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Energy transitions research: Insights and cautionary tales

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ABSTRACT

This short essay first reviews the pioneers of energy transition research both in terms of data as well as theories. Three major insights that have emerged from this nascent research fields are summarized highlighting the importance of energy end-use and services, the lengthy process of transitions, as well as the patterns that characterize successful scale up of technologies and industries that drive historical energy transitions. The essay concludes with cautionary notes also derived from historical experience. In order to trigger a next energy transition policies and innovation efforts need to be persistent and continuous, aligned, as well as balanced. It is argued that current policy frameworks in place invariably do not meet these criteria and need to change in order to successfully trigger a next energy transition towards sustainability.

1. Introduction

An old adage states that those who are not prepared to learn from history are bound to repeat past mistakes. The purpose of this short essay is therefore above all to argue for the value of research into historical energy transitions that can reveal patterns, dynamics, and drivers of past changeovers in energy systems. History does not preordain the future, but it is the only observational space available from which to draw lessons from and to inform policy models and makers of what it takes to initiate and to sustain a much needed next energy transition towards sustainability. While the past may be prelude, the future will in many aspects unfold under decidedly different conditions shaped by the twin forces of globalization and planetary scale environmental constraints, including above all (but not limited to) climate change.

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. Some two billion people continue to remain excluded from the benefits of past energy transitions that have vastly improved access to modern and clean energy services for households and businesses. The costs of energy keep rising, especially when the ever increasing external costs of current energy systems are factored in. The news from the climate front are disquieting: in order to limit the magnitude of future climate change, time is running out quickly, with models suggesting the need for a global "emissions peak" within the next one or two decades (IPCC AR4, 2007) against a backdrop of continued high emissions growth and political and diplomatic policy "gridlock" (Victor, 2011). All this implies ever higher urgency for both policy making and for research that can help to craft policy choices. It is this context that historical energy transition research can help. By outlining the drivers of past energy transitions and the pace at which these transitions have unfolded valuable lessons, but also cautionary tales, can be drawn.

In this short essay three main insights that have emerged from a growing body of evidence and studies in energy transitions are discussed. They are not the only ones provided by this emerging research field, but were chosen here as input to the ongoing discussions in the modeling and policy communities that are invited to ponder how modeled and envisaged transition strategies compare with historical experience. A definitive literature review of transition research remains outstanding in this embryonic field. Therefore below discussion will also pay (a partial) tribute to pioneers and path-breaking studies in energy transition research. It is a fair assessment that to date energy transition research was mainly performed by individual (and I may add: heroic) researchers that have battled against the odds of widely dispersed and obscure data sources, lack of interest (and funding), even against well-intended advice to focus on the present rather than the past. There is promise of a newly emerging research community (see the Knowledge Network for Energy Transitions http://www.netransitions.net/) that can better leverage individual contributions, share data and research insights, ultimately engaging other researchers (particularly from emerging economies) and entering a dialog with much more established research communities in modeling and policy studies. But by and large,

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we owe knowledge and insights to the early pioneers of transition research. Standing on the shoulders of these "giants" now allows us to look both deep into the energy past and distill lessons for the future.

2. The data pioneers

2.1. Global and international studies

Our understanding of history critically depends on data that are key in comparative and interpretive research alike. Therefore tribute is due first of all to Palmer Cosslett Putnam, whose *Energy in the Future*, published in 1953 (and known to few), was the first[3] study to publish detailed historical primary energy accounts for all major energy-using countries as well as the globe. Putnam was also the first to estimate non-commercial (traditional) energy use, which is key in understanding the earlier history of fossil fuel use, displacing traditional energy carriers and associated technologies. A later sequel by Joel Darmstadter and colleagues (1971) synthesized the statistics of the League of Nations and the United Nations, that have been early statistical pioneers in developing methods and data sets related to energy use. Schilling and Hildebrandt (1977) drew and extended these earlier studies with a special focus on electricity. Their data provided both inspiration and direct input for the first quantitative modeling study determining comparative, consistent metrics of "change-over"-times of energy systems performed by Cesare Marchetti and Nebojsa Nakicenovic at IIASA in the 1970s and drawing on diffusion theory and models (Marchetti and Nakicenovic, 1979). Their insight that characteristic time constants of change (only a seeming oxymoron) range between 5 to 10 decades in large, complex systems like energy, is by now widely recognized, even if not necessarily reflected in policy designs and models. In the tradition of these earlier quantitative, comparative historical energy accounts, Astrid Kander and colleagues have developed a rich data set on energy transitions in various countries in Europe that invites comparative interpretations (Kander et al., in press, cf. discussion below). A common trait of these studies is their focus on (primary) energy supply and their publication in form of monographs which limits data sharing and dissemination. Fortunately, estimates on global final energy use and data publication and sharing via the Internet have now also become available (Grubler, 1998, 2008) and are expanding (cf. http://www.netransitions.net/resources/view/165158/?topic=67730).

