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ORIGINAL ARTICLE

A new framework for environmental education about energy transition: investment and the energy regulatory and industrial complex

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Abstract

Modern societies depend upon fossil fuel–based energy systems for energy services, but, despite huge benefits, many negative environmental consequences have resulted from fossil fuels. The most important is climate change, caused by greenhouse gases emitted from production and use of fossil fuels. Over the past 50 years, environmental education has increasingly embraced the need for curriculum on climate change, but these curricular efforts have not delved deeply enough into building student knowledge and analytical skills about energy systems and the imperative transition away from fossil fuels. Based on political–ecological ideas, we propose a new framework for building environmental curriculum about energy and energy transitions: the Energy Regulatory and Industrial Complex (ERIC) with an embedded Energy Investment Cycle (EIC), a systemic perspective to help students focus on the key role of decision-making about energy investments. ERIC and EIC also bolster recognition of the components of energy systems, how they relate to each other, and the challenges of transforming an energy system. Environmental education involves a large variety of disciplinary and interdisciplinary perspectives among instructors serving students at many levels and from different preparations. Accordingly, we do not attempt to provide exact instructions on how to use ERIC and EIC. Instead, our intention is to help faculty develop curricula for different disciplinary and interdisciplinary courses and degree programs. To that end, we conclude with brief illustrations of possible uses of ERIC and EIC. We argue that our proposed framework will stimulate better understanding of energy-environmental interactions and thereby promote constructive discussions about energy transitions away from fossil fuels.

Keywords Decarbonization · Electrification · Electricity · Energy systems · Climate change · Energy transition · Environmental education · Energy education · Energy investment · Political ecology

Introduction

Species in the genus *Homo*, among all species, have had a unique relationship with energy for perhaps a million years. Like all other animals, *Homo* consumes food for metabolic energy and thus has always depended on green plants for survival. Only *Homo*, however, mastered fire as a tool and used its heat and light for cooking food, warmth, and protection from predators. Long before modern humans evolved, their direct ancestors had fire, and no people today live without it. Our species appears obligately dependent on energy from sources other than food, and firewood (biomass) was the only significant, non-food energy source for hundreds of thousands of years, until about 500 years ago (Perkins 2017).

Medieval England learned to use coal as a substitute, and obtaining the vastly greater amount of energy in this fossil biomass was an energy and technology transition that transformed humans to modern, economically developed, urban-industrial societies. Such societies use three fossil fuels (coal, petroleum, and natural gas) for about 80% of their energy other than food. Energy uniquely shaped human biological and social evolution and ecology and also Earth's physical environment.

Climate change, however, poses catastrophic risks to modern culture and stems largely from production and use of fossil fuels, like coal. For over 30 years, environmental educators have sought to educate students about these

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threats. This paper builds on an earlier paper on the connections of climate and energy education (Perkins et al. 2014), calling for further promotion of energy education as part of environmental education.

- First, it endorses and contributes to calls for reframing climate education to education about *transition of energy systems from fossil fuels to renewable energy sources* (Jorgenson et al. 2019).
- Second, our proposed framework builds on a diagram showing flows of materials and energy through social and political networks of decision-making related to regulation, investment, and innovation.
- Third, we utilize political ecology to reconceptualize environmental education on energy, as advocated by Meek and Lloro-Bidart (2017) and Henderson and Zarger (2017).
- Fourth, we suggest ways for environmental educators to use our framework in a mix of disciplines, institutions, courses, and degree programs.

Climate change, energy, and environmental education

Environmental education in its modern form did not exist before pioneering work in the late 1960s by Bill Stapp and colleagues (Stapp et al. 1968). Early programs did not include climate change—scientific findings at that time merely speculated that it might happen (Weart 2013). Nevertheless, Stapp's work presaged the heart of political ecology, i.e., the connections among environmental impacts, politics and social conditions, and environmental education.

After the 1990s, climate change entered environmental education based on extensive reports from the UN's Intergovernmental Panel on Climate Change (IPCC). Recently, IPCC reported that climate change posed serious global threats to environmental stability and human wellbeing and required international cooperation to combat (IPCC 2021). The IPCC's reports identified the release of carbon dioxide and methane, predominantly from use of fossil fuels, as the major greenhouse gases causing the earth's average surface temperature to rise (IPCC 2007, 2018). In turn, higher temperatures forced changes in the climate patterns to which human life had adapted. Most climate scientists and environmental educators concluded that such changes required mitigation, meaning reduction or elimination in the uses of fossil fuels, or a way to capture and bury the two gases unleashed by production and use of coal, oil, and natural gas.

Environmental curricula incorporated the need for mitigation and identified multiple pathways for reducing emissions of the two primary greenhouse gases. Simply stopping use of fossil fuels, however, was not an option: they enabled the existence of prosperous, modern, developed societies (Smil 2016; Perkins 2017). The public and government officials could not countenance discarding the services and benefits of fossil fuel–derived energy.

How, therefore, was mitigation to be accomplished? *Energy efficient technology*, like LED lights, could maintain benefits while using lower amounts of fuel. *New habits*, such as using mass transit instead of cars, could conserve fuel use but maintain mobility. *Capturing the gases and burying them* (carbon capture and storage (CCS)) could keep them out of the atmosphere and oceans by putting them underground.

However, simply using lower amounts of fossil fuels slowed, but did not stop, emissions and the progression of climate change. As useful as efficiency, conservation, and CCS might be, elimination of emissions in the first place was essential. That required a transition in energy systems and meant switching from fossil fuels to other energy sources with zero or low emissions (decarbonization) and delivering energy services with electricity (electrification). We used ideas from political ecology to visualize the challenges involved.

Political ecology and frameworks for teaching energy

Political ecology does not have a precise definition, but it incorporates a research agenda focusing on interactions among (a) political economy (the creation and distribution of wealth entangled with the exercise of political power), (b) the politics of knowledge (exercise of political power to shape the objectives and purposes of education), (c) ecology (the distribution and abundance of organisms shaped by the physical environment), and (d) environmental changes (physical changes that affect biological and social functions) (drawn from Meek and Lloro-Bidart 2017).

Our previous experiences in teaching energy issues to undergraduates and graduate students (Box 1) drew upon ideas from political ecology to develop the socio-political ecology framework, which helped students see and understand pathways involved in taking natural resources (primary energy sources) from raw materials to energy services (Fig. 1). The political ecology and socio-political ecology frameworks attracted us because of their utility in explaining various environmental issues and problems.

