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Review

Rethinking energy innovation and social science

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ABSTRACT

Managing climate change will require massive innovation in the technological infrastructure for producing and using energy. Private market forces have driven the innovations that led to similar transitions in the past. However, because the value of mitigating the climate change is a public good, unaided private markets are not likely to produce the innovations needed to respond to a climate-driven transition. As a result, social sciences should play an important role in stimulating change in two ways. One is to influence consumer choice by other than price signals. The limited deployment of economically attractive energy efficiency technologies is an example of this need. The second role for social sciences is to ensure that governance institutions and polices provide a durable but adaptable framework for driving innovation during the long process of changing the energy system. Strategies for social sciences to engage with policy makers in these two areas are suggested.

Managing climate change will require massive innovation in many of the planet's major energy systems, and ours is no exception. And the reason is perfectly straightforward. The existing system relies heavily on fossil fuels that produce carbon dioxide emissions as they are burned to produce energy. To manage climate change, those emissions must drop nearly to zero over the next four or five decades. For that to happen, the energy system must adopt new technologies that either do not use fossil fuels or that continue to rely on fossil fuels but capture and sequester the resulting carbon dioxide emissions.

The energy system infrastructure is massive, so changing it in such a fundamental way is a formidable challenge. Yet it is a challenge that has been met several times over the past couple of centuries [1]. At roughly sixty-year intervals, the system's dominant fuel has evolved from wood to coal to oil and gas – plus a bit of enriched uranium. Technological innovation enabled this evolution. Thus, the steam engine, the internal combustion engine, and the ability to generate and distribute electricity made these successive fuel transitions possible.

Looking forward, however, the question is whether the energy system can transition more or less on automatic pilot as it has in the past. We think not. And importantly for the inaugural edition of this journal, we believe that one crucial difference in the coming transition will be the need to employ the tools of social science in ways that were unnecessary in the past. We see two principal challenges that stand in the way of meeting this need. First, the coming transition will need more than market forces to encourage individuals and organizations to adopt and use the new technology that must be deployed. Understanding and influencing choice is a topic about which several social science disciplines know quite a lot. Unfortunately, however, it is a topic long ignored by traditional energy policy-makers and so linking these policy-makers with the appropriate social sciences is a considerable challenge.

Second, we believe that existing governance institutions and policy frameworks will have to adapt to the unique characteristics of climate-induced technological innovation. While senior policy-makers recognize this problem in a general way, the specific nature of this adaptation is not well understood. The social sciences that study such institutions and frameworks will need to tackle the governance problem in a comprehensive way.

A final word of introduction. Our point of view in this essay is that of a policy maker looking to manage a complex transition, not as a practicing social scientist working within a disciplinary framework. Accordingly, when we argue that social sciences have a major role to play in the coming energy transition, we mean to include any of the social sciences that turn out to be useful in solving the policy problems attendant on the energy transition. In general, of course, disciplines that study choice – psychology, sociology, behavioral and decision sciences, and economics, for example – will likely be prominent in encouraging the adoption and use of new technology. And political sciences, law, and policy studies will be crucial in studying governance issues. But to limit the role of social science

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in the coming energy transition to a few familiar compartments would be a mistake. Rather, we think it likely that the needs of the coming transition will encourage new thinking within disciplinary lines, as well as the crossing of those lines in the service of policy needs.

Within this context, then, the purpose of this article is thus to invite attention of energy policy-makers to this role of the social sciences and to sketch some of the social science research opportunities that lie ahead. We begin with outlining briefly the basis for our conclusion about the nature of the coming transition, and then turn to some of the issues of individual behavior and governance structures that we believe the social sciences must address.

The main driver of past energy system transitions has been the creation of consumer value that the market could easily capture [2]. Thus, the steam engine and coal made possible the industrial revolution and opened up the water and rail transportation networks. The internal combustion engine and liquid fuel created unprecedented individual mobility. Distributed electricity meant light, comfort, and convenience for homes and workplaces at the flick of a switch, and also contributed importantly to increasing economic efficiency. Because individual and institutional consumers prized these values, they willingly paid to adopt the new technology of a changing energy system.

