Sustainable Energy for University Science Majors: Developing Guidelines for Educators

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ABSTRACT

This paper describes the basic tenets of a sustainable energy course for university science majors. First, it outlines the three core components of the course: 1. The scientific evidence for the connection between climate change and energy usage; 2. An analysis of the capacity and environmental impact of various renewable and traditional energy resources; 3. An overview of alternative pathways for the main energy usage in society—heating/cooling, transportation, and manufacturing. The course aims not only to present factual knowledge, but also to develop a critical approach for weighing between alternative energy solutions based on quantitative analyses. To meet these objectives, we suggest pedagogical considerations for organizing the content of the course, supporting student learning and raising student interest. For example, quantitative problems that can be investigated in the course are discussed as well as place-based examples of energy production from the local environment that can increase motivation for learning. Lastly, we suggest an agenda for research that examines the outcomes of sustainable energy courses that utilize place-based pedagogy. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/16-157.1]

Key words: sustainable energy, renewable energy, place attachment, undergraduate science courses

INTRODUCTION

Sustainability is a vision for human and environmental development that uses Earth's resources so as not to deplete them and minimizes the potential damage to the planet. Sustainability has many aspects, some practical—such as the effect of pollution and waste on health issues and some ethical—such as providing equity in the control and use of natural resources. However, if one topic is to be chosen as most important for sustainable development, it would be the management and use of energy (Raven, 2002).

The main issue at stake in relation to energy use is climate change. The December 2015 Paris Climate Summit has defined a global goal—keeping the average global temperature from reaching 2°C above preindustrial levels by reducing CO_2 emissions (Cornwall, 2015). The quantity of manmade CO_2 emissions is the product of four components: the number of people, services (per person), energy (per service), and CO_2 emitted per energy unit produced (Gates, 2010). Assuming that governmental actions that curb population growth (e.g., by limiting the number of babies per family in China) are unethical and that allowing the services people use (e.g., public transportation, indoor temperature control, lighting) to improve is an inherent incentive for economic and technological development, one needs to address the latter two factors—energy per service and CO_2 emitted per energy unit—to reduce greenhouse gas emissions. Energy per service is related to the efficiency of energy transformations. That is, to promote a more sustainable future, we need to find ways to increase the efficiency of the processes in which energy is being used to manufacture goods, move people and goods around, heat houses, etc. Although this factor is significant, the most important factor is investigating available energy resources as well as the environmental and economic tradeoffs that are incurred in using them. Solar, wind, and hydropower sources, as well as various nuclear energy resources, emit only marginal amounts of greenhouse gases in mining the materials for the power generators and building them (Hoffert et al., 2002). However, the utility of renewables like wind, hydro, and solar depends largely on the local climate and geography. Thus the aforementioned Paris Summit acknowledged that the actions that must take place toward achieving reduced greenhouse gas emissions vary among nations (Cornwall, 2015).

The central idea in developing a sustainable energy future is to supply the energy for the things people need, while making a minimal impact on the environment (e.g., CO_2 emissions, radioactive waste). This goal is achieved by legislation that incentivizes renewable energy production and requires manufacturers to raise the standards on the efficiency of appliances and devices that provide the utility for people (e.g., heating, transportation). However, understanding the path to a more sustainable future should not be limited to politicians or decision-makers since citizens can promote legislation in a free democratic society and adapt their own behaviors to reduce emissions (e.g., when building their homes, or choosing their means for transportation). Making a personal effort to reduce emissions is often a value-driven choice because it favors a hidden benefit (of the planet) over personal comfort. Thus, understanding the science of sustainable energy may affect public values and beliefs.

In reality, public understanding of energy related concepts in general, and their environmental impact in particular, is poor. Research reports have documented student difficulties in understanding fundamental energy-related concepts such as the law of energy conservation (Goldring and Osborne, 1994) and misunderstandings of issues related to alternative energy resources (Cheong et al., 2015). For example, about one-third of the students in the

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aforementioned study (Cheong et al., 2015) stated that all biodiesel products emit less greenhouse gases than regular diesel fuels, yet this is, in fact, false. The obscure public knowledge on these issues has tremendous political implications because it impairs the ability of citizens to make logical decisions that impact their future. This is indicated by a study on socio-scientific decisions of secondary school students related to renewable energy issues (Sakschewski et al., 2014). Thus, learning the scientific basis for sustainable energy should prepare people to make educated decisions when voting on energy related regulations (e.g., allowing natural gas fracking) and to provide knowledge on how to decrease their own greenhouse gas emissions.

