Energy Research & Social Science 37 (2018) 175–190

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework

Aleh Cherp[a,b,*], Vadim Vinichenko[a], Jessica Jewell[c,f], Elina Brutschin[d], Benjamin Sovacool[e]

[a] Department of Environmental Sciences and Policy, Central European University, Nádor u. 9, 1051, Budapest, Hungary
[b] International Institute for Industrial Environmental Economics at Lund University, Tegnérplatsen 4, 22100, Lund, Sweden
[c] Energy Program, International Institute for Applied Systems Analysis, Schlossplatz 1, 2361 Laxenburg, Austria
[d] Department of International Relations, Webster Vienna Private University, Palais Wenkheim, Praterstr. 23, 1020 Vienna, Austria
[e] Science Policy Research Unit, University of Sussex, Jubilee Building, Falmer, Brighton BN1 9RH, United Kingdom
[f] Centre for Climate and Energy Transformations and Geography Department, University of Bergen, Fosswinckelsgt. 6, PB 7802, N-5020 Bergen, Norway

ARTICLE INFO

Keywords:
Energy transitions
Meta-theoretical framework
Variables
Co-evolution

ABSTRACT

Economic development, technological innovation, and policy change are especially prominent factors shaping energy transitions. Therefore explaining energy transitions requires combining insights from disciplines investigating these factors. The existing literature is not consistent in identifying these disciplines nor proposing how they can be combined. We conceptualize national energy transitions as a co-evolution of three types of systems: energy flows and markets, energy technologies, and energy-related policies. The focus on the three types of systems gives rise to three perspectives on national energy transitions: techno-economic with its roots in energy systems analysis and various domains of economics; socio-technical with its roots in sociology of technology, STS, and evolutionary economics; and political with its roots in political science. We use the three perspectives as an organizing principle to propose a meta-theoretical framework for analyzing national energy transitions. Following Elinor Ostrom's approach, the proposed framework explains national energy transitions through a nested conceptual map of variables and theories. In comparison with the existing meta-theoretical literature, the three perspectives framework elevates the role of political science since policies are likely to be increasingly prominent in shaping 21st century energy transitions.

1. Introduction

The ways societies use energy have changed over the course of history, are changing at present, and will certainly change in the future. These long-term changes, energy transitions, are shaped by economic development, technological innovation, and policies among other factors. At the same time, governments around the world are called on to steer energy production and consumption so as to solve, not aggravate, international security, poverty, climate change and other global challenges [1]. Yet, such calls can only be meaningful if they are based on a systematic understanding of national energy transitions an understanding, which remains elusive despite a large and growing literature on the topic.

One difficulty in explaining energy transitions is the disciplinary diversity of required scholarly approaches. Existing reviews of the vast transition literature identify relevant knowledge from economics, sociology of technology, political science, geography, history and other disciplines [2–7]. A consensus of these reviews is that since a single theory of transitions may not be feasible due to their complexity, they should instead be analysed using *several* theories [3,8,7]. But what are these theories, which disciplines should they represent, and how can they be integrated? The existing literature does not provide consistent answers.

This inconsistency largely results from the fact that the existing reviews significantly vary in their scope and method. For example, some of them focus on *energy* transitions [9,4] while others cover *low-carbon* transitions [3] and yet others extend to *sustainability* transitions [10,7]. While these concepts are overlapping (energy transitions may

Abbreviations: ACF, Advocacy Coalition Framework; CCS, carbon capture and storage; IAM, Integrated Assessment Model; MLP, multi-level perspective; SNM, strategic niche management; STS, science, technology, and society/science and technology studies; TIS, technological innovation system; TM, transition management

* Corresponding author at: Department of Environmental Sciences and Policy, Central European University, Nádor u. 9, 1051, Budapest, Hungary.
E-mail addresses: cherpa@ceu.edu, acherp@gmail.com (A. Cherp), vinichenko@gmail.com (V. Vinichenko), jewell@iiasa.ac.at (J. Jewell), Elina.Brutschin@webster.ac.at (E. Brutschin), B.Sovacool@sussex.ac.uk (B. Sovacool).

http://dx.doi.org/10.1016/j.erss.2017.09.015
Received 11 January 2017; Received in revised form 6 September 2017; Accepted 11 September 2017

be 'low-carbon' or 'sustainable'), they are clearly not identical,[1] and therefore are not necessarily explained by the same theories. With respect to their method, the existing meta-theoretical reviews range from inductive accounts of history of thought [4,6] to bibliographical studies centered on several influential papers [5], to deductive analyses based on the nature of the problem in question [9,11,6].

Our paper aims to advance understanding of energy transitions by proposing a meta-theoretical framework based on several scholarly traditions. We make three choices about the scope of phenomena which we analyze. Our first choice is about the boundaries of energy systems which we limit to **the energy sector**, i.e. to conversion and use of energy by people. Economic and population growth as well as other factors outside of the energy sector clearly influence energy transitions, but we choose to consider them as external driving forces rather than central foci of our analysis (see for example Section 3.1 on energy demand). Similarly, the wider effects of energy transitions on societies are outside of the scope of our analysis.