Moreover, in the words of Robert Heilbroner, pursuit of these values created a market-driven "force field" that fostered the sustained innovation required to change the energy system over several decades [3]. This force field is essential to the innovation process because innovation is not the result of a few dramatic inventions but rather is an incremental, cumulative, and integrative process that unfolds over time. Research shows that innovators typically draw on ideas from a variety of sources to make small advances that can add up to a major technological change. Automobiles are a good example. There is a vast difference between the gas guzzlers of the late 1960s to the sophisticated hybrid vehicles of today. This progress is the product of adapting for the automobile advances in fields as different as catalytic chemistry, materials, and digital controls. But those changes came to market one model year at a time. In short, the process of technological change was incremental, integrative, and cumulative.

As this modern view of its workings has developed, the energy innovation process has come to be understood as a complex and recursive one. The President's Council of Advisors on Science and Technology (PCAST) has adopted a useful and accurate description of this messy process as being defined by four major elements [4].

- Invention: Discovery, creation of knowledge, generation of prototypes
- Translation: Creation of a commercial product or process
- Adoption: Deployment and initial use of a new technology
- Diffusion: Increasing adoption and use of a technology

It is important to understand that movement through these stages of innovation is not linear. Rather, because the process is incremental and cumulative, it requires complex feedback loops to solve problems as they occur and to integrate new ideas as they emerge.

This review of the history of energy transitions and of the latest understanding of the innovation process, while brief, is enough to explain why we conclude that a climate-induced change in the energy system is unlikely to unfold as in the past. The problem lies in the fact that the value of mitigating climate change is a public good, not one that markets can easily capture. Furthermore, the incidence of costs and benefits of mitigation are widely separated. For example, limiting carbon dioxide emissions imposes costs now on the current generation of emitters in order to produce benefits that may be realized by future generations.

These characteristics of the climate problem inhibit a new energy transition in two ways. First, consumers would have pay for change that does not produce a new energy service of value to them. They don't care how electricity is produced somewhere in the world in the future, only that the lights at home come on now. Second, the economic force field needed to sustain widespread innovation would be weak at best in the absence of a strong and persistent value driver. Thus, both the first part of the innovation process (invention and translation) and the latter part (adoption and diffusion) are likely to encounter significant obstacles.

A key issue for climate policy, then, is how to drive the innovation process in the presence of these obstacles. The most common answer comes from economics – put a price on carbon – and there is much to be said for that policy. But we believe that there is more to it than that – that more profound changes in individual decision making and institutional behavior are needed. That is where additional social sciences come in, and it is to these possibilities that we now turn.

The energy efficiency paradox is the classic example of the importance of individual decision making. With an accelerated effort to employ a variety of efficiency technologies in the buildings, transportation, and industrial sectors, the United States by 2030 could reduce its energy use by 30 percent while saving money. This reduction would lower total U.S. energy use below the 1990 level. In buildings alone, existing cost-effective technologies could eliminate the need to increase electric generating capacity in the next 15 years even with economic and population growth [5].

Most of these efficiency technologies are available today and deliver the same services as their less efficient counterparts, and many have already been demonstrated in other developed countries and some U.S. states. So the efficiency paradox is that these cost-effective technologies aren't being adopted. In general, the reason for this dilemma is well-known. Because the aggregated action of individuals and organizations determine many aspects of how energy is used, adoption and deployment of new energy efficiency technology is affected as much by individual choice, preference, and behavior as by technical performance.

The barriers created by individual choice abound. Some arise because of a mismatch in economic incentives. For example, there is often a disconnect between the person who invests in the technology and the one who benefits from it. Builders and landlords decide on energy efficiency investments but do not realize the savings since they do not pay energy bills. Even when an investor pays for the electricity, an energy efficiency investment might become worthless with volatile fuel prices. Risk-averse investors prefer to pay a higher price for energy than commit to large efficiency investments.

Non-economic incentives are also important, but not always well understood. For example, there has been some recent research to determine if and how monitoring and reporting of building energy use could induce occupants to conserve energy long enough to have lasting impact. One of the largest efforts is that of a program managed by a company called Opower. They deploy software technology at scale to utility companies. The goal of the product, a paper home energy report that offers insights to consumers on their home energy consumption, is to help the utilities lower energy usage. A key aspect of the program, devised through social science research, showcases how a consumer's usage compares to their neighbors. Also, the reports are distributed on an opt-out versus opt-in basis. The program has shown to lower home energy usage by 1.5–3%, a decrease which persists for multiple years [6]. But persistence seems to be important in achieving this result. Another study, which provided feedback to a much smaller group, found