Framework for comparing ecosystem impacts of unconventional energy development on western US rangelands

Introduction

Energy is fundamental to sustainable development because it provides the means for resolving challenges facing humanity, including water and food shortages and poverty (Serageldin 1999; Kalogirou 2005). More diverse energy sources are needed for countries to progress towards energy independence and to meet future food production needs. The USA Task Force on Strategic Unconventional Fuels concluded that development of a domestic unconventional fuels industry is necessary. Rangelands represent a major source of alternative energies.

To evaluate shifts in land use, a framework to systematically identify biophysical-socioeconomic links that influence delivery of ecosystem services is needed. The Sustainable Rangelands Roundtable (SRR) developed the Integrated Social, Economic and Ecological Conceptual (ISEEC) framework (Figure 1) to meet this need. The framework can be applied for comparison of effects on ecosystem services of exploiting rangeland-based biofuel, natural gas and wind energy resources.

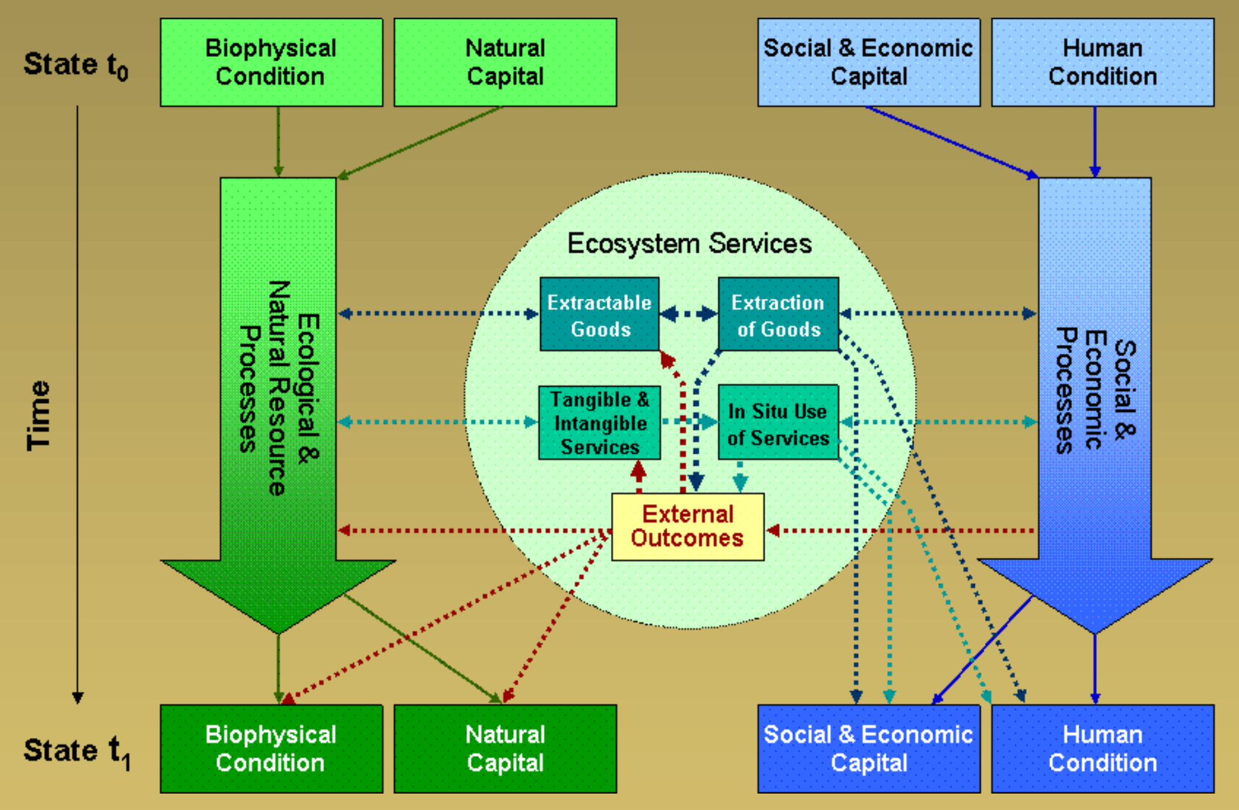

Figure 1. Integrated Social, Economic, and Ecological Concept (ISEEC) for identifying linkages that affect delivery of rangeland ecosystem goods and services. Graphic courtesy Dr. Urs Kreuter.

The framework can also be used for selecting suitable indicators to monitor changes in the biophysical-socioeconomic links affected by development of these unconventional energy sources. This type of approach may enhance coordination between federal, state and local agencies attempting to set polices and regulations for sustainable development of unconventional energy resources on rangelands.