Secondly, we follow Grübler et al. [12] who define an energy transition "as **a change in the state of an energy system** as opposed to a change in individual energy technology or fuel source". This definition contrasts complex and pervasive systemic transitions on decadal scales with more trivial and shallower[2] shifts in individual energy technologies in specific markets that may occur in matter of a few years. The wider scientific consensus is that mitigating the risks of the climate change and addressing other sustainability challenges would require such deeper transitions involving many different technologies and encompassing national and global scales [1,6]. However, deep and wide energy transitions do not necessarily lead to 'clean', 'modern', 'low-carbon' or 'distributed' energy systems. Indeed, most historical examples of such grand transitions involve fossil fuels and more recently nuclear energy [14]. We include such transitions in the scope of our analysis because we believe that the mechanisms of energy transitions depend more on their scale and depth than on their normatively evaluated direction or effects.[3] Though it sets us apart from some transition studies which are primarily interested in 'green' technologies, it is in line with most long-term scenarios of climate change mitigation, which typically envision deploying a wide range of technologies ranging from carbon capture and storage (CCS) and nuclear power to hydrogen, biomass, renewables, and energy efficiency [15].

Our final choice is to focus on **national** (rather than sectoral or local) energy transitions. With all their complexities, national energy transitions relate to relatively well-defined national economies, laws and regulations, natural resources, and infrastructure. These factors are accounted for in national statistics and plans available for empirical analysis that can validate or refute theoretical explanations [4,16]. Moreover, since nation states have the most obvious mandate to govern energy systems, it is at the national level where some of the most significant decisions to steer energy systems to avoid dangerous climate change are and will be made [17].

These are not the only possible choices in studying energy transitions. For example, illuminating studies were conducted in analyzing the rise and fall of individual energy technologies [18–20]. On the other end of the spectrum, Perez [21] framed the expansion of electric production and steel making as part of a wider technological "surge" also involving changes in finance, lifestyles and politics. Similarly, many contemporary scholars are interested in social 'transformations' accompanying changes in energy systems [22]. Other research looks beyond national systems to study changes at the local [23], sub-national such as states in the USA [24], sectoral such as pulp and paper industry [25,26] or supranational such as Nordic region [27] or the European Union [28] scales. We hope that by creating an analytical framework for decadal-scale changes in relatively well-defined national energy systems our analysis will support and supplement these other important streams of research.

We use a deductive method of identifying scholarly approaches relevant to understanding national energy transitions based on the concept of co-evolution of natural, technological and social systems [29–31,21]. In Section 3, we argue that national energy transitions involve co-evolution of distinct systems delineated by (a) energy flows and markets, (b) energy technologies embedded in their socio-technical context, and (c) political actions affecting formulation and implementation of energy policies. We further show how scholarly analysis of these distinct systems gives rise to the techno-economic, the socio-technical and the political perspectives on national energy transitions. In Section 4, we compare the three perspectives to the frameworks in existing meta-theoretical studies, summarize fits and misfits of each perspective, and propose a general method for their application following the framework approach developed by Elinor Ostrom and her colleagues. This framework is illustrated in Section 4.4 using an example of comparing electricity transitions in Germany and Japan. Section 5 concludes the paper and proposes a further research agenda.

2. Literature review

The majority of publications on energy transitions use existing theories for analyzing empirical cases of transitions (e.g. [32]) or exploring transition scenarios (e.g. [33]). Other studies propose new theories of transitions [34–36]. In addition, several meta-theoretical studies review the state of knowledge on transitions. In searching for relevant literature, we aimed to identify key peer-reviewed English-language publications of this latter type. Our search focused on academic journals hosting the debate on energy transitions (*Research Policy*, *Energy Policy*, *Energy Research & Social Science,* and *Global Environmental Change, Environmental Innovation and Societal Transition, and Technological Forecasting and Social Change*). Section 2.1 summarizes the insights from these reviews while Section 2.2 discusses existing proposals for integrating transition theories as well as approaches for analyzing co-evolving natural, technological and social systems.

2.1. Existing reviews and categorisations of approaches to transition studies

Economists and historians have been interested in long-term changes in human use of energy resources since at least the 1960s (e.g. [37]). Studies of *past* transitions have often been motivated by the aspiration to anticipate potential *future* transitions. First quantitative scenarios of future energy transitions were developed in the 1970s and combined forward-looking projections of economic and population growth and resource availability with empirical observations on how energy conversion and use changed historically (e.g. [38]). These scenarios were based on engineering and economic theories, such as technological substitution [39], which Marchetti and Nakicenovic [40] extended to energy sources [4].

A review by Grübler [4] highlighted the importance of this pioneering research as well as pointed out other contributions from economic history and theory [41,42], history [43] and social studies of technology [44]. Grübler's paper was published in the special issue of *Energy Policy* on energy transitions. In the editorial to this issue, Fouquet and Pearson [45] argued that aggregate long-term changes in energy use by entire societies need to be understood as combinations of changes in the use of individual energy technologies.

Such technological change was explored in several strands of studies developed separately from both macro historical analyses and forward-looking models. A particular boost to these studies was given by the

[1] Low-carbon transitions may occur outside of the energy sector (e.g. in urban planning, industry, agriculture and forestry). 'Sustainability' transitions may also include changes in food systems, distribution of wealth, human rights, governance and conflicts.

[2] While there is no universal agreement how large a change would constitute a transition, scholars have developed a robust understanding of the relationship between the speed, the scale, and the depth/complexity of change (see e.g. [12,13]).

[3] For example, in Section 3.4 we illustrate our approach in case of the transition from nuclear to renewable power in Germany, which is largely carbon-neutral.