Teaching the science of sustainable energy, as well as other scientific topics, should be tailored to fit its target population. Following Feinstein et al. (2013) we distinguish between educating those who enter the "STEM (science, technology, engineering, and mathematics) pipeline" and choose a career in science or engineering and the "Competent Outsiders"—people who are not trained in STEM-related professions but acquired sufficient resources for grappling with scientific questions in their everyday lives (e.g., in relation to health or nutrition). Sustainability education for the latter, nonscientist group aims at conveying basic competencies (Wiek at al., 2011) or "literacies," i.e., the central concepts, questions, and inquiry methods of the field. Such an approach is very limited in its consequences: For example, it may encourage people to "examine" their own Carbon footprint using a carbon calculator (Whitmarsh et al., 2009), but does not clarify the scientific models at the basis of the calculator. Science majors usually have background knowledge in chemistry, physics, and calculus and can therefore go beyond the qualitative conceptualizations of sustainable energy science. Thus, much like business and economics majors are more capable to scrutinize the financial logic of government policies than the lay person; science majors may have more tools to elevate sustainability-related debates from the slogan level to facts-based analyses. By getting acquainted with the sustainable energy landscape, and acquiring the appropriate tool set, science majors may become agents of change for shaping the public opinion about this complex topic.

The free textbook "Sustainable Energy without the Hot Air" (MacKay, 2008) by the late David MacKay is an example for a syllabus of a course that discusses the path to a sustainable future from a scientific perspective. It presents a rigorous quantitative analysis of the energy used by society, current major energy resources, and feasible alternative ones. It then applies the calculated quantities to suggest sustainable energy plans for the United Kingdom. Mackay's approach to applying the science of sustainable energy using a local example deserves some attention. As mentioned already, the Paris convention expected different investments from each country based on its wealth and contribution to global greenhouse gas emissions. This reflects not only the commitment to invest in developing sustainable technologies but also to adjust the solutions to the needs mandated by the country's local climate and available natural resources. Thus, for example, the cloudy weather in London, and the wind conditions off the shores of the United Kingdom mandate different investments in renewables than sunny desert climates in other places in the world, such as the American Southwest.

In this article we use a synthesis of textbooks and scientific papers to outline what we see as the essential components of a course on sustainable energy for science majors. We then suggest that place-based education can contextualize a course on sustainable energy, and suggest directions for future research.

CORE CONTENT OF SUSTAINABLE ENERGY COURSES FOR UNIVERSITY SCIENCE MAJORS

Sustainable energy is an emerging scientific field, and therefore its core ideas are not as established as in fields such as cell biology or thermodynamics. There were several attempts to establish guidelines for university sustainability courses for nonscientists or teachers (e.g., Warren et al., 2014; Wiek et al., 2013), these courses include a wide array of topics and not only energy issues. A group of researchers who investigated specifically the topic of teaching sustainable energy proposed a structure for a high school curriculum (Engström et al., 2011), but other than some textbooks, we found no clear standards for teaching sustainable energy for university science majors. In the following, we establish the fundamental tenets of a sustainable energy debate based on textbooks and classroom research.

The scientific aspects of the sustainable energy landscape are presented in several university level textbooks (Hobson, 2007). These vary from texts that are largely descriptive with little quantitative data (Schobert, 2002; Boyle et al., 2003) to ones that employ mainly algebra-based calculations (Mackay, 2008; Hinrichs and Kleinbach, 2013; Ehrlich, 2013) to calculus-based analyses intended for graduate level courses (Tester et al., 2005; Rez, in press). Most textbooks present the fundamental ideas of energy as an introduction, and dedicate a section to energy units and conversions. One textbook presents itself as suitable to an introductory level course for science majors and nonscientists (Hinrichs and Kleinbach, 2013) but most textbooks that utilize quantitative analysis rely on learners' prior knowledge in mechanics, electricity and magnetism, and thermodynamics (Mackay, 2008; Tester et al., 2005; Ehrlich, 2013).