The Sustainable Rangelands Roundtable (SRR) recognized a critical need to understand rangelands' contributions to alternative energies and other ecosystem goods and services, as well as potential tradeoffs, implicit in land management and policy decisions. The complexity of these interactions highlights the importance of standardized assessment to track changes and inform management to maintain provision of all rangeland ecosystem goods and services (Maczko and Hidinger eds. 2008), including energy.

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In the USA, rangelands cover over 300 million ha or one third of the country (Joyce 1989; Mitchell 2000; Havstad et al. 2007), mainly west of the 95th meridian. These lands provide commodity, amenity, and spiritual values (Shields et al. 2002) that are vital to the well-being of our Nation. Since 2001, SRR, a partnership of rangeland scientists and ecologists, policy and legal experts, sociologists, economists, environmental advocates, and industry supporters, has distilled five criteria and 64 indicators embodying social, economic, and ecological factors for assessing rangeland sustainability (Mitchell et al. 2010). The criteria are:

Criterion I: Conservation & Maintenance of Soil & Water Resources on Rangelands
Criterion II: Conservation & Maintenance of Plant & Animal Resources on Rangelands
Criterion III: Maintenance of Productive Capacity on Rangelands
Criterion IV: Maintenance & Enhancement of Multiple Economic & Social Benefits for Current & Future Generations
Criterion V: Legal, Institutional & Economic Framework for Rangeland Conservation & Sustainable Management

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Biofuels, Natural Gas, and Wind Energy

Rangelands in the western USA hold significant potential for developing domestic fuels because much of the nation's unconventional oil and gas reserves and renewable biofuel and wind are located there (Black and Veatch 2008). A focus on three unconventional energy sources: renewable biofuel, shale-based natural gas, and wind energy is appropriate for three reasons. Each represents a "dual- use" energy resource, i.e., it does not preclude the use of rangelands for traditional purposes (Pimentel et al. 1994). These energy sources are vertically distributed below, at, and above ground level; thus, their development will affect rangelands in different ways. The exploitation of each energy resource relies on well-established technologies; therefore, they are likely to be developed in the near future.

Biofuels -- Switchgrass (*Panicum virgatum L.*) has attracted attention for energy production due to its potential for producing biomass in areas where the productive capacity for other biofuel crops is low (Walsh et al. 2003; Adler et al. 2007; Mitchell et al. 2008). However, concern exists over converting native rangelands to biofuel monocultures (Cook et al. 1991; Bies 2006; Fargione et al. 2008, 2009; Groom et al. 2008). Not all rangeland plant biomass can be used for biofuel because some is required for forage and to protect soils. The Western Renewable Energy Zones (WREZ) (Black and Veatch 2009; WGA 2009) analysis assumed one third of available biomass could be used for power. Potential for rangeland biofuel production was identified in western states including Montana, Idaho, Utah, Colorado, Arizona, New Mexico and Texas.

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Natural Gas -- In the USA, rich shale formations (plays) that contain hydrocarbon gasses hold an estimated 1,744 trillion cubic feet (tcf) of recoverable reserves (USDOE 2006; Kuuskraa et al. 2007). Full development of natural gas reserves hinges on the energy industry's ability to balance exploration/production processes and compliance with regulatory statutes and environmental directives administered by federal and state agencies (GWPAC 2009). Tied to that are efforts to reduce the surface disturbance of siting wells, reduce wildlife and community impacts, and protect groundwater resources. Currently identified shale gas plays in rangelands of the western USA extend southwards from Montana through Wyoming, Utah, Colorado and New Mexico to Texas.

Wind Energy – Wind-energy proponents emphasize a persistent energy source with no direct emission of pollutants. However, wind-energy facilities can cause wildlife habitat destruction and collision-related fatalities of bats and birds (Kunz et al. 2007; Black and Veatch 2009; Curry 2009). The National Research Council's Committee on Environmental Impacts of Wind-Energy Projects recommended that federal, state and local agencies use a coordinated approach to evaluate planning, regulation, and location of wind-energy projects (NRC 2007). Based on the WREZ, rangelands with highest wind energy production potential extend from Montana and Wyoming into Colorado, New Mexico and northern Texas.