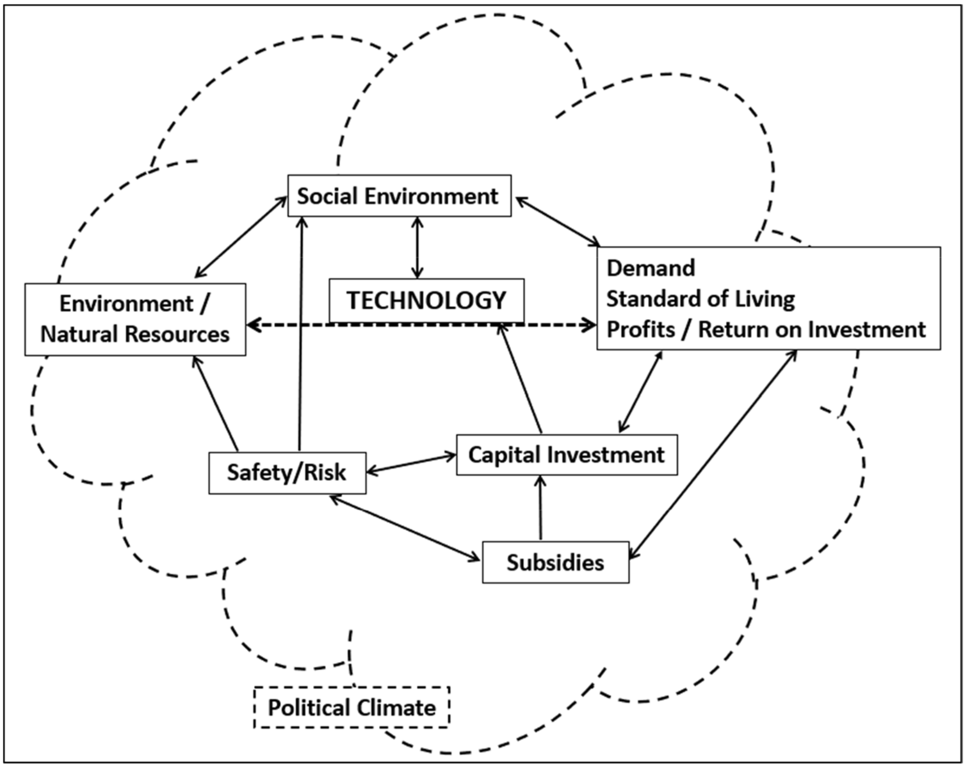

Fig. 1 The socio-political ecology of energy: understanding the connections between society, natural resources, demand for energy, and investments in technology

Box 1 Authors' teaching experiences leading to proposed framework

Energy Matters: Building the Path to Sustainability—Framed discussions of the U.S. and global energy economies, their problems, and avenues for reconstructing them around the major sources of energy: coal, oil, gas, hydropower, nuclear, solar, biomass, wind, and geothermal

Electrons to Renewable Energy Credits: An Introduction to Electricity and Electricity Policy—Reviewed the basic concepts of electrical generation and the evolution of electrical and energy policy in the United States, setting the stage for discussion of the transition from the centralized, grid-tied electrical system to a more renewably sourced, decentralized one

The Promises and Pitfalls of Clean Energy—Based on the premise that decisions to invest in clean or renewable energy now and in the future depends on the types of policies in place to support that investment (such as feed-in-tariffs or production tax credits), the political and industrial will to move away from fossil fuels, and social pressures for greener economies. Still, even "clean" energy technologies have impacts on the environment, the locality, and society itself

Climate Solutions in a Diverse World—Acknowledged that developmental pathways and technological changes, especially those taking place beyond Europe and the United States, can transform societies and energy systems. In addition, those systems may serve as models for making *all* energy systems more sustainable

Ecological and Social Sustainability—Adopted an interdisciplinary, systems-thinking approach to understand coupled natural/social systems as they related to global climate change. Intertwined topics included the carbon cycle over geologic and modern time scales; scientific evidence for climate change, including the contributions of energy production and consumption; concepts of resilience and thresholds; the understanding and communication of uncertainty; and environmental justice

Political ecology first emerged in the 1970s to help explain the connections among economics, politics, and nature. It built on the ideas of political economy (with its attentions to historical processes, structural forces, distributions of power, and institutional activities as they shape economic outcomes), but with a focus on the impacts of those human economic systems on the natural world (Blaikie and Brookfield 1987; Greenberg and Park 1994; Robbins 2004).

Perkins (1997) used political ecology to explore the role of changing technology in the Green Revolution of the 1950s and 1960s—in that case, the technology included new fertilizers and high-yield crop varieties which led to increased agricultural output and food production around the world, but also decreased crop diversity and increased the dominance of large, highly mechanized farm operations and large agrochemical companies in the food supply chain.

More recent work has relied on political ecology to better understand the power and politics of waste management (Cornea et al. 2016) and of clean water access and wastewater disposal in urban and peri-urban environments in India (Karpouzoglou et al. 2018); the role of "expert" knowledge in environmental impact statement development and the increased marginalization of artisanal and small-scale miners (Spiegel 2017); the role of government in supporting multinational corporation's role in the deforestation associated with palm oil farming (Bennett et al. 2018); the imposition of property rights and power structures, and the accompanying processes of exclusion that accompany state-backed forest conservation projects in the Global South (Asiyanbi 2016); and infrastructure standards—the institutional efforts necessary to create standardized environments (such as canals) as a precondition for worldwide economic integration and maritime transportation (Carse and Lewis 2016).

In the energy realm, political ecology has been used to explore the locus of political power associated with the spread of renewable energy projects in Europe (Dunlap 2020) and throughout the Global South (Ahlborg and Nightingale 2018; McCarthy and Thatcher 2019). Moore (2019) developed an extensive case study of proposals to install large solar farms in Morocco and transmit the electricity to the European Union. As a result of these studies, we have a better understanding of the political power dynamics associated with siting these projects, the increasingly uneven distributions of costs and benefits that result from imbalances of political power, and the contested domains of energy resource control.

In our earlier socio-political ecology framework (Fig. 1), technology mediated between societal and business demands and the resources of the natural environment. We acknowledged the policies and politics that created the context within which energy decisions were made, a context that changed from place to place and over time. We emphasized the roles of people in creating technology, shaping economic systems, affecting power dynamics, and tapping environmental resources, as well as the reciprocal impact of all of those on people—the social environment (Saul and Perkins 2014; Perkins 2017; Saul 2017). We also drew attention to the role of capital investment and issues of risk and safety as they pertained to the choices between fossil fuel–driven technologies and renewable ones.

Useful as the framework was, however, we learned of the need for a more elaborate framework to explain the energy system and the social context surrounding energy economies. We knew that energy systems required continual investments to function, but the challenges of high decarbonization and electrification indicated the need for more details. We had too easily assumed that—if engineers could transform renewable energy sources to electricity at a cost on par with or lower than existing sources—decarbonization and electrification would proceed. Lack of public understanding and political debates, however, hindered necessary levels of investments in a decarbonized, electrified energy economy.

For example, two episodes of rolling blackouts afflicted customers in California in 2020 (due to extreme hot weather) and Texas in 2021 (due to extreme cold weather). These two extreme weather events launched debates between critics and supporters of renewable energy. Governor Greg Abbott (R, TX), for example, blamed the failure of his state's electric grid on failure of Texas' wind power. Unfortunately for his argument, most of the power generation shut down by cold weather used natural gas (Mena 2021). The *Wall Street Journal* sniped that California's rush to decarbonize its economy had led to insufficient capacity to use natural gas to generate electricity (*Wall Street Journal* 2020). More even-handed analyses of both events revealed a more complicated situation than politically motivated attacks (California ISO 2021; "KSAT Explains," 2021; Sparber 2021), but the facts of grid collapses spotlight the fundamental importance of public and private emotional, intellectual, and financial investments in decarbonization and electrification. Other events also pointed to the reality of entrenched interests fiercely resisting, obfuscating, and misleading about climate change and energy transition (For example, Dunlap and Brulle 2015; Stokes 2020).

