



Original research article

How long will it take? Conceptualizing the temporal dynamics of energy transitions[☆]Benjamin K. Sovacool^{a,b,*}^a Department of Business and Technology, Aarhus University, Birk Centerpark 15, DK-7400 Herning, Denmark^b Science Policy Research Unit (SPRU), School of Business, Management, and Economics, University of Sussex, United Kingdom

ARTICLE INFO

Article history:

Received 11 March 2015

Received in revised form 19 October 2015

Accepted 9 December 2015

Available online 19 January 2016

Keywords:

Time

Speed

Energy transition

Socio-technical transition

ABSTRACT

Transitioning away from our current global energy system is of paramount importance. The speed at which a transition can take place—its timing, or temporal dynamics—is a critical element of consideration. This study therefore investigates the issue of time in global and national energy transitions by asking: What does the mainstream academic literature suggest about the time scale of energy transitions? Additionally, what does some of the more recent empirical data related to transitions say, or challenge, about conventional views? In answering these questions, the article presents a “mainstream” view of energy transitions as long, protracted affairs, often taking decades to centuries to occur. However, the article then offers some empirical evidence that the predominant view of timing may not always be supported by the evidence. With this in mind, the final part of the article argues for more transparent conceptions and definitions of energy transitions, and it asks for analysis that recognizes the causal complexity underlying them.

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1. Introduction

Transitioning away from our current global energy system is of paramount importance [1]. As Grubler compellingly writes, “the need for the ‘next’ energy transition is widely apparent as current energy systems are simply unsustainable on all accounts of social, economic, and environmental criteria [2]”. And as Miller et al. add, “the future of energy systems is one of the central policy challenges facing industrial countries [3]”. Unfortunately, however, neither private markets nor government agencies seem likely to spur a transition on their own [4]. Moreover, transitions to newer, cleaner energy systems such as sources of renewable electricity [5,6] or electric vehicles [7,8] often require significant shifts not only in technology, but in political regulations, tariffs and pricing regimes, and the behavior of users and adopters.

The speed at which a transition can take place—its timing, or temporal dynamics—is a vital element of consideration. According to the International Energy Agency, for example, if “action to reduce CO₂ emissions is not taken before 2017, all the allowable CO₂ emis-

sions would be locked-in by energy infrastructure existing at that time [9]”. In other words, if a transition does not occur quickly, or soon, it may be too late. Giddens went so far as to call this the “climate paradox”, the fact that by the time humanity may come to fully realize how much they need to shift to low-carbon forms of energy, they will have already passed the point of no return [10].

This study, therefore, investigates the critical issue of time in global and national energy transitions. Although other elements of transitions such as their scale, magnitude, direction, drivers, actors, and mechanisms are touched upon when exploring this theme, the article’s central purpose is to ask: What does the mainstream academic literature suggest about the time scale of energy transitions? In addition, what does some of the more recent empirical data related to transitions say, or challenge, about the mainstream view?

In answering these questions, the article proceeds as follows. It begins by presenting a mainstream view of energy transitions as long, protracted affairs, often taking decades to centuries to occur. Part of this argument draws from the history of previous major energy transitions such as the switch from wood to coal or coal to oil. Part of this argument also draws on the sheer scale and complexity involved in major transitions, as well as the tendency for new systems to face the “lock-in” or “path dependency” of existing systems. However, the article then offers some empirical evidence that the predominant view of timing may not always be supported by the evidence. The second half of the paper shows that there have

[☆] The author of this paper is an editor for Energy Research & Social Science. They were not involved in managing the peer review process for this article.

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Table 1
Five definitions of energy transitions.

Definition	Source
A change in fuels (e.g., from wood to coal or coal to oil) and their associated technologies (e.g., from steam engines to internal combustion engines)	Hirsh and Jones [22]
Shifts in the fuel source for energy production and the technologies used to exploit that fuel	Miller et al. [23]
A particularly significant set of changes to the patterns of energy use in a society, potentially affecting resources, carriers, converters, and services	O'Connor [24]
The switch from an economic system dependent on one or a series of energy sources and technologies to another	Fouquet and Pearson [25]
The time that elapses between the introduction of a new primary energy source, or prime mover, and its rise to claiming a substantial share of the overall market	Smil [26]

been many transitions—at varying scales and sectors—that have occurred quite quickly—that is, between a few years and a decade or so, or within a single generation. At smaller scales, the adoption of cookstoves, air conditioners, and flex-fuel vehicles are excellent examples. At the state or national scale, almost complete transitions to oil and electricity in Kuwait, natural gas in the Netherlands, and nuclear electricity in France took only a decade, roughly, to occur. This part of the article presents ten case studies of energy transitions that, in aggregate, affected almost one billion people and needed only 1–16 years to unfold. Clearly, this evidence suggests that some energy transitions can occur much more quickly than commonly believed.