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Applying ISEEC to Three Unconventional Energy Resources

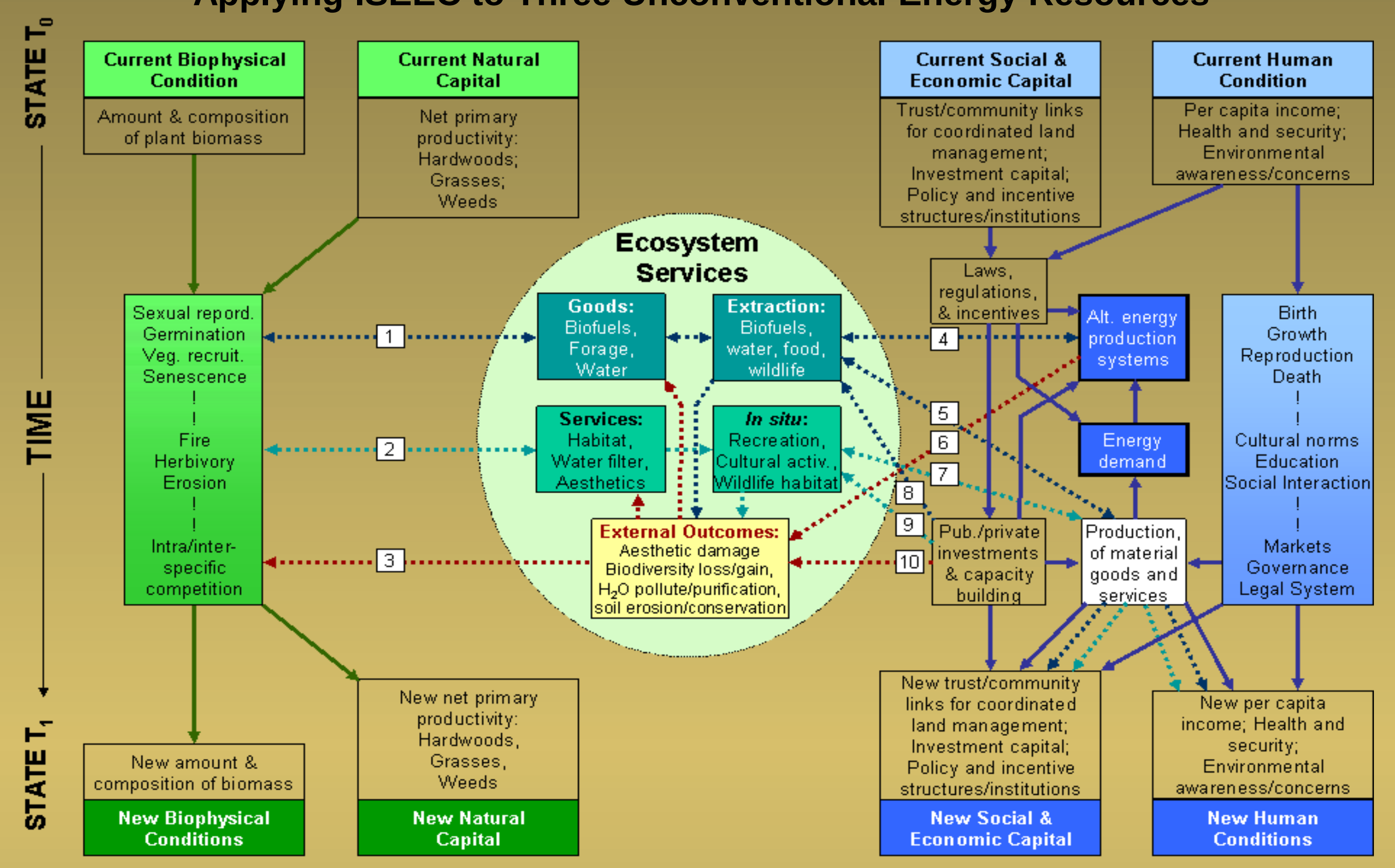

Figure 2: Application of the ISEEC framework to identify key biophysical-socioeconomic linkages that impact the delivery of ecosystem goods and services, and that affect or are affected by biofuel production from rangeland ecosystems. Numbered boxes indicate linkages between biophysical and socioeconomic subsystems that affect delivery of ecosystem services and that link to comparisons of effects of biofuel, natural gas and wind energy production in Table 2 and to description of monitoring criteria and indicators in Table 1. Graphic courtesy Dr. Urs Kreuter.