Students as citizens must be literate enough about energy systems to understand the role of investments in decarbonization and electrification. They must also understand how energy transitions based on new energy resources and technologies will trigger socio-political factors affecting resources, communities, and skills needed. Social and economic inequalities will arise, and future citizens will decide the methods for addressing these consequences of transitioning to new energy systems. Visualizations like those provided here allow students and citizens to better understand the many components of energy systems and how they interact, the points at which they can influence the system, and positive and negative feedback loops.

Energy Regulatory and Industrial Complex and the Energy Investment Cycle

Derived from political ecology, our new framework highlights the perpetual cycle in which investments produce the services and wealth of modern societies: the Energy Regulatory and Industrial Complex (ERIC) and its embedded Energy Investment Cycle (EIC) (Fig. 2).

At the center of the framework lies its core proposition: the perpetual flow of investments creating and maintaining energy systems, which we discuss further in the next section. To mitigate the worst risks of climate change, investments must, within a decade or two, increasingly develop energy sources (a) without carbon emissions and (b) with electrified energy services. Decarbonization means stopping investments that support the development and use of fossil

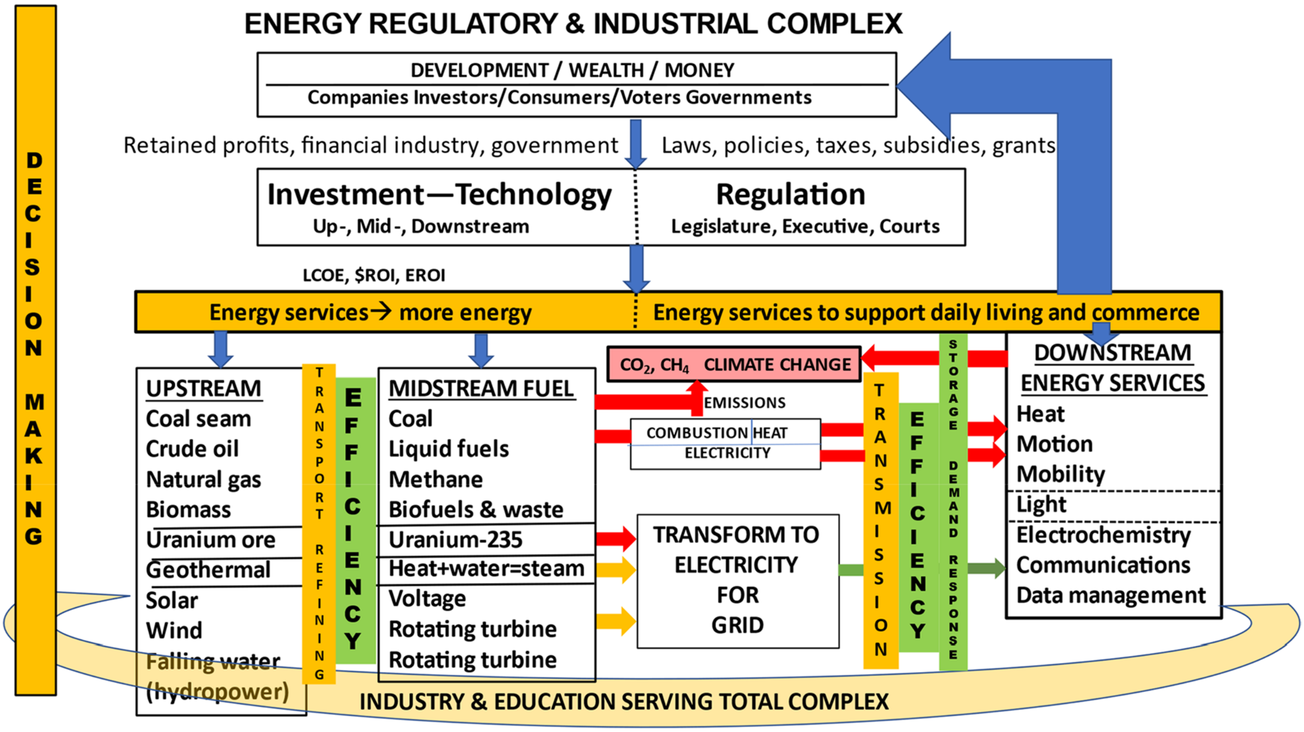

Fig. 2 The electricity regulatory and industrial complex and its energy investment cycle

fuels, and electrification means investing in infrastructure and devices to supply energy services with electricity.

ERIC portrays a system. A system is composed of interconnected elements, organized in a coherent way to achieve something—a function or purpose (Anderson and Johnson 1997; Meadows 2008). The interconnections between the elements describe how they feed into or relate to each other (Arnold and Wade 2015). A system identifies interdependencies among technology, natural resources in the environment, supplies of and demand for energy, and policy. It does not predict behavior or ask "what if" questions (see Meadows 2008; Arnold and Wade 2015). ERIC aims to organize and describe a system with flows of energy and wealth from energy services through key steps of the energy system. It also shows locations releasing greenhouse gases.

ERIC depicts an embedded *perpetual cycle of investments* needed to build and rebuild the knowledge and the material infrastructure needed to deliver energy services. Without investment, no energy services exist; only investments directed to appropriate ends can accomplish decarbonization and electrification to mitigate climate change. Investment and investment decision-making are inherently social activities. Cultural norms and public policy guide investors, and their decisions reflect worldviews, values, concerns for the social benefits or health impacts, and the attitudes of peers (Chassot et al. 2014; Masini and Menichetti 2013; Strantzali and Aravossis 2016). Social investment for sustainable growth currently attracts considerable interest (Deeming and Smyth 2018).

The modern, perpetual energy investment cycle emerged with the transformation of medieval agrarian societies to modernity, powered by coal and initiated first in England (Wrigley 2010). By the mid-1900s, modern societies relied on nine primary energy sources: coal, oil, and natural gas (fossil fuels); uranium (nuclear power); and solar radiation, wind, falling water (hydropower), geothermal heat, and biomass (renewable energy sources). With appropriate technology, these resources provided seven categories of energy services: heat, motion, mobility, light, electrochemistry, communications, and data management. People want these *services*, and they must use *primary energy sources* to achieve them.

Energy services currently derive directly from heat of combustion (fossil fuels, biomass) or indirectly from electricity, an energy carrier generated from steam turbines using heat of combustion to make steam. Renewable energy resources—especially solar radiation, wind, and hydropower—deliver services by transformation to electricity. These three renewable sources can supply large amounts of renewable energy (Delucchi and Jacobson 2011; Jacobson et al. 2015), and they are likely to comprise the bulk of renewable energy in the future. These three sources provide energy services by transformation to electricity, so the needed energy transitions require electrification of many services currently derived directly from heat of combustion: heat, transport, and many industrial processes.