Although the energy problem is multifaceted and complex, the synthesis of textbooks and articles reveals three essential components for presenting the sustainable energy problem and solutions. These main components are: 1. Setting the stage—the challenge of curbing global warming. 2. Getting acquainted with the various energy resources and their contribution to greenhouse gas emissions. 3. How to reduce emissions while maintaining the services needed for society.

The first component of the course encompasses the scientific evidence for anthropogenic global warming—the change in climate caused by humanity's unprecedented greenhouse gas emissions. It stipulates that humans are responsible for most of the increase in greenhouse gas in the atmosphere (mainly CO_2, but also methane and nitrous oxides). It also discusses the inability to offset CO_2 emissions through sequestration, either by planting forests or by other technological solutions. Finally, the first component of the course explicates why relying upon market forces (e.g., prices, supply, and demand) for solving the global warming problem is insufficient, and has to be supplemented by governmental investments in sustainable energy technologies that are not profitable in the short term but will be sorely needed in the future.

The second component of a sustainable energy course encompasses a detailed analysis of the energy resources that are used by humans. It includes an analysis of the traditional, fossil fuel resources such as coal, oil, and natural gas; a derivation of the maximum efficiency of these resources; and the chemical reactions that take place in the energy production. An important message emerging from this analysis is that producing energy from natural gas is better than coal because it is more efficient, thus producing less CO_2 and other contaminates per energy unit. This section of the course also discusses the opportunities and dangers in fracking such as releasing fumes of methane into the atmosphere. It then maps the alternatives to fossil fuel resources and explicates why solar power can be by far the largest and most sustainable source of non-fossil-fuel energy but that it requires a storage scheme for nighttime and cloudy days. Hydroelectric and wind power are the other two important sources that provide a substantial share of renewable energy production. Some people predict that these three renewables can supply all of the energy needed for the world by 2030 (Jacobson and Delucchi, 2011). Others posit that renewables are insufficient for supplying the world's energy needs with current technology and that nuclear power should play an essential role in reducing greenhouse gas emissions (Schiermeier et al., 2008). This point is illustrated in Mackay's words:

> *''We have a clear conclusion: the non-solar renewables may be 'huge,' but they are not huge enough. For a complete a plan that adds up, we must rely on one or more forms of solar power. Or use nuclear power. Or both.''* (Mackay, 2008, 238)

Other energy resources, such as geothermal, biofuels, wave, and tide are also discussed—but in less detail, reflecting their relevance to a global energy program (Schiermeier et al., 2008). The ''renewable'' energy resources are then scrutinized, by considering their ''sustainability'' in light of their cost, their potential to reduce greenhouse gas emissions, and other risks that they may cause. For example, biofuels produced from sugar canes or corn is a renewable energy resource, but it is not sustainable because its combustion produces CO_2 and because the growth rate of crops is too slow for providing the energy needs of a developed country. The main ideas related to the second part of the course are summarized in Table I. Finally, an important take-home message in this part of the course is that although greenhouse gas emissions can be radically reduced, it is impossible to completely eliminate fossil fuel combustion with the current technology and level of services. For example, there is currently no alternative for using fossil fuels for transatlantic flights (assuming that people will continue to fly between continents) or to transfer electricity produced in solar power plants in places with abundant sunlight (e.g., the Sahara desert) to other places. Therefore, research should continue to pursue energy resources (e.g., nuclear fusion) that are currently impossible to harness and means to transfer energy efficiently from place to place (Hoffert et al., 2002).

The third component of the course is an analysis of energy usage by society. It is organized by the major utilities people use: buildings (heating, cooling, and lighting), transportation (of goods and people), and manufacturing. In western societies, each accounts for about one-third of the overall energy use. As shown in Table I, this part of the course includes an analysis of the energy required for heating and cooling at different temperatures, insulation, and building architectures. In addition, it entails a comparison of the energy efficiency of various means of transportation, based on physics models such as air drag, torque, and heat engines. Finally, this part of the course analyzes the energy that is used in manufacturing and goods such as growing crops, raising cattle, and making other products, and the contribution of recycling to reducing energy consumption.