In Figure 2, the biophysical subsystem produces the ecosystem goods and services listed in the center of the diagram. The extent to which these goods and services are utilized is determined by socioeconomic factors shown on the right side of the diagram. Explicitly, [1] and [2] represent the biophysical processes that produce ecosystem goods (e.g., biofuel, forage and water) and services (e.g., wildlife habitat, water filtration and aesthetic amenities) on rangelands. Link [3] represents the negative or positive feedback effects on biophysical processes of utilizing or conserving the ecosystem goods and services. The extraction of rangeland-based ecosystem goods is affected by demand for and supply of biofuel [4] and other rangeland-based goods (water, food and wildlife) [5]. This is driven by societal demand for energy to produce manufactured goods and services, which is, in turn, affected by population size, wealth, education, cultural norms and values, and the legal framework. Investments in technology and management systems needed to meet this demand [8] are not only affected by the level of demand but also by laws, regulations and incentives that influence investments in alternative markets for ecosystem goods. The deleterious external outcomes (soil erosion, water pollution, green house gas emissions, an biodiversity decline) of using ecosystem goods for energy production [6] are offset by private and public investments in effective mitigation measures [10]. The *in situ* utilization of ecosystem services (e.g., through recreation) is represented by link [7]. The extent to which these services are utilized is also influenced by social factors affecting demand and investments in the development of industries (e.g., tourism) that facilitate their use [9]. The negative impacts of exploiting such ecosystem services are also moderated by investments in appropriate mitigation measures [10].

Indicators for Monitoring Biophysical and Socio-economic Interactions

From its inception, the discipline of range science has emphasized the need for monitoring (Campbell 1948) to identify changes in rangelands and determine trade-offs among alternative rangeland uses. SRR criteria and indicators to apply to the development of unconventional energy sources on rangelands (Table 1) were identified using the ISEEC framework . The biophysical links [1], [2] and [3] can be monitored by indicators that have been commonly used by natural resource scientists and managers, while indicators to monitor the first three socioeconomic links ([4], [5] and [6]) are relatively straightforward.

More challenging is the identification of indicators to characterize the latter four socio-economic links ([7], [8], [9] and [10]), which relate to the *in situ* use of ecosystem services and public and private investment in ecosystem goods and services as well as programs aimed at mitigating the deleterious effects of using these goods and services. Many *in situ* ecosystem services represent public goods from which society at large benefits at the expense of private landowners who provide them without public compensation (Lant et al. 2008). In addition, values of several ecosystem services (e.g., aesthetic quality) are qualitative and changes are more difficult to evaluate and often require indirect valuation techniques (Daly and Farley 2004).

Linkage	Description	Criteria	Indicator [a]
1 & 2	Composition of plant biomass Plant biomass	II	Spatial extent of vegetation communities [12]
			Fragmentation of rangeland plant communities [14]
		III	Above ground plant biomass [21]
3	Soil condition	I	Area of soils with significantly diminished organic matter and/or C/N ratio [1]
			Area with significant change in bare ground [4]
			Area with accelerated soil erosion [5]
	Water quality	I	Percent surface water with significantly reduced chemical, physical, and biological properties [7]
			Changes in frequency and duration of surface no-flow periods in streams [9]
	Biodiversity	II	Spatial extent of vegetation communities [12]
			Population and range of rangeland-dep. species [20]
4 & 5	Biofuel resource utilization Other rangeland goods utilization	IV	Value of plants harvested from rangeland [27]
			Value of production of rangeland products [28]
			Return on investment in alternative enterprises (livestock, wildlife, water harvesting, biofuel, etc. [32]
6	Direct biofuel harvesting impacts	I	Area of soils with significantly diminished organic matter and/or C/N ratio [1]
			Area with significant change in bare ground [4]
			Area with accelerated soil erosion [5]
		II	Spatial extent of vegetation communities [12]
			Population and geographic range of rangeland dependent-species [20]
7	Rangeland services utilization	IV	Return on investment in alternative enterprises (hunting, other recreation, other cultural activities, etc. [32]
			Area of rangelands under conservation ownership [33]
8, 9 & 10	Public investment & capacity building Private investment & capacity building	V	Extent to which government agencies and NGOs affect conservation/management of rangelands [56]
			Extent to which economic policies support conservation/ management of rangelands [57]
			Professional education/technical assistance support [59]
			Conservation/rangeland management support [60]
			Resources for monitoring rangeland condition [63]
			Conservation/management research/dev. support [64]

Table 1. Criteria and indicators for monitoring changes in key linkages affecting ecosystem goods and services in biofuel, natural gas and wind energy development on rangelands.

a - SRR Indicators for monitoring rangeland sustainability (brackets providing SRR indicator number; Maczko et al. 2004)

Evaluating Potential Effects of Development of Three Unconventional Energy Resources

To demonstrate the use of the ISEEC framework for comparing the potential effects of developing alternative rangeland-based energy resources, we compare possible effects of developing each of the three unconventional energy resources on each of the 10 links shown in Figure 2. In Table 2, the biophysical and socio-economic impacts represent the two sides of the benefits and costs ledger for each of the three energy resources.