2. Energy transitions: conceptualizations from the literature

This section of the article presents a “mainstream” view of energy transitions drawn mostly from the academic and policy literature about transitions. It introduces definitions and statements about the timing behind transitions and discusses how the historical record confirms these conceptualizations. It also illustrates the complexity, phases, and path dependent nature of energy transitions.

2.1. Definitions, timing, and contextual specificity

As Table 1 reveals, although there is no standard or commonly accepted definition of an energy transition in the recent academic literature, there is a common theme within them. An energy transition most broadly involves a change in an energy system, usually to a particular fuel source, technology, or prime mover (a device that converts energy into useful services, such as an automobile or television) [11–14]. Some studies choose to focus only on the first of those dimensions—fuels such as oil, coal, gas, and uranium—causing some to critique that they narrowly frame transitions as a way of foreclosing future change [15] or of masking “the social and political dimensions of energy systems behind a false veneer of limited technological choices [16]”. Others take a broader view that encompasses shifts in technology as well as the resulting “constellation of energy inputs and outputs involving suppliers, distributors, and end users along with institutions of regulation, conversion and trade [17]”, or structural changes in the way energy services are delivered. Still others argue that the term “energy transition” is meant to be similar to energy “transformation” or “revolution”, a disruptive or radical transformation of both technology and social practices [18–20], often centered on expanding access to energy, or abundance, but occasionally focused on scarcity [21].

Transitions, perhaps obviously, must be measured over time, usually from the point at which an energy system or technology occupies a 1% market share and then grows or shrinks accordingly. As Melosi puts it, “The concept of ‘energy transitions’ is based on the notion that a single energy source, or group of related sources, dominated the market during a particular period or era, eventually to be challenged and then replaced by another major source or sources [18]”. Smil even puts a definitive threshold to his definition, arguing that an energy transition refers to the time that elapses between the introduction of a new fuel or prime mover” and its rise to 25% of national or global market share [26]. So does Grubler, who argues that “grand transitions” can occur when they reach 50% of a market [27].

Complicating matters, in some circumstances what may seem a sweeping transition or radical transformation can actually be a bundle of more discrete conversions. As O'Connor concludes, “Big transitions are the sum of many small ones. Looking at overall energy consumption will miss the small-scale changes that are the foundation of the transitions [28]”. The big ascent of oil at the start of the previous century, for example, can also be interpreted as a series of less grand changes involving:

- The switch from animal power to internal combustion engines for private vehicles, and the social rejection of electric vehicles [29];
- The conversion of steam engines on ships and locomotives to diesel for marine vessels and trains [30];
- The shift from candles and kerosene for lighting to oil based lamps [31];
- The adaptation of coal boilers to oil boilers for the generation of electric power [32];
- The exchange of wooden fireplaces and coal stoves to oil and gas furnaces in homes [33].

Similarly, a transition in the United States to air conditioning, explored in greater detail below, was actually the result of concurrent innovations in air circulation, heat exchangers, heat pumps, halocarbon refrigerants, customization and mass production, and marketing [34]. It is occasionally these “minor transitions” that, when they occur in a concerted manner, create the “major transitions” that are so easily identifiable.

Sometimes, however, measuring a transition is more complicated than it may seem. An energy system can grow rapidly in an absolute sense but still fail to grow in a comparative sense. Hydroelectricity in the United States was a low-cost source of energy in the 1950s and 1960s, where it grew in capacity threefold from 1949 to 1964. However, during this time, because other sources of energy (and demand for electricity) grew faster, hydropower's overall national share dropped from 32% to 16%. Similarly, from 2000 to 2010, global annual investment in solar PV increased by a factor of 16, investment in wind grew fourfold, investment in solar heating threefold. This sounds impressive—yet the overall contribution of solar (heating and PV) and wind to total global final energy consumption grew from less than one-tenth of one percent to slightly less than 1% over the same period [35,36], a proverbial drop in the bucket.

In other situations, the rise of an energy system may depend, or be mutually dependent on, another—meaning it can be a mistake to identify or analyze a single energy system or technology by itself. Occasionally, two shifts have to occur to result in one combined effect, since the one tends to require in tandem the adoption of the other. As Fig. 1 illustrates, Grubler found this to be the case with technologies such as the railway and the telegraph as well as the road network for automobiles and oil pipelines [37].

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