrastructure that supports research and innovation about renewable marine energy [29]. This is especially clear in this brief example of marine energy in Scotland, partly because the shift has been so targeted and so drastic [22,30]. Yet changes to knowledge infrastructures like these are ongoing across different energy contexts and sectors as transitions take hold. This is just a brief example of the many ways that an 'old' knowledge infrastructure can change to accommodate new interests, rather than necessarily being swept away to be replaced by wholly new knowledge infrastructures.

5. Conclusion

We began by asking what research on knowledge infrastructures could add to the study of energy and energy transitions, and we have provided some glimpses of what might be possible with further research in this area. Exploring knowledge infrastructures in energy provides an additional lens through which to view transition and change by focusing on the scientific and knowledge creation enterprises that support energy research. Because they take networks of people, their behaviors, organizations, standards, data, artifacts, and instruments into account, knowledge infrastructures link macro, *meso*, and micro scales [4], aligning well with the multi-level perspectives dynamics [31] in energy transitions literature. The conceptual and material work done by knowledge infrastructures has implications for understanding how the "sociotechnical" operates on multiple scales of energy transitions, both spatially and temporally, because they explicitly take the long-term into account. Because knowledge infrastructures "embed social norms, relationships, and ways of thinking, acting, and working," when they change, "authority, influence, and power are redistributed" [3]. This means that they are important to consider when both researching and promoting energy transitions, as they drive and influence them in important ways, holding potential to both stifle and foster change.

But it is not only knowledge at stake here, it is the transition itself. In other words, understanding what supports or disables energy research, in the form of knowledge infrastructures, informs our understanding of what enables or hinders energy transitions more broadly, and our ability to take action to facilitate energy transitions. Knowledge infrastructures are necessary because they enable the research and development of renewable energy technologies, giving some energy futures traction, and making others less possible. To take this all a step further, might we be able to resist some forms of lock-in by looking at the sociotechnical through this lens? As infrastructures are built, "social, ethical and political values" are also being built into them, and they can become self-perpetuating [5]. Infrastructures can help "design communities, technologies and knowledge" [5]. Most importantly, infrastructures make some objects visible, while others are backgrounded, or even "imperceptible" [10]. This is important when thinking in terms of renewable energy futures. The knowledge work that is necessary for energy transitions to occur will need to shift along with the sources of energy that are being utilized, and knowledge infrastructures will be needed to support this work. This is not a techno-optimism along the lines of "if you build it, they will come," for as a historical perspective on infrastructure has shown time and again, utopian infrastructures often become ghost infrastructures [14]. As we seek to transition, it will be important to foster changes in the culture and organizations of energy, but so too in how we do research about energy; here we have emphasized the supporting structures that make research possible with the hope that researchers, policy actors and practitioners will take knowledge infrastructures into account. Knowledge infrastructures that can be both long-term and adaptive will be necessary to support these shifts. We hope that more studies will endeavor to understand how knowledge infrastructures change and adapt, how they interact with energy transitions, and how they may support them in the long-term. In order for transitions in energy to occur, so too will knowledge infrastructures have to change. A knowledge infrastructures perspective highlights how experts, organizations, and technologies have both sedimented and adaptive qualities that affect the ability of the energy sector to transition. The visible consequences of transition and change that come into view by looking at knowledge infrastructures provide a powerful addition to energy social science.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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