Technology for *converting* solar radiation, wind, and hydropower to electricity is well developed, and further innovations will continue to improve conversion technologies. Renewable electricity generation, however, is intermittent, which necessitates storage technologies to permit use of that electricity at any time. Batteries and other storage technologies have improved remarkably in the past two decades and continue to do so (Bermudez 2017; Kittner et al. 2017; Koohi-Fayegh and Rosen 2020; Ma et al. 2021). Technology for *transmitting* and *distributing* electricity is also well developed. Investments in new technology and technological innovations have been spurred by a wide range of policies at the federal, state, and local levels, including investment and production tax credits, renewable portfolio standards, loan guarantees, grants, and rebate programs (aka subsidies) (Perkins 2017; Stokes 2020).

Electrification, however, has vulnerabilities, such as adverse weather and cyber-attacks. In addition, multiple renewable sources generating small amounts of intermittent electricity create other challenges, such as intermittency, the potential for power surges, and a need for voltage regulation. As a result, new types of electric grids and new regulatory patterns to support them will be essential to achieve as close to 100% renewable energy as possible. Investments must address these challenges, and ERIC visualizes the perpetual investment cycle, with which instructors can organize and systematically explore both technological and socio-political contexts relevant for new patterns of investment.

We begin our examination of ERIC with ENERGY SERVICES in the lower right, the desired objective of all investments in energy. Then, going up and counterclockwise, the material wealth of modern societies derives from energy services. Systems of modern money measure different forms of wealth—imperfectly—in units of currency. People in developed societies have, for example, more material things, do less physical work, have more food and water, and live in better and more comfortable shelters than do people in agrarian or hunter/gathering cultures. They accumulate goods, and, importantly, have an excess of money for new investments.

WEALTH/MONEY are controlled by people, organized into three categories: companies, investors/consumers/voters, and governments. People make decisions about investment in a context of REGULATION. The cycle continues to INVESTMENT, and TECHNOLOGY is the key to obtain primary energy sources, refine/transport them as needed, and use them to generate ENERGY SERVICES.

INVESTMENTS go into three steps that transform raw, primary energy sources to energy services. INVESTMENTS also go into ENERGY SERVICES deployed outside the cycle of producing new energy but essential for other economic activities and daily life.

- UPSTREAM investments make it possible to procure raw, primary energy sources, e.g., crude oil or a site rich in solar or wind energy.
- MIDSTREAM activities produce something ready to use, e.g., gasoline or voltage from a photovoltaic (PV) panel. (Some sources define MIDSTREAM functions strictly as transport of raw materials such as crude oil; refinement to gasoline in this definition occurs in DOWNSTREAM (EnergyHQ 2021). Our use of these industry-terms recognizes that transport and other events occur between both UPSTREAM and MIDSTREAM and between MIDSTREAM and DOWNSTREAM.)
- DOWNSTREAM: For most citizens and consumers, ENERGY SERVICES are the important—and most recognizable—feature of energy, and we designate them as the final or DOWNSTREAM end of the three phases. We identify seven categories of ENERGY SERVICES. Combustion of fossil fuels or biomass provides “Heat,” an ENERGY SERVICE when used directly, such as using natural gas for heating water or cooking. “Heat” can also provide ENERGY SERVICES indirectly, such as “Motion” (e.g., gasoline powering a chain saw) or “Mobility” (e.g., diesel fuel powering an automobile or truck). Combustion can also supply “Light,” another ENERGY SERVICE, for example by burning a candle (made from biomass or fossil fuels). Heat from combustion and from fission of uranium (nuclear power) can also change water to steam and generate electricity, which can power all seven categories of ENERGY SERVICES.
- Solar PV produces electricity directly from solar radiation, and wind, and falling water (hydropower) spin turbogenerators to produce electricity. Electricity from these sources can power all DOWNSTREAM services without

transformation to heat. Solar-thermal and geothermal sources can also supply heat for direct use, e.g. heating interior spaces or water, rather than transformation to electricity.

- Light is the only DOWNSTREAM energy service derivable from both combustion and electricity. Heat, motion, and mobility can derive from combustion directly or indirectly through electricity. Electrochemistry, communications, and data management require electricity.

When the cycle ends at the DOWNSTREAM energy services, it begins again as the producers of fuel and generators of electricity earn a return on their investments by selling their products to consumers, who in turn use ENERGY SERVICES to live and to produce WEALTH and MONEY. Energy companies invest part of their profits in a new cycle to perpetuate production of energy and ENERGY SERVICES.

As to amounts of MONEY involved, the next section summarizes current (2019) levels expended, mostly for production and use of fossil fuels. Over time, depletion of raw energy sources (e.g., exhaustion of an oil well), depreciation of infrastructure (e.g., power plants or devices using energy), and new technology require perpetual building and rebuilding. Thus, INVESTMENT must continue in perpetuity for sustainable energy services. If INVESTMENT ever stops, so, too, will energy services.

It can be easy to support funding for existing extraction operations, conversion facilities, and distribution systems as long as they continue to produce desired outputs. Moving off the well-worn path requires an interruption of the cycle, a diversion of funds to research and development or to lobbying for regulatory modifications, and new subsidies or protections. The Energy Policy Act of 2005, for example, aimed to inject new life into the aging U.S. nuclear power industry with its extension of the Price-Anderson Nuclear Industries Indemnity Act, loan guarantees for up to 80% of the cost of new nuclear projects, production tax credits of up to $125 million per year, cost overrun support for the first six new reactors, and almost three billion dollars for research and development related activities (Energy Policy Act of 2005). Despite that government backing, the expected nuclear renaissance did not materialize.

Note that Fig. 2 also depicts the support of multiple INDUSTRIES and EDUCATIONAL institutions. This support includes material infrastructure and expertise, both of which require continual investments to produce them. For example, passage of materials and/or energy through the three phases UPSTREAM to DOWNSTREAM and use of energy both require infrastructure (such as automobiles and highways to support "Mobility") and expertise (such as degree holders as technicians, engineers, and personnel for regulatory agencies). Similarly, so do auxiliary inputs between phases, for TRANSPORT, REFINING, EFFICIENCY, TRANSMISSION, STORAGE, and DEMAND RESPONSE. It's important to remember that ERIC and EIC cannot function without continual investments in supporting industries and educational institutions.

Finally, Fig. 2 shows the most dangerous unwanted side effect of current energy systems based on fossil fuels, CLIMATE CHANGE. Carbon dioxide comes from combustion of fossil fuels. Methane emissions, without combustion, occur at each of the three phases, from UPSTREAM to DOWNSTREAM.

Other environmental consequences could be added to Fig. 2, but this version avoids complicating the graphic. For example, each of UPSTREAM, MIDSTREAM, and DOWNSTREAM phases disrupts ecosystems, e.g., by mining, manufacturing, building infrastructure, and waste disposal. The framework (Fig. 2) can support teaching about the many consequences of ENERGY SERVICES. None of the nine primary energy sources is without its benefits and its undesired consequences. The intrinsic tradeoff of living in modern societies is that people and governments must balance benefits with harms. Investments ideally should go to processes and technologies with great advantages and minimal, tolerable downsides.

