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The emerging field of energy transitions: Progress, challenges, and opportunities

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ABSTRACT

Energy transitions are an unmistakable part of today's public discourse. Whether shaped by fuel price fluctuation, environmental and security concerns, aspects of technology change, or goals to improve energy access, attention regularly turns to ways in which to improve energy pathways. Yet what is understood about energy system change is still emerging. This article explores the evolving field of energy transitions with an aim to connect and enlarge the scholarship. Definitions and examples of energy transitions are discussed, together with core ideas on trade-offs, urgency, and innovation. Global developments in energy and related mega-trends are then reviewed to highlight areas of analytical significance. Key information sources and suppliers are examined next. The article concludes with ideas about opportunities for further research.

1. Introduction

Changing the way we utilize energy is a recurring theme in today's public discussions. One need only look to policies that prioritize greener economies, evolutions in unconventional oil and gas, or post-Fukushima adjustments in nuclear energy utilization to see elements of change underway.

Despite frequent focus, no universally accepted definition of 'energy transition' exists. A review of energy transition writing shows that varied meanings have been in use since the early 1900s for topics, including quantum electrodynamics and industrial adaptation (Fig. 1).

Writing on the subject in the 1930s, for instance, considered change in energy states that occurs with molecular dissociation [2]. Coverage in the 1970s centered on fuel substitution and resource limitations [3]. More recent writing highlights ways to transform economies in order to reduce carbon emissions [4]. The contemporary focus also emphasizes how developments in technology, information and practices can alter the way that energy is utilized [5]. To bridge these nuances in meaning, a more cross-cutting definition is used here – namely, a shift in the nature or pattern of how energy is utilized within a system.[2] This definition recognizes the change associated with fuel type, access, sourcing, delivery, reliability, or end use as well as with the overall orientation of the system. Change can occur at any level – from local systems to the global one – and is relevant for societal practices and preferences, infrastructure, as well as oversight [6].

Prominent examples of energy transitions are evident today. Change in the Danish energy system, for instance, reflects a rise in the overall annual share of wind power in the electricity mix from under 1% in 1980 to 33% in 2013 [7]. Similar growth occurred in the Danes' use of combined heat and power (CHP or cogeneration), rising from 18% to 75% in total thermal production between 1980 and 2012, and from 39% to 73% in district heating [8]. These changes have enabled the Danish energy system to become increasingly

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[2] An energy system is a constellation of energy inputs and outputs, involving suppliers, distributors, and end users along with institutions of regulation, conversion and trade. Energy system change and energy transitions or shifts are used interchangeably in this article.

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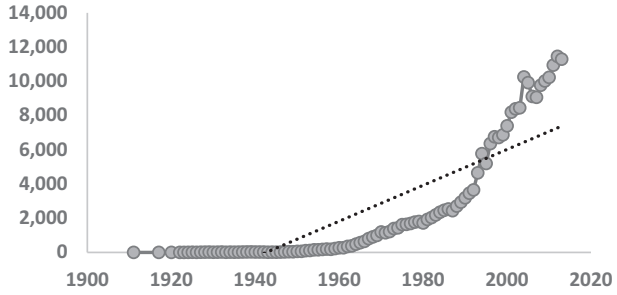

Fig. 1. Publications covering 'energy transitions'.
Source: Based on 'energy transition' in titles, abstracts, or keywords of scholarly publications [1] A more, narrow search of the social sciences and humanities revealed a similar, albeit smaller-scaled, trend. The search could also be varied for related terms like 'energy system change', 'energy transformations', etc.

decentralized and efficient[3] [9]. Somewhat different in nature is Germany's nuclear phase-out, following the Fukushima Daichi accident in 2011. This shift entailed the shutdown of 8 out of 17 nuclear reactors, with the remaining nuclear fleet scheduled for closure by 2022 [10]. If the German power supply is considered between 2010 and 2012, the total decreased by 3% [11] as its share from renewable energy rose from 10% to 12% [12].[4] Contrary to some expectations, Germany's net exports in electricity also grew by 5586 GWh in the period between 2010 and 2012 [11,13].[5] Yet another example of an energy transition can be seen with what is occurring in the United States. In this instance, the application of hydraulic fracturing and horizontal drilling technology to unconventional gas and oil in recent years has contributed to a notable rise in output. Between 2002 and 2012, natural gas and oil production grew by 27% and 13%, respectively [14]. In line with these changes, the United States has reduced its oil imports by 30% and is on the cusp of becoming a net exporter of natural gas [15].

