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Integrating social-ecological dynamics and resilience into energy systems research

Jennifer Hodbod[a,*], W. Neil Adger[b]

[a] Walton Sustainability Solutions Initiative, Global Institute of Sustainability, Arizona State University, USA
[b] Geography, College of Life and Environmental Sciences, University of Exeter, UK

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ABSTRACT

The ecological impact of energy production and consumption is often relegated in analytical accounts of the evolution of energy systems, where production and consumption patterns are analysed as the interaction of social, economic and technological factors. Ecological and social–ecological dynamics are, we argue, critical in the context of imperatives for access to modern energy services that are inadequate for significant sections of the world's population. The ecological impacts of energy use are often analysed as a set of externalities, many of which are uncertain or unquantifiable, particularly if they stem from earth system change such as anthropogenic climate change. Here we outline the benefits from analysing energy systems as social–ecological systems. We review the extensive literature from ecology and resilience theories, and compare the analytical domains, major findings and emphasis of social–ecological systems with socio-technical transition research. We illustrate these differences with the example of the multi-scale impacts of biofuel expansion. We show that social–ecological systems research combines analysis of interactions with ecological systems and power relations between actors in energy systems, and has the potential to do so across production, distribution and consumption domains whilst illustrating the dynamics of such energy systems, identifying potential trade-offs and regime shifts.

1. Introduction

There is a cogent argument for the utilization of social science related disciplines, methods, concepts and topics in contemporary energy studies research [1]. We argue in this paper that the integration of ecological dynamics are also under-appreciated. There is an intrinsic link between current energy regimes, renewable and non-renewable natural resources, and global and place-specific environmental change. Energy production and consumption patterns are, therefore, not only determined by the interaction of social, economic and technological factors, but also by ecological dynamics. The importance of ecological dynamics within energy production and consumption are often relegated in analytical accounts of the evolution of energy systems. Such ecological impacts are often analysed as a set of energy externalities, many of which are uncertain or unquantifiable, particularly if they stem from whole earth system change such as driving anthropogenic climate change. The uncertainty around impacts explains the lack of integration into traditional analyses of energy systems and we suggest that this creates an opportunity for framing energy systems as inherent social–ecological systems that have inherent vulnerabilities, resilience and capacities for change.

There are still huge challenges for energy systems to achieving social, economic and environmental sustainability [2]. The global energy system continues to be locked-in to fossil fuels and presents four main challenges to sustainability [3,4]:

1. The challenge to reduce greenhouse gas emissions from fossil fuels contributing to climate change at a global scale (with differentiated local impacts), and as the primary source of local air pollution with direct impacts on well-being and ecosystems;
2. The challenge of energy security through increasing demand and limited supply of fossil fuel products, and price uncertainties;
3. The challenge of pervasive subsidy of fossil fuels and the geopolitical dimensions of the carbon economy;
4. The challenge of universal access to energy services and energy poverty.

To take the example of energy poverty, 1.6 billion people lack access to electricity whilst 2.4 billion rely on biomass and other solid fuels (i.e. wood, charcoal, waste) for cooking [5,6]. This challenge is being tackled, for example, by international initiatives

* Corresponding author. Tel.: +1 4809652549.
E-mail address: jennifer.hodbod@asu.edu (J. Hodbod).

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and domestic policy strategies that create pressure for the expansion of clean energy access in developing countries (such as the Global Alliance for Clean Cookstoves) [7]. The challenge of universal access to non-biomass fuels has also promoted the use of liquid biofuels in the agricultural, industrial and residential energy sectors to allow a range of applications including off-grid electrification, household energy, small machinery power, irrigation pumping and food production equipment [7,8]. A reduction in the use of biomass for Total Primary Energy Supply has been shown to have highly significant benefits for rural and urban poor populations through reductions in acute respiratory infections in women and children [9]. Similarly a reduction on biomass dependence affects land use, tree cover, and an increase in the proportion of agricultural residues returned to agricultural land [10]. There are also time savings for women, who traditionally collect biomass fuels, but could benefit from increased income-earning activities, education, or leisure time. There are, therefore, demonstrable benefits to increasing universal access to modern energy sources, but also significant political economy dimensions that prevent access to energy for low income groups globally.