Money in the Energy Investment Cycle

Our earlier work (Perkins et al. 2014) alluded to the importance of investments in energy and climate education, but our proposed framework (Fig. 2) amplifies investment as a central component for energy education. We maintain that energy education should focus on the transition away from fossil fuels, and that transition requires a change in investment patterns. In this section, we present a brief overview of current investments each year in energy production worldwide.

The world currently invests $1.891 trillion per year (2019 dollars) to increase and replace fossil fuel and other primary energy resources needed to keep energy flowing. For example, the oil industry invested $470 billion in 2019 to increase and maintain fuel oil supplies and an additional $23 billion went into maintaining and replacing oil-fired electric power

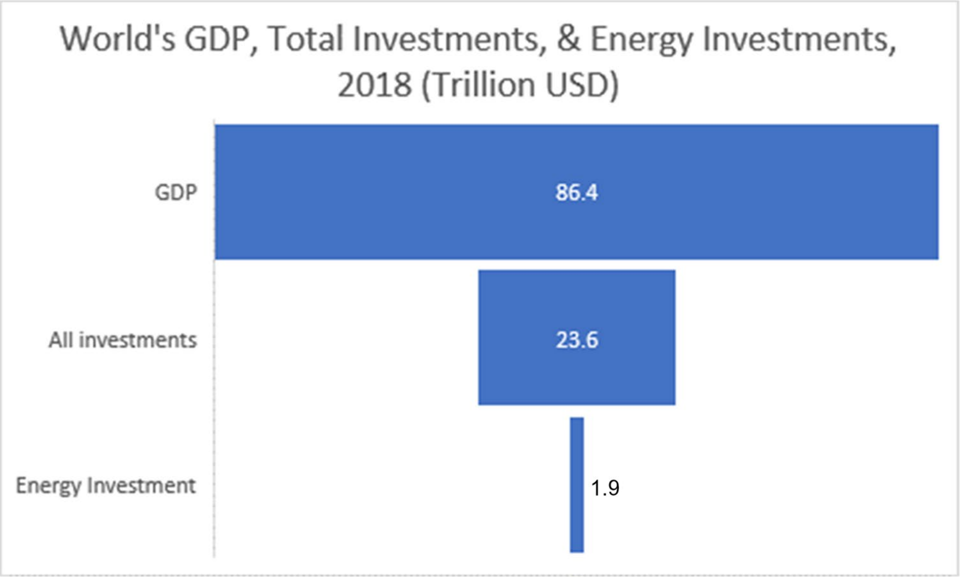

Fig. 3 Energy investments compared to all other investments and to world GDP, 2018 (trillion $US). Energy investments total $1.9 trillion

plants. This was a total of $493 billion, or 26% of the total. Total investment in fossil fuels to produce fuel and electricity totaled $976 billion, 52% of the total. In short, the majority of the world's 2019 investment in energy went to fossil fuels (International Energy Agency 2020).

Based on these estimates, the world has not yet begun channeling most of its annual investment dollars into renewable energy sources. In addition, solar, wind, and hydropower deliver their energy services via transformation to electrical energy, so some investments in these sources must go to electrical infrastructure. Since 2015, the percentage of funds going into renewable energy for electricity have remained about the same, around 15–16%. In 2019, the total invested in renewable energy (except biofuels) for electricity and energy efficiency totaled $560 billion (30 percent of total invested). Additional small investments also supported renewable energy by going to batteries and biofuels (International Energy Agency 2020).

Investments in energy are a part of total funds invested in all sorts of things every year and a small part of the world's Gross Domestic Product (GDP)—the total of all goods and services produced each year measured in dollars. In 2018, the GDP was $86.4 trillion, total investments were $23.6 trillion (27 percent of GDP), and energy investments were $1.9 trillion (2% of GDP) (Fig. 3) (World Bank (a) 2020; World Bank (b) 2020).

Energy investments may be a small part of the world's GDP and less than 10% of all investments. On this scale, they look trivial. However, energy investments are the foundation of both GDP and all other investments. Were energy investments to cease, the GDP and other investments would enter a steep decline, and economies would collapse.

Investments will not stop. Instead, the question is, “Will investors direct their efforts towards a transition to mitigate climate change, or will they continue along current pathways with most funds going to perpetuate uses of fossil fuels?” Regardless of the answers to this question, however, ERIC and its embedded EIC will continue to depict energy systems in the future. Changes will affect the specifics of investments, not the existence of perpetual investments.

A new direction for the Energy Investment Cycle

Moving the Energy Investment Cycle in a new direction involves multiple actors and institutions, and it will affect economies, politics, and cultures at local to regional to national to international scales. As argued earlier, todays' students will be tomorrows' decision-makers; they need to understand how to initiate change. Full treatment is far beyond the scope of this paper. Instead, we briefly illustrate two general principles and provide examples of proposals for the future.

First, every investment involves a decision by someone or some group to spend money to achieve a specific objective. Of all energy investment possibilities, however, choice of raw, primary energy source to develop and exploit towers over all other choices. A simple reason governs this paramount status: each of the nine primary energy sources has

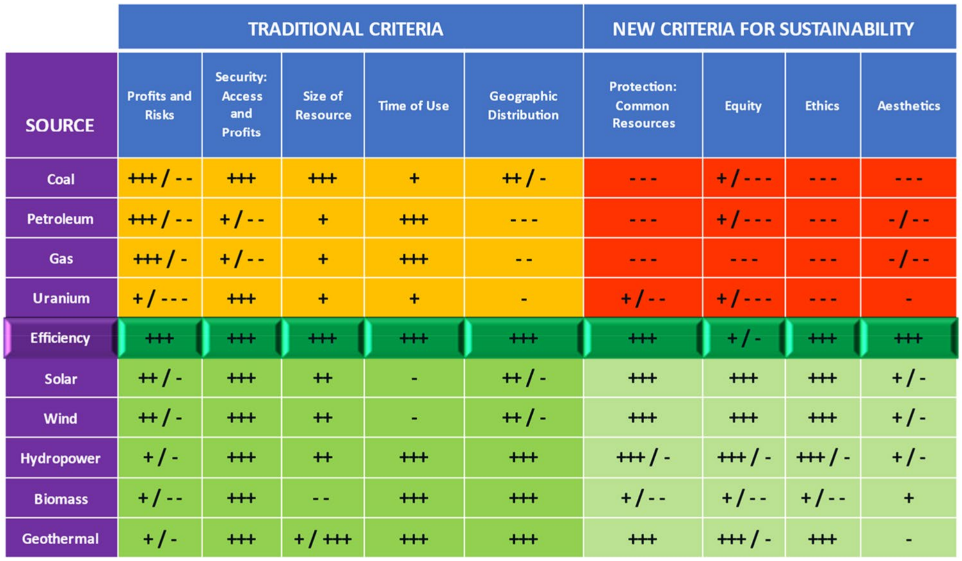

Fig. 4 Energy-sustainability matrix, a summary of strengths and weaknesses of energy sources in providing perpetual energy services. This is a tool for stimulating political and social discussions about energy investment decisions. Pluses (+) indicate strength and minuses (−) indicate weakness. See Perkins (2017, Chapter 10) for detailed discussion

