Viewpoint

Catalyzing climate solutions through energy and carbon education

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Decades of hard work by scientists, teachers, journalists, and other societal actors have led to general public acceptance that the climate is rapidly changing. The evidence is obvious in record-setting temperatures and the increasing number and severity of wildfires, droughts, and floods. With growing renewable electricity production there is also increasing optimism that we can peak or slightly reduce carbon emissions by 2030 and greatly reduce greenhouse gas emissions by 2050. Despite the rising public awareness about climate change and the rapid growth of renewable energy, however, global CO_2 emissions from fossil fuel and energy use per person (capita) continue to increase (**Figure 1**). From 2000 to 2023 the average annual per capita global energy use increased by 22%, from 18,000 to 21,000 kWh/cap-y. The increasing rate in the past decade appears slower than that between 2000 and 2010, but except for notable declines during the recession of 2010 and COVID-19 in 2020, the rise in energy use continues essentially unabated.

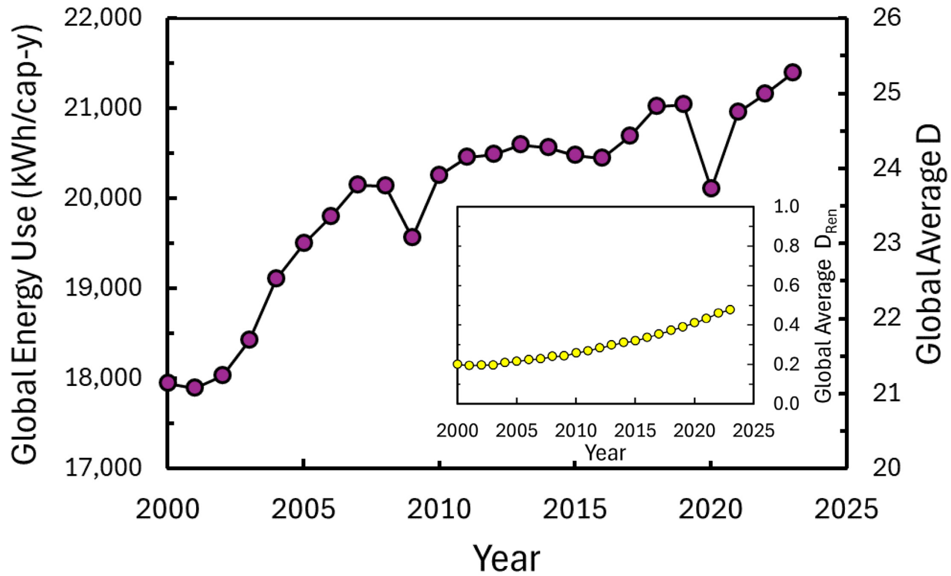

Figure 1. Global annual primary energy use per person (cap) and daily average primary energy use based on D where 1 D is the primary energy relative to daily food energy per person. Inset: average daily renewable energy use in units of D_{Ren}, from 2000 to 2023. (Data source: https://ourworldindata.org/)

The path to climate change mitigation starts with education. Effectively addressing climate change begins with widespread education on how fossil fuel energy use and other activities, such as land use change and certain chemicals (such as refrigerants), contribute to greenhouse gas (GHG) emissions. As we have seen in other situations,[1] effective climate solutions will ultimately require both education and policy changes that lead to adoption and enforcement of new laws and regulations . For example, Calorie labels on food items does not consistently reduce average consumption of higher calorie meals[2] despite general acceptance that overeating and obesity contributes to poor health. Warning labels on cigarette boxes helped reduce smoking but a substantial reduction in the number of smokers was achieved through new policies and laws that banned smoking in public areas. Successfully addressing climate change requires widespread education to lead to general knowledge about how our choices and changes in personal activities influence climate change. Such comprehension could help provide increased public support for new policies to implement high-impact solutions. Furthermore, public education is often more effective when it is designed with local to global contexts and considerations in mind. Because climate solutions must be global in scope and equitable, educational efforts should address the need for reduction in fossil fuel use by rich countries while also emphasizing increased access to clean and affordable energy in poorer countries. Understanding how our personal activities fit into the context of complex systems helps us identify opportunities to initiate systemic changes with even broader impact.

Environmental engineers and scientists should lead broad education initiatives on climate solutions. Education about climate and energy should begin as early as possible in our K-12 system, but immediate dissemination is especially needed at our universities for students that will soon be entering the workforce. Studies show that students in higher education are extremely concerned about climate change and they feel powerless to enact solutions[3]. Education can help engage them in solutions.