2.2. National-level Studies

A first pioneering in-depth country level study for the US was conducted by Schurr and Netschert (1960). More important than their exercise in forecasting the future (that actually proved quite accurate) was a richness of data and analysis on energy end-use sectors which provides insightful reading still today. John Fisher (1974)[4] drawing on Schurr/Netschert and also Dewhurst and Associates (1947, 1955) was the first to probe into the formidable improvements of energy supply technologies in terms of efficiency and cost declines (being one of the earliest examples of so-called "learning curve" analyses in the energy field), thus opening the "black box" (Rosenberg, 1994) of drivers of energy transitions. (For a contemporary update review see Cleveland, 2008; for online data see Grubler, 1998). The energy history of the United Kingdom, the pioneer of the Industrial Revolution, which energy-wise was above all one of a transition to coal-based steam power, has been extensively studied by historians. Nonetheless energy accounts largely focused on coal, short-thrifting (or underestimating) traditional energy carriers and applications (e.g., Nef, 1926). Peter Pearson and Roger Fouquet (Fouquet and Pearson, 1998) broke this impasse, and quite boldly, aiming at nothing less than a time perspective of 1000 years. Fouquet's 2008, *Heat, Power, and Light* also constitutes a formidable "classic" in energy transition research, as being the first to study the long-term evolution of energy services for light, mobility, power, and thermal energy end-uses integrating energy accounts with efficiency and costs of energy service provision. Space limitations do not allow to review the richness of national energy transition studies here, but an important reminder is in place: by and large the literature focuses on industrialized countries, hardly covering the (ongoing) energy transitions in emerging economies,[5] which remains an important area for future research. A second limitation of energy transition research to date (including the contributions by this author) has been the focus on energy inputs rather than on energy outputs (in terms of delivered useful energy or energy services proper), a limitation arising first of all from the much sparser historical records on energy end-use.[6] As argued below, an energy service perspective not only provides a more pertinent perspective of energy transitions and their drivers, including secular trends in efficiency improvements and cost/price declines, but may ultimately also challenge the prevailing wisdom about the significant inertia and the slow rates of change in capital (and infrastructure) intensive energy systems.

3. Pioneering theories and histories

As is often the case in science, theory and models follow empirical understanding and data rather than the other way around. It is interesting to note that the first discussion of energy transitions emerged from bold exercises in future scenarios rather than from historical accounts. Harrison (Brown 1954, 1956, see also Brown, 1976) and Alvin Weinberg (1959, and Weinberg and Hammond, 1972) were among the first to probe the consequences of a truly long-term, futuristic energy perspective, contrasting current energy systems with the perceived requirements of the long-term future, that, from the perspective of the 1960s invariably implied a transition to a technological monoculture (a process of "technological denudation" in the terminology of Harrison Brown) represented by nuclear energy as seemingly evident long-term replacement of the fossil fuel age. A similar vision also underpinned the first truly global energy scenario study performed at IIASA, summarized in the monumental Energy in a Finite World (Haefele et al., 1981). Perhaps the disenchantment arising from the realization that the envisaged rapid transition to nuclear faced more hurdles than anticipated due to public opposition, rising technological complexities, unresolved waste and proliferation concerns, and above all ever escalating costs (for ex post quantifications see e.g. Cohn 1997; Koomey and Hultman, 2007, and Grubler, 2010) provided an impetus for exploring alternatives for future transitions, including energy

[3] Equally noteworthy is the prescient discussion of CO_2 and climate change in the same reference.

[4] In a historical irony, John Fisher, who proposed a by now widely used model of technological substitution in 1970 (Fisher and Pry, 1970), which was later successfully extended and deployed by Marchetti and Nakicenovic (1979), failed to see its applicability to the very energy transition he described in his 1974 *Energy Crises in Perspective*. Sometimes a "forest" escapes attention due to too many trees.

[5] A notable exception being the comparison of transitions between industrialized and emerging energy economies performed by Marcotullio and Schulz (2006).

[6] Fouquet's work referred to above being the most notable exception. In this context the historical work on exergy analysis performed by Bob Ayres and Benjamin Warr (Ayres et al., 2003) deserve special mentioning.