	TRADITIONAL CRITERIA					NEW CRITERIA FOR SUSTAINABILITY			
SOURCE	Profits and Risks	Security: Access and Profits	Size of Resource	Time of Use	Geographic Distribution	Protection: Common Resources	Equity	Ethics	Aesthetics
Coal	+++ / - -	+++	+++	+	++ / -	- - -	+ / - - -	- - -	- - -
Petroleum	+++ / - -	+ / - -	+	+++	- - -	- - -	+ / - - -	- - -	- / - -
Gas	+++ / -	+ / - -	+	+++	- -	- - -	- - -	- - -	- / - -
Uranium	+ / - - -	+++	+	+	-	+ / - -	+ / - - -	- - -	-
Efficiency	+++	+++	+++	+++	+++	+++	+ / -	+++	+++
Solar	++ / -	+++	++	-	++ / -	+++	+++	+++	+ / -
Wind	++ / -	+++	++	-	++ / -	+++	+++	+++	+ / -
Hydropower	+ / -	+++	++	+++	+++	+++ / -	+++ / -	+++ / -	+ / -
Biomass	+ / - -	+++	- -	+++	+++	+ / - -	+ / - -	+ / - -	+
Geothermal	+ / -	+++	+ / +++	+++	+++	+++	+++ / -	+++	-

limited ability to substitute directly for another primary energy source (García-Olivares 2015). Some examples are obvious. If an investor directs money to produce natural gas, that investment cannot directly produce photovoltaic (PV) electricity; only an investment in PV panels can do that. Similarly, an investment to find petroleum deposits will not produce nuclear electricity; only investments to find and exploit uranium can do that.

A few investments can utilize limited substitutability of primary energy sources. For example, a coal-fired electricity-generating plant can be modified to use biomass or natural gas. Investments needed to achieve the substitution may be less than needed to build a new facility using biomass or gas, so some investments have gone along such pathways. Nevertheless, most investors consciously judge the wisdom of a prospective project by focusing specifically on only one of the nine primary energy sources and the service it can provide, e.g., find a good, windy place to erect a wind turbine to produce electricity.

Consequently, inability to substitute means the comparative strengths and weaknesses of each of the nine primary energy sources matters a great deal. Earlier, Perkins (2017, Chapter 10) developed a scoring method to judge each of the nine sources, plus efficiency, against each of nine criteria (Fig. 4). In this assessment method, the fossil fuels all had fatal weaknesses, because their use intrinsically releases carbon dioxide and methane, the greenhouse gases most responsible for human-caused climate change. Despite their long history of use and many benefits, further investments in these primary energy sources will inevitably threaten higher risks from climate change.

Second, investors know that a decision to invest involves risk. Investors may or may not make their money back, let alone make a profit. Seasoned investors are cautious and will avoid risks they judge excessive. However, in our fast-changing world, not even they have all the information they need to make solid decisions.

Consequently, every investment, even one like others in the past, is a step into the unknown. Many things can go wrong. Will the device or process work as predicted? Is a skilled workforce available for operations? Will customers buy it, and will the public accept it? Will future social, economic, and political constraints allow its use for the predicted lifetime of the device?

Government policies can ease investment risks but not eliminate them. Will the government change directions and cease favorable treatment? Support or mere tolerance for an investment at one time may disappear quickly. Investors may welcome a favorable regulatory environment, but they cannot count on it.

Specificity, comparative strengths and weaknesses, and potential for shifts by governments always guide investors, but risks remain. Three examples illustrate current developments affecting future investment decisions.

The first is a resolution passed in 2015 by the General Assembly of the United Nations, “Transforming Our World: the 2030 Agenda for Sustainable Development” (United Nations 2015). Highly aspirational, the world governance body put forth 17 specific goals for achieving a better life for every person on the planet. The resolution, however, lacked specific action plans, and some of the goals could interact negatively with each other. Nevertheless, it called, implicitly, for a sweeping restructuring of the world's political economy, an opportunity not to be squandered (Costanza et al. 2016).

Sustainable Development Goal 7 (SDG 7) focuses on energy specifically, "Ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations 2015, pp. 18 and 23). SDG 7 addresses both promotion of renewable energy and environmental/social justice. It calls for ending energy poverty, increasing the share of renewable energy in the world's economy, and improving energy efficiency. SDG 7 also calls for international cooperation to promote these aspirations in less industrialized parts of the world.

In the second example, two members of the U.S. Congress proposed a Green New Deal (GND) in February 2019 (Markey et al. 2019; Ocasio-Cortez 2019). The GND appropriately garnered an outpouring of attention, some positive and some not. In contrast to earlier efforts to shape the energy industries of the USA, the GND proposed the first actions truly commensurate with the size and nature of problems generated by the US' and world's reliance on fossil fuels.

Climate change—its current damages and its projected future catastrophic risks—drove the proposed GND's objectives: reduction of global greenhouse gas emissions by 40–60% by 2030 and net zero carbon emissions by 2050. Far more than a change in energy sources and technology, however, amplified the GND's grand scale. Renewable energy sources, energy efficiency, and other policies bolstered the "green" designation, but the GND also sought to ensure environmental and social justice. It advocated for participation in decision-making by those typically not consulted: workers, labor unions, local communities, people of color, and others, all disadvantaged by multiple economic changes over the past 40 years. This social component—inspired by the role of equity in sustainability—merited the designation of "new deal," a harking back to President Franklin Roosevelt's New Deal of the 1930s.

The GND has not yet become the policy of the USA. Important elements included in it, however, became part of the new infrastructure proposals of President Biden's administration in 2021. In contrast, its political opponents have ridiculed and turned it into talking points. Nevertheless, the GND turned debates about climate change towards a confrontation with socio-political-economic structures, a rhetorical reframing that may resonate better with citizens (Meyer 2019).

A third example promoting changed patterns of investment came from the International Energy Agency (IEA) in May 2021. This aspirational report described.

> . . . *the world's first comprehensive study of how to transition to a net zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal energy access, and enabling robust economic growth* (International Energy Agency 2021, p. 30).

Among other dependencies, the roadmap rests heavily on a substantial increase in investment in infrastructure supporting decarbonization and electrification while simultaneously decreasing investments aimed at production and use of fossil fuels. Much of the switch in investment patterns occurs between 2021 and 2030, but over the entire period 2021–2050, the annual average energy sector investment is only about 1% higher, as a proportion of global GDP, than it has been in the past 5 years (International Energy Agency 2021, p. 154).

Even if SDG 7, the GND, and IEA's roadmap have not yet made a new world for decision-making on energy investments, they all reflect two propositions: (a) changed investment patterns can produce technologically successful decarbonization and electrification and (b) the energy transition also includes social and environmental processes and goals. Dual dependence on both technological change and social-environmental factors makes attention to investment patterns a key point for environmental scholars.