The "+" symbol indicates a positive effect or benefit, "–" indicates a negative effect or cost, and "0" indicates no effect. Double positive and double symbols represent potentially greater impact of developing the unconventional energy source on the specified link. To be clear, these are anticipated differences and do not represent an assessment of expertise opinion or any measured effects, which are lacking. No net effect of developing each energy source is provided in Table 2 because the symbols are not measured effects and, therefore, cannot be added up.

While we have speculated about the potential effects of energy development for each of the socioeconomic-biophysical links discussed below, the lack of quantitative data prevented us from suggesting an overall net effect of developing these three unconventional energy sources either own their own or in combination. That will require in depth future research.

	Biofuel		Natural gas		Wind	
Linkage	Bio-physical	Socio-economic	Bio-physical	Socio-Economic	Bio-physical	Socio-economic
[1a] e/s goods prod. - energy	+ +		0		0	
[1b] e/s goods prod. - other	+		+ +		+ +	
[2] e/s service supply	+		+ +		+ +	
[4] energy supply		+ +		+		+
[5] other e/s good supply		+		+ +		+ +
[7] e/s service supply		0		+ +		+
[8a] e/s extraction invest. - energy		– –		– –		– –
[8b] e/s extraction invest. - other		–		–		–
[9] e/s service utilization invest.		–		–		–
[10] mitigation investments		– –		–		– –
[3] = [6 + 8 + 9 + 10] biophysical feedback	– – –		–		– –	
Sub-total effect	+	– – –	+ + +	0	+ +	– –
Total (biophysical – socio-econ)	– –		+ + +		0	

Table 2: Comparative effects on ecosystem (e/s) linkages shown in Figure 2 for biofuel, natural gas, and wind energy production. (Symbols: "+" indicates a positive overall effect on the linkage, "0" represents no effect, and "–" represents a negative effect).

Management Implications

Ostrom (2009) emphasized that the problem of planning and management in complex socio-ecological systems is the inconsistent use of concepts and terms. Similarly the NRC (2007) emphasized the need for federal, state and local agencies to use a coordinated approach for evaluating the planning, regulation, and location of wind-energy projects. These challenges apply to a multitude of rangeland management issues, including the development of unconventional energy resources.

Obtaining a conceptual framework to guide and inform an evaluation of energy development on rangelands is the first step to addressing this challenge if the goal of rapidly developing an unconventional fuels industry is to be attained without causing undue environmental and social harm. Research to quantify the biophysical-socioeconomic linkages affecting ecosystem goods and services is the next step. Together these will lead to management recommendations to offset the potential impacts in the near term. The resilience of rangelands to other stressors in the longer term, in the context of sustainability, remains to be assessed.

The ISEEC framework provides rangeland managers with a tool to systematically and comprehensively identify the biophysical-socioeconomic links that affect the ecosystems they are attempting to manage and to identify suitable indicators for monitoring changes to these links. This work shows how a social-ecological framework, such as the ISEEC framework, could be used to frame and facilitate an evaluation of tradeoffs related to energy development on rangelands.

Photo courtesy NRCS

Conclusions

To facilitate the disentanglement of the socio-ecological complexity in rangeland ecosystems, the SRR develop the ISEEC framework as a tool to simply and systematically specify biophysical and socioeconomic links that characterize these social-ecological systems. A key objective of applying the ISEEC framework is to provide consistent and comprehensive information over time to a wide range of decision makers and stakeholders regarding the effects of alternative uses of rangelands on the ecosystem goods and services that they provide (Fox et al. 2009). This improves understanding of the effects of rangeland development alternatives on the biophysical attributes of rangelands, on local communities and economies, and on state and federal revenues. Such information is necessary for the formulation of development plans that minimize negative biophysical and socio-economic impacts on complex socio-ecological rangeland systems.

We have presented a systematic indicator-based approach for developing a comprehensive data set to support coordinated planning and regulation for the development of unconventional energy resources on rangelands. The next step in responding to the USA Department of Energy's recommendation to immediately catalyze a domestic unconventional fuels industry (USDOE 2010) is to conduct the necessary research to quantity the effect of energy development on the 10 biophysical-socioeconomic links that we identified here. The hypothetical relationships that we presented for these 10 links could be used as a starting point for such research.

Photo courtesy NRCS

Literature Cited

For full literature citations, please see Kreuter, U.P., W.E. Fox, J.A. Tanaka, K.A. Maczko, J.E. Mitchell, D.W. McCollum, C.S. Duke, and L. Hidinger. 2012. Framework for comparing ecosystem impacts of developing unconventional energy resources on western US rangelands. Journal of Rangeland Ecology and Management 65: 433-443.

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