Transformations and opportunities for change in the production, distribution and consumption within energy systems all have links to multiple social and ecological processes. Whilst addressing these challenges requires integrated solutions with competing objectives, there are strong drivers for transformation to decarbonised systems that provide energy access to all. Whether change is introduced top down or grows from the bottom up, we argue that understanding the dynamics and the opportunities for progressive change will require models that explicitly incorporate social–ecological dynamics and the nature of resilience.

2. Bringing ecological resilience into energy analytics

Resilience is a systematic property that refers to the magnitude of change a system can experience before shifting into an alternative state [11,12]. Whilst introduced in the field of ecology in the 1960s, in the last decade the concept of resilience has been taken up by social scientists to investigate non-equilibrium system dynamics in social–ecological systems [13]. As a result, resilience has also been widely recognised as a policy goal in urban planning, development strategies, and the management of critical national infrastructure [14,15]. Social–ecological resilience has three components: the amount of disturbance a system can absorb and still remain in the same state; the degree to which the system is capable of self-organisation; and the degree to which the system can build up and increase the capacity for learning and adaptation [16].

The combination of robustness, autonomy and learning signifies that a system is resilient if it can adapt to remain in the same state, but is also resilient if it has a high enough capacity to deliberately transform into new forms and configurations. In comparison, a system that undergoes a regime shift unintentionally due to a lack of adaptive capacity lacks resilience. Integrating these ideas of dynamics and intentionality is important when framing the behaviour of social–ecological systems.

Social–ecological systems are integrated systems in which humans are part of nature and therefore cultural, political, social, economic, ecological and technological components interact [17]. The interacting components form a complex and dynamic entity, the analysis of which requires a holistic approach. The equal attention paid to the social and ecological components of a system, and the focus on the relationships between these components rather than their individual functions, is key within resilience theory [18]. A social–ecological resilience framework is therefore able to illustrate the dynamics of such systems, identifying potential trade-offs and regime shifts.

There are diverse ecological dimensions of energy production and consumption. Much analysis of the costs of energy use focus on direct impacts on well-being such as on health, or their economic costs and presents such results in cost-effectiveness, cost-benefit or life cycle frameworks. The costs of fossil fuel based electricity generation, of hydro-power or biofuel alternatives, as well as of the energy dimension of consumption patterns, can all be compared using such analyses [19,20]. There are well-established critiques of economic valuation of environmental externalities [21,22]. They highlight how the meaningfulness of monetary valuation breaks down the further the externality is from market-type impacts. An economic cost of air pollution on labour productivity is unambiguous. By contrast, the economic cost of species extinction or the loss of visual landscape amenity, are less meaningful. Hence externalities associated with ecological decline in particular are much less consistent with economic values, not least in the intrinsic values of nature beyond the ethnocentric framing [23,24].

In economic analysis of energy externalities, for example, impacts are often valued as loss of biological diversity or valuable habitat, valued in economic metrics through replacement cost or of the economic values of genetic material [25]. But many ecological values are context and place specific and have wide ranges of attributed economic values. Such wide variation and analytical difficulties in attributing value in effect introduces uncertainty to such analysis. More fundamentally, however, the economic externality framing has significant limitations in incorporating dynamic and contextual dimensions of ecosystem responses to interventions. Ecological impacts are generally accounted as the externalities associated with habitat loss, changing land use, or pollution loading, costed as replacements for the ecosystem service, or by comparison of values lost through choice experiments to compare ecological loss with some other reference-good. But ecosystem stress has multiple routes to affect system resilience, through closing off future options, brining ecosystems close to thresholds of regime shifts that may be effectively irreversible, and other non-linear effects [26].

Hence we argue that conceptualising energy systems through a resilience framework internalises the ecological variables that are often externalised in traditional analyses, by framing them as equally as important as the economic, technological and political factors. The benefits of a resilience framework will be outlined below, but in summary, such a framework allows a wider analysis of the trade-offs between the elements listed above to be highlighted, providing greater information about potential changes in the system.

3. Systems: social, technical, and ecological

3.1. Traditions, convergence and difference

If ecological dynamics are difficult to incorporate in standard energy analyses, we argue that more systems-oriented analysis presents opportunities to examine both the environmental and ecological dimensions as well as portraying more fully how energy fits within society. There are two distinct and parallel systems analyses, based on different traditions. First, social–ecological systems research explicitly analyses the biological basis of ecosystems and their interaction with social processes including the exploitation and relationship to biological and other resources. A parallel tradition focuses on socio-technical systems as interactions between social practices and technological artefacts that influence each other. Analysis of such systems has commonly been utilised to

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