Debates about investment will continue to include the necessity and/or feasibility of ending greenhouse gas emissions from energy. Unfortunately, these debates remain clouded by arguments that risks of climate change are small, even though anthropogenic climate change is real and happening now (Stern et al. 2016). Neoskeptical views hold existing evidence insufficient to predict catastrophic results (Koonin 2021). In addition, others contend the genuine benefits provided by fossil fuels are too valuable for improving human wellbeing and should not be discarded (Epstein 2014; Koonin 2021). Such arguments are not trivial or easily ignored; but we believe they miss important evidence. Acceptance of such skeptical views in the political arena indicate that environmental students should learn their strengths and weaknesses (Forinash et al. 2021). Investment patterns cannot change until such political and moral debates dissipate.

Changes to energy and environment curricula required

People across the USA have already had positive experiences with renewable energy resources and negative health and environmental experiences with fossil fuels. Why, therefore, has there not been more movement on the energy transition? Are health and environmental effects not well recognized and understood? Compared to the benefits and low costs of fossil fuels, do health and environmental effects not seem bad, or bad enough? Has a sense of inability to change something so ingrained as fossil fuel energy led to giving up? Do higher (and still dropping) costs of renewable energy, sunk costs in fossil fuels and related infrastructure, inertia of habit, and inconvenience of change explain the slowness? Or do the pursuit of wealth and the attributes of modern living impede change from a fairly certain situation to one characterized by more uncertainty? All these factors and more contribute to resistance or slowness to changing investment patterns.

Given these multiple factors, the key question centers on actions to inform and educate the public and students for future decision-making. Education that informs can enable people to think critically about possible technological, cultural, and political changes, but education by itself does not inevitably lead to change. Nevertheless, we conclude that the evidence indicating severe risks from climate change (e.g., IPCC 2021) makes the case for reform of education about energy. We propose ERIC as a framework showing (a) the centrality of investments in modern energy systems and (b) the linkages between energy services and atmospheric emissions of carbon dioxide and methane, the two most important greenhouse gases. Here, we briefly summarize major, current patterns in energy education. Then, we illustrate the utility of ERIC for new, enriched environmental education about energy, focusing on the imperative to alter investment patterns.

Currently, technical energy education tends to reside in engineering and the sciences instead of in environmental education: (a) the physics of energy, units and measurements, the laws of thermodynamics, energy systems, and renewable energy technologies (Belu et al. 2017; Cashman et al. 2005); (b) the need to include ideas of sustainability in engineering energy programs (Desha and Hargroves 2010); and (c) the suggestion that problem-based learning and case study analyses could help students understand the application of energy principles in the real world (Durrans et al. 2020). Some argue for closer ties between energy curricula and industry (Pecen et al. 2003). Others focus on the outcomes of energy programs, such as energy conservation (Cotton et al. 2015) or pro-environmental behavior (Patel 2017). History and our own teaching experiences have shown us that that such contents are necessary but not sufficient to spur the requisite transformation of our energy systems.

As indicated earlier (Box 1), courses we have taught focused on energy systems and their linkages to the broader policy context. We explored the energy resources available and their respective dimension of sustainability, contributions of fossil fuel emissions to climate change, justice issues related to resource extraction, facility siting, and access to electricity. In essence, we covered the natural resources/technology/demand axis of the socio-political ecology framework and the policy climate (Fig. 1). While we may have examined the first costs or perhaps the levelized costs of various of technologies, we did not delve deeply into the investments necessary to spur change from "business as usual" to a new energy future. As noted in the previous section, the key role of investment in energy transitions demands just that.

How would we add the energy investment cycle into courses on environmental education, climate change, and energy? Fig. 2 can help. First, students need to understand that energy resources, energy technologies, and investments in energy form an intricate system. As such, making changes in any one part has ripple effects throughout. Nothing happens in isolation. That means, too, that some changes may have unintended consequences and disrupt equilibrium in the system. Other changes may accelerate change to a new equilibrium state for the system. Many other elements of the entire system would need to readjust.

In short, ERIC and its embedded investment cycle are inherently dynamic. Investment decisions now are not the same as they were in 1950 or in 1900, and today's energy systems are consequently not the same. Changes now underway mean that investments in 2070 will not be the same as today, nor will the energy systems constructed decades from now be the same. Investors are constantly changing their decisions as technology, environmental consequences, government policies, and consumer choices change.

All energy educators, including those from environmental studies and sciences, participate in these changes as they produce new knowledge and accommodate technological, environmental, cultural, social, economic, and political changes. In six key areas, environmental educators should develop their courses and degree programs to include (a) the choice of primary energy source, (b) dollars flowing in investment streams, (c) upstream decisions, (d) midstream decisions, (e) downstream decisions, and (f) investments in supporting industries and education.

Some of these topics have obvious, strong links to specific disciplines, but others emerge from Fig. 2 and draw upon multiple perspectives. Brief sketches of each topic illustrate examples of the ways environmental education can enrich its coverage of energy (Box 2).

Box 2 Illustrative examples of topics on energy for environmental education

Introductory learning about energy and environment

Energy education in environmental studies is likely—especially at the introductory level—to be tightly linked to climate change education. In turn, solutions to climate change may include a necessity to reduce carbon emissions from uses of fossil fuels. Students in these classes, typically advanced secondary school students or lower division undergraduates, may learn best by starting with efforts to explore and visualize their local environment. After learning the basics about the physical nature of energy (see Forinash et al. 2021), introduce ERIC with exercises to visualize the energy system supporting a local area. Which energy services do students use? Their families and neighbors? What primary energy sources power those services? What company or agency supplies the energy? Who made the investments to enable the supplies of energy? What effects follow from the upstream to downstream processes to obtain energy services? What must happen to the local ERIC to mitigate climate change? Older and well-prepared students can sketch the local ERIC and pathways to transition in more detail and more quantitatively

Dollars flowing in investment streams

Dwyer (2011) argued for a baseline of understanding of the economic and social components of energy use, arguing that this will, in turn, result in more sustainable energy practices (and not just panic in the face of climate change). Following their review of the literature on renewable energy education and training, Kandpal and Broman (2014) call for a curriculum that covers "resource potential, existing technologies to harness them, economics and energetics of these technologies, and socio-cultural, environmental and institutional issues related to their development and utilization" (p. 6). In their survey of students at Finland's Aalto University, Mälkki and Paatero (2015) found that "Cost accounting and investment analysis" ranked 5th in the list of categories of knowledge students wanted to be exposed to, above "Energy policy" (ranked 9th), "Energy and greenhouse gases" (10th), and "Innovations in energy technology" (13th). ERIC can be used to help students visualize the role of economic principles, cost accounting and investments in the context of energy systems. For example, how do interest rates and changes in them affect choices of resources or technologies? What do interest rates tell us about how we, as a society, value the present versus the future? How have policies that offer tax credits for investment or production affected the comparative costs of various options and thus investments in them? What have been the impacts on the growth of clean/renewable energy? Furthermore, how can students account for elements not traded in a marketplace when conducting their benefit/cost analyses?

Upstream investment decisions

Exploitation and development of all nine primary energy sources begins with control of a defined area of the earth's surface, either dry or submerged under water. Development of energy means harvesting the source on or under the identified area: coal, petroleum, gas, uranium, geothermal heat, and biomass require extraction of minerals, removal of biological materials, or capturing underground heat. Development of energy from solar, wind, and water (hydropower) require controlling the extraction of energy from above the surface of the area. In short, development of all energy sources requires "land use" in the broadest sense

In other words, decisions about upstream investment decisions lie at the heart of multiple topics in environmental studies and sciences. Who controls the surface area? How was control achieved? Was it democratically achieved or did control follow military or political conquest? What adverse effects follow development of energy resources? Does development affect water resources? Does extraction release or leave toxic materials on the surface? Which ones? Are natural ecosystems affected? How much? Does removal of energy affect different groups of people unequally? Who wins and who loses? Are effects of removal reversible? How long does it take? What does the area look like after removal? Like a war zone of destruction? What policies and laws govern removal practices and technology? Is monitoring of affects or storage of wastes required?

Midstream investment decisions

Once development produces the raw material of the energy source, the raw material generally requires both transport and further technological processing to make it into the useful fuel. Crude oil, e.g., must move from wellhead to refinery for manufacturing gasoline or diesel fuel ready to use. Similarly, water backed up behind a dam must fall through a turbine to manufacture electricity. In some cases, midstream processes lie far away from raw material production. Crude oil may come from Saudi Arabia, but refining happens in Texas. Both transport and refining raise all the same questions surrounding upstream events. In other cases, consequences of upstream processes have unintended but unavoidable affects. For example, installation of wind turbines for electricity with low carbon emissions also creates unwanted affects. Residents disliking the visual pollution of the turbines may oppose or even block installation of them. How should environmental education portray conflict between efforts to mitigate climate change with maintenance of attractive visual landscapes (Aposstol et al. 2017)?

Downstream investment decisions

Substitution of solar, wind, and falling water (hydropower) for fossil fuels intrinsically requires electrification of devices downstream to use the energy. Heat from combustion of fossil fuels for mobility, for example, uses an internal combustion engine, but electrified mobility relies on electric motors. The electricity must come from onboard storage (batteries) or manufacture (fuel cells powered by hydrogen). An investment in electrified mobility technology, therefore, generally must precede ability to use low-carbon primary energy sources. Alternatively, but not yet commercial, renewable electricity could manufacture liquid fuels from atmospheric carbon dioxide and renewable hydrogen production (both midstream processes). All the questions about upstream and midstream processes encountered above, therefore, combine with new midstream processes to produce liquid, carbon-based fuels that don't add new fossil carbon to the atmosphere. Environmental education includes the types of analyses needed to enable mobility, e.g. airplanes, that is hard to electrify

Investments in supporting industries and education

At the end of 2020, about 3 million Americans worked in the clean energy sector (E2, 2021). Many people worked to produce, install, and maintain solar panels and wind turbines. Jobs in that sector also included hydrogen and fuel cell development, electric vehicle design and manufacture, grid modernization, and energy efficiency upgrades. In fact, in 2020, while 47% of jobs fell under the umbrella of repair and maintenance (of solar panels and wind turbines for example), 20% were in professional services, and 16% were in manufacturing. The fastest growing areas: clean vehicles, followed by grid modernization and storage

How can we best prepare students for energy jobs of the future? ERIC helps educators and their students understand the similarities and differences among the resources and technologies of the past and those of the twenty-first century. For example, the mechanical systems that once predominated are giving way to computer-based systems and "smart" technologies. Should we introduce them to the principles behind steam- and water-driven turbines and to the workings of the nacelle of a giant wind turbine? How do we best explore the positive and negative impacts of infrastructure investments that we now take for granted—the high voltage power lines that connect large dams to populations centers in the West, the underground network of power and cable lines that keep communications flowing, and the over 300,000 miles of gas pipelines crisscrossing the country? What kinds of resources, technologies, and investments will be needed to ensure an equitable level of energy services reaches people in increasingly remote locations in the United States and around the world? In other words, what do we need to teach students so they can be active participants in that energy future?

Environmental courses and programs would need to link topics like those in Box 2 directly to energy *systems*. Students would begin to think about costs and benefits or strengths and weaknesses, including the social and environmental costs and benefits, over the short and long term. Students would be encouraged to consider the destructive extraction of resources that feed nuclear, coal, and fossil fuel facilities as well as the inefficiencies of today's commercial solar panels, hydroelectric plants, and combustion engines.

Students in environmental courses and programs should be encouraged to dive deeper into the end uses of energy and potential alternative ways of achieving the same goal. For example, consider the following types of questions that can be inserted into environmental education:

- What might be the cost of replacing existing infrastructure to accommodate change? What methods, policies, and questions arise from using subsidies, taxes, rebates, loans and grants, portfolio standards, and exemptions that encourage the use of one resource or technology over another?
- How do carbon taxes affect companies, communities, and individuals dependent on fossil fuels?
- Why did expiration of wind subsidies have such an impact on that industry?
- What do numbers tell us? Are they derived in ways that inspire confidence? For example, students need to gain skills in critical assessment of numbers about emissions of greenhouse gases and quantitative consequences for climate, waste products from production and use of energy, land use required for energy production, and risks (probabilities) of harm from climate change or production and use of energy from different primary energy sources (see, e.g., Porter's *Trust in Numbers* 1995).
- What considerations defy reduction to numbers or to dollars? If these considerations are important and potentially generate conflicts, what avenues can lead to acceptable problem solving?
- How fast can transition happen once all dimensions of ERIC and investment become clear? Will the rate of transition be fast enough to prevent the worst, predicted ravages of climate change?

Conclusions

Energy services, derived through multi-faceted energy systems, enabled modern societies, and engineers have made these systems invisible to most people. If no problems arose from energy systems, such as climate change, invisibility would not matter. Sadly, many problems exist, ranging from climate change to other forms of pollution to habitat destruction and destruction of vital ecosystem services. On top of those immediate problems, long-term depletion of fossil fuels also threatens the future stability of modern life. In a word, the world's fossil fuel–driven energy systems lack the ability to sustain energy services on which most of the world depends for comfort, safety, prosperity, and survival.

ERIC and its embedded energy investment cycle provide a framework for exploring these issues in environmental studies and sciences. A key solution to ending invisibility of energy are methods to make energy systems visible. The frameworks we have developed from a political–ecological perspective provide one technique for unveiling what otherwise remains hidden or only partially visible.

The frameworks and diagrams presented here will help students to see climate change as a consequence of modern energy systems and to see the many components of the energy system needing reform to mitigate climate change. Other energy problems have other consequences not discussed here, and ERIC will assist development of skills to see how such problems relate to modern energy systems. For example, many energy issues exist as a nexus of problems with multiple natural resources, such as the energy-food-water nexus. In addition, energy poverty plagues many communities and areas; also, assets stranded by decarbonization and electrification will generate injustices needing amelioration. Our hope, however, is that the material presented here will play a constructive role in educating students, all of whom will become energy decision-makers in one form or another. They will need these skills in resolving many energy dilemmas.

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