While the above examples offer interesting views of contemporary energy system change, they do not entirely explain how the shifts are accomplished or what implications the transition may have. That is where social science plays an instrumental role. The launch of the Energy Research & Social Science journal provides a forum to more fully explore such areas.

In this article, I draw upon previous analyses of energy systems and technology change [16,17], surveys of data and literature, as well as discussions with energy researchers,[6] to explore elements in the emergent field of energy transitions. The resultant overview identifies a number of areas where researchers, particularly those in the social sciences and humanities, might strengthen the scholarship. Other articles in this special issue consider related themes, including Sovacool's content analysis of energy publications and proposed research agenda [18]; Brown and Pasqualetti's discussion of geographic contributions to energy-society studies [19]; Fri and Savitz's writing on ways that the social sciences can support the management of an energy transition [20]; and Jones and Hirsh's exploration of how history enhances energy research and policy [21], among others.

With this context in mind, I begin by examining some prevailing ideas relating to energy system change. I then evaluate key patterns of analytical significance in energy transitions and related megatrends. This is followed, next, by a discussion of key resources, actors and theory. I conclude with some ideas about opportunities for further research.

2. Ideas about energy transitions

To understand the nature of energy transitions studies, it's useful to first identify prominent ideas in the energy and policy communities.

2.1. Urgency

In today's discussions, an often-articulated perspective emphasizes how current conditions (unlike those in previous periods) present an imperative to alter society's energy utilization [20,22–24]. This view is shaped by pressures relating to sustainability, access, security and/or reliability of energy. It's worth noting that pressures to alter energy pathways have existed in the past, particularly during periods of war and global oil shocks. Societal responses to the oil shocks of the 1970s and early 1980s, for example, included country-level initiatives that strengthened domestic energy self-sufficiency through conservation, efficiency and/or scaling of domestic sourcing and industries [16,17,25]. What differs today is arguably a heightened awareness relating to the scope of energy challenges, their cross-border impacts, and efforts (depending on the challenge) that may be needed. It is, here, where social science has potentially its most significant role. Natural science and technological solutions can be brilliant, and yet remain untapped within a lab or field project. Understanding how knowledge, perceptions and practices are shaped and influence; what finance and markets can and cannot do; and how a society's 'social contract' enables or detracts from problem-solving are areas where scholarship can contributen.

2.2. Tradeoffs

The International Energy Agency estimates that roughly $38 trillion is needed in global investment to meet energy demand by 2035 [26]. Questions naturally arise about who pays (i.e. consumers, tax payers, industry, etc.), who decides, and how this is settled. One can also ask whether strategic interests such as jobs, science and technology leadership, relevant timelines, flexible response, and responsible stewardship are prioritized. Similarly, what is required for underlying infrastructure (i.e. land use and siting, displacement, and acceptance)? Are short-term objectives guiding choices and/or are longer-term aspects also seriously weighed? If more significantly altered pathways are considered, such questions are amplified by institutional considerations of how to navigate new directions. Whichever path is taken, costs entail more than finance. There are political, environmental, security and other societal effects that are not monetized. Understanding the tradeoffs and how to effectively address them is a fundamental concern for decision-makers, and a pivotal area for scholarly investigation.

2.3. Innovation

Game-changing breakthroughs in how energy is sourced, delivered and utilized – such as what historically occurred with the combustion engine or controlled nuclear fission – are often pointed to as being critical for a new energy transition. In this line of thinking, there is no shortage of writing on the concept of accelerating innovation [27,28]. However, care is needed in how innovation

[3] Danish CHP plants can scale heat or power output, based on demand. Since they also have heat storage, surpluses can be set aside for later use. Note: The shift in self-sufficiency and clean energy is another area of significance in energy transitions research.
[4] The domestic power supply (production with net imports) declined 3% from 613,941 GWh to 597,059 GWh [11]. The trend toward renewables continued in 2013 to 11.8% [12].
[5] Imports grew by 3307 GWh, while exports increased by 8893 GWh. [11]
[6] This essay is not intended to be a comprehensive review.

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