These three components are, in our view, essential for conveying a thorough picture of sustainable energy science. The introduction on global warming and its relation to energy at the outset of the course is essential for setting the stage for the subsequent discussion. The distinction between the latter two components of the course—energy resources and energy consumption—is not rigid, and can therefore be organized in various ways.

BEYOND CONTENT OF SUSTAINABLE ENERGY COURSES: ROLES OF PLACE AND VALUES

Sustainability education aims not only at building student knowledge, but also at promoting certain norms and behaviors. Universities have declared that it is their duty to propagate environmental literacy and to promote the practice of environmental ethics in society (CRE-Copernicus, 1994). Developing knowledge about sustainable energy options enables better decision-making on the subject. However, knowledge alone is insufficient for explaining the ways people think about environmental issues such as climate change, and develop a pro-environmental attitude and behavior. For example, political party affiliations have a significant effect on people's acceptance of the veracity of human-influenced global warming (McCright et al., 2016). Culture is also an important factor in how people interpret the physical landscape and relate to sustainability issues (Apple et al., 2014) and adopting pro-environmental views is strongly related to people's emotions such as the love of nature or fear of environmental disasters (Kals and Maes, 2002). Therefore, university courses addressing sustainability or global warming should accommodate students' emotions and cultural perspectives, and relate to them.

Altering the pedagogical focus of geoscience courses can be useful not only for learning content, but also for developing norms and values (Yacobucci, 2013; Foley et al., 2015). For example, estimating the amount of emissions that result from producing one pound of red meat and comparing it with growing the same amount of grain such as soy, may lead to preferring diets that curb or eliminate meat consumption (Gossard and York, 2003). People who decide to change their behavior to reduce their environmental footprint believe that the state of the planet is more important than their personal needs. Such value-driven

TABLE I: Main ideas in sustainable energy conveyed in the course.

Energy Resources (Component II)	• All forms of alternative energy sources are location dependent. Solar does not contribute much in cloudy areas, geothermal is limited to few locations along fault lines, wind turbines are useful only in places where there are constant strong winds throughout the year, and hydropower requires a water source and significant elevation differences.
	• Alternative energy resources such as wind, solar, tide, and wave must be supplemented by a complementary storage scheme such as hydroelectric power, battery power, or latent heat storage.
	• Replacement of coal-based power plants with natural gas-based combined-cycle power plants reduces CO_2 emissions.
	• The best current solution for reduction of CO_2 emissions in places where sunlight is not abundant is replacing coal by hydropower (if available), nuclear power, or combined cycle gas turbines.
	• Giant solar farms in the deserts of the Sahara, Middle East, or Southwest United States will help only with an efficient technology for transferring the electricity over long distances (currently not practical, due to losses in transmission lines).
	• The common process used in nuclear power plants today is nuclear fission. The energy source that should be developed for the future is most likely, nuclear fusion.
Energy Use in Services (Component III)	Energy Used in Buildings:
	• Heating—Use heat pumps for heating and air conditioning for cooling, with the exception of very cold climates. Energy consumption is determined by insulation, size of building, but most importantly by the "degree days" measure. Places closer to the Earth's poles have colder climates and require more heating.
	• Lighting—Smart window planning and replacing incandescent lightbulbs with LEDs or fluorescent lightbulbs.
	• Water heating—Solar thermal water heating should be used in a sunny weather.
	Energy Used in Transportation
	• An electric train is the least polluting form of transportation.
	• Diesel engines are slightly more efficient than gasoline one (Otto cycles). If people have to go by car, electric/hybrid is the least polluting in terms of greenhouse gas emissions.
	Energy Used in Manufacturing:
	• Energy can be reduced by consuming less meat, which requires much more energy input per nutrient value than grains and produces more methane.
	• Energy is needed for producing steel, cement, plastic, silicon, and aluminum and can be reduced by recycling (e.g., recycling aluminum reduces energy use since extracting the metal from the ore requires much energy). Some forms of recycling are more questionable from an energy standpoint (e.g., plastic, glass).

beliefs can be cultivated in sustainability courses through discussions of facts and estimates or integrated into course activities such as lab work (Surpless et al., 2014). Research showed that university lab sessions that introduced geoscience concepts using social and historical context of places, were perceived by students as more engaging and meaningful than any equivalent laboratory section (Kirkby, 2014).