However, integrating climate solutions into higher education curricula faces several challenges, including leadership to advocate for its importance in crowded degree programs, and effective methods of communication for curriculum development.[4] We propose here that environmental engineers and scientists rise to the biggest challenge of our time and lead the effort to educate students across the university about climate solutions. Efforts by this group alone will not reach everyone at our campuses, and universities are only a small fraction of the population. However, engineers play a crucial role in developing and implementing technologies that are essential for rapidly curbing carbon emissions. Among engineering disciplines, environmental engineers are unique in their broad training in biology, chemistry, physics, and working on complex and interdisciplinary problems. Environmental engineers have long been leaders in engineering solutions to environmental challenges that concern the public, first in water and health and then in soil and air pollution. They have changed disposal of solid waste in dumps to recycling programs; they have engineered landfills and developed solutions to handling and disposal of hazardous wastes. They have relatively unique skills and training to lead educational efforts on climate solutions. Communication of climate solutions must go beyond engineering programs and include students in all disciplines. Environmental engineers have the experience to provide leadership through collaborations with colleagues in other disciplines such as law, business, and agricultural sciences, enabling effective education across the whole university. Many of these researchers also have opportunities to broaden their impact outside of the university, for example, through engagement with K-12 teachers and students, and other organizations focused on education of diverse communities.

An educational challenge of units and big numbers. A key educational challenge for developing curricula around climate solutions for a broader university audience is how to improve the tangibility of quantifying energy consumption and carbon emissions, which is often muddled by big numbers and esoteric units. Most people do not have the training to equate different energy units, for example, to compare kilowatt-hours of electricity with gallons of gasoline. Many energy units, such as quads (quadrillion BTU) or exajoules, are also just too "big" to sensibly comprehend. Translating energy consumption into carbon emissions is nontrivial. Finally, educating diverse audiences about how to assess the effectiveness of different climate solutions requires the presentation of energy and carbon associated with activities such as choices of food, clothing, and transportation in broadly understandable numbers.

***The D and C approach*.** To make energy use and carbon emissions understandable by everyone, we need to: provide a common terminology to quantify energy use and carbon emissions; avoid big numbers as much as possible; and use numbers with intrinsic meaning that connect to our personal lives. One effective approach is to quantify energy relative to daily food energy used by one average person, and carbon emissions based on the CO_2 that an individual releases every day due to metabolizing that food. In this approach we define 1 D as 2000 Calories or 2000 kilocalories (kcal, or 8.4 megajoules), the average energy needed from food each day.[5] Other energy use by a person each day, such as gasoline for a car or electricity for a home, is then compared to 1 D of daily food energy. For example, using 1 gallon (3.78 liters) of gasoline every day equals 15.2 D, or 15.2 times your daily food energy. We can compare total energy using D to clearly see the magnitude of both excessive energy use and inequities. For example, the US average energy use is 91 D compared to 45 D for Germany and 37 D for China (for 2023), but energy use is only 4.1 D in Ghana and 1.0 D in Ethiopia (2021, most recent numbers). The global average is 25.3 D (2023), and energy increase expressed in units of D has gone up by 4.1 D since 2000 (**Figure 1**). Unfortunately, renewable energy production has not kept pace, with an increase of only 0.28 D over that same period (**Figure 1 inset**).

Carbon emissions are similarly normalized using food consumption by defining 1 C as the amount of CO_2 emitted from an average person due to metabolizing 1 D of food (based on based on oxidation of proteins, carbohydrates, and lipids to CO_2). On average this baseline of 1 C equates to 2 pounds (0.9 kg) of CO_2 per day emitted from eating food. C calculations show where large reductions in CO_2 emissions are possible. For example, if a person stopped using 1 gallon of gasoline per day, that would reduce their personal emissions by 10 C, which is 22% of the US average for all fossil fuel use of 45 C (2022), and 71% of the total global average of 14 C.

Education on energy and carbon emissions using D and C is just the start. Once we understand energy use normalized by D and C, it becomes easier to relate to larger numbers used for a country. For example, 45 C equates to 5.1 gigatons (Gt) annually for the US population, directly translating gigatons to daily averages. This use of C therefore allows us to examine how our actions impact CO_2 emissions using commonly relatable metrics, thus combatting the feeling of powerlessness in reducing GHG emissions in our own daily lives while also making involvement in climate solutions