Another way of developing interest and values is to relate to students' sense of place (Apple et al., 2014). Sense of place is a measure of the meaning people give to a place and their attachment to it (Semken and Freeman, 2008). Thus, sense of place is a combination of the cognitive salience of the place in people's mind and their emotional relation with it. An increased sense of place is related to people's willingness to conserve and maintain the environment (Stedman, 2002). We suggest that place-based education in university courses can promote transformative learning of sustainability through cognitive, emotional, and active pedagogies, i.e., engaging "the head, heart and hands" (Sipos et al., 2008). However, there has not been much research on how it can play out in building students' knowledge about sustainable energy and in influencing their views on sustainable, environmental choices.

ADDITIONAL PEDAGOGICAL ASPECTS FOR PRESENTING SCIENCE OF SUSTAINABLE ENERGY

In addition to presenting sustainable energy ideas through the context of place, we recommend a few other guidelines to streamline the variety and complexity of topics involved. The abundance of details concerning the structure and function of electric power generators, the considerations in examining the least polluting form of transportation, or the most efficient appliances, require some organizing principles to make the content manageable. To that end, we suggest highlighting the "big ideas" (e.g., greenhouse gas emissions should be reduced; the energy in sunlight contains much more energy than needed by society), and presenting a small number of simplified models of processes, fundamental laws, and actual quantities. In addition, we acknowledge that the content of a sustainable energy course should be flexible enough to accommodate energy innovations, and socio-scientific debates in the field (e.g., tradeoffs in natural gas fracking). To meet these unique requirements, we suggest that a course on sustainable energy should take into account the following guidelines:

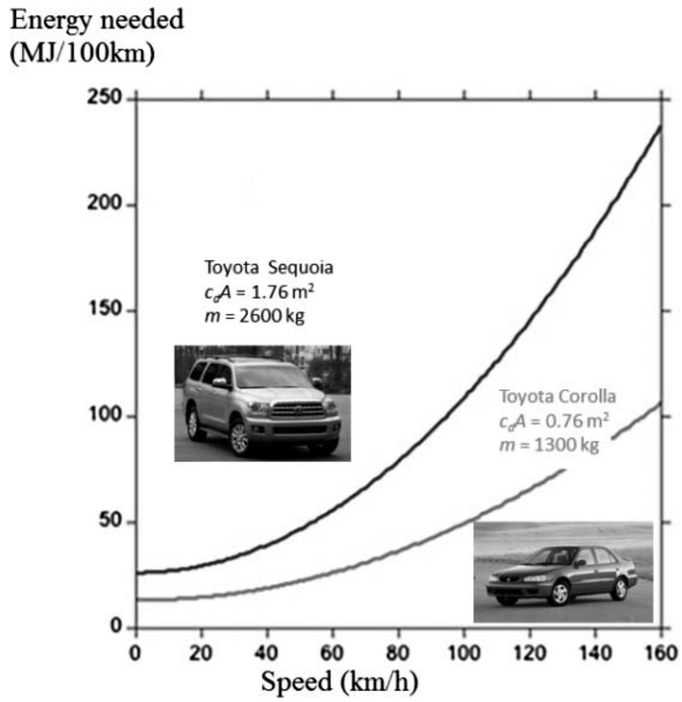

FIGURE 1: Illustration of the energy needed to drive 100 km in two types of vehicles. The difference is related mainly to air drag which increases with speed.[3]

1. Course content should reflect the practicability of available resources for a sustainable energy plan—the course should discuss both conventional and alternative energy resources that make sense *locally* and globally (e.g., solar photovoltaic or solar thermal) and de-emphasize solutions that do not (e.g., tide-based generators along U.S. coasts where tides are not significant). This guideline reflects the application of place-based education, because the resources of the local area are discussed in detail.
2. Comparisons are instructive. To be able to identify significant aspects in the energy landscape, students need to develop a "feeling" of the relevant quantities (e.g., kg CO_2 per km per person) of alternatives (e.g., car or SUV) and to compare them. Comparisons such as the one shown in Fig. 1 are very common in textbooks (e.g., comparison between bike and car in Mackay, 2008, 257–259).
3. Numbers are not arbitrary. The maximum efficiency of devices such as diesel heat engines or wind turbines are not just random numbers. They are derived from fundamental principles such as the Laws of Thermodynamics or Betz's law.
4. Focus on the main features of systems. The purpose of the course is to provide an overview and not to dwell on engineering details or the cost-effectiveness of specific devices unless these are absolutely necessary for understanding a concept. For example, when quantifying the energy used in buildings we neglect the energy needed for devices such as phone chargers, which is much smaller than the energy needed to heat water for showers, lighting, cooking, etc.

Guidelines 1 and 2 epitomize the "Modeling Instruction" learning approach (Hestenes, 1987) in which students are trained to analyze problems by building simplified models of the system, and applying the laws of the theory to make predictions or build explanations.

5. Provide concrete examples for energy use from local and familiar places or institutions. For example, we can calculate the energy needed for cooling and lighting the building in which the lessons take place and compare the calculation with the actual electricity usage. To understand larger scale considerations, an engineer from a local electric power company can explain how renewables are integrated into the power production scheme.
6. Use scientific facts to challenge questionable solutions. For example, when asking if biofuels are sustainable, one needs to analyze the energy yield of photosynthesis as well as the growth rate of plants, and conclude that growing biofuels is not an effective land use for reducing greenhouse gas emissions compared to other methods such as solar or solar/thermal. Convincing oneself that some popular solutions to socio-scientific problems is problematic from the scientific viewpoint is crucial for developing critical thinking and being able to investigate such controversial issues when they occur (Kolstoe, 2006).

Guidelines 1 and 5 reflect place-based learning, and the others reflect the effort to make the content coherent and to cultivate critical thinking. We do not make any recommendation regarding the learning style in the course, and leave that to the preferences of the instructor and the number of students enrolled. A course can be lecture based, or utilize a "flipped classroom" in which students read the relevant chapter or watch a video lecture prior to class, and then discuss it in class in the context of peer instruction (Mazur, 1997). Because a course on sustainable energy usually presents quantitative analyses of systems, we recommend in-class or homework assignments that include calculations of comparable options of transportation, heating, or other forms of energy usage. This component can reflect an active, hands-on comparison of energy flow in systems that are of interest to the students such as electric cars versus hybrids, airplanes versus fast trains, etc. The culminating signature assignment can be either an exam or a research paper, depending on the class size, platform (online / on campus), and availability of teaching assistants.

EVALUATION OF SUSTAINABLE ENERGY COURSES: AGENDA FOR RESEARCH

We argue that the learning objectives of sustainable energy courses for science majors encompass knowledge gains as well as attitudinal changes. These, in turn, mandate an evaluation that inspects student growth along two trajectories: cognitive and emotional. To evaluate conceptual

[3] This graph is derived from the expression, Energy/distance = $F_D = \mu_{rr} mg + \frac{1}{2} c_d A \rho v^2$, where c_d is the air drag coefficient, A is the surface area, ρ is the air density and v is the speed, m is mass of the vehicle and μ_{rr} is the coefficient of rolling resistance (friction).

understanding of the topic, survey instruments similar to those used in Cheong et al. (2015) or in Sakschewski et al. (2014) should be developed for the undergraduate level. These should be combined with attitudinal surveys of approaches toward sustainable energy policy and everyday choices of consumption, housing, and transportation. In addition, questionnaires such as the place-attachment instrument (Williams and Vaske, 2003) should be incorporated to evaluate students' attachment to the place that serves as the main context for place-based examples in the course. To compare students' attitudes towards sustainable energy issues at the beginning and end of the course, one will need to compare posttest to pretest results. Specific aspects of the curriculum such as the role of place-based education can be studied using quasi-experimental comparisons of courses in which the connection with places is related to the core content (through field trips or videos) and similar courses that do not emphasize this connection.

CONCLUSION

This paper lays foundations for teaching the science of sustainable energy to science majors. We outlined the importance of teaching science majors about this subject, as well as main ideas that should be included in the course. Then, we suggested several pedagogies for presenting the topic, specifically, presenting energy issues within the local context in the spirit of place-based education. We believe that sustainable energy education is of crucial importance and intend to continue investigating the topic in order to promote its teaching and learning in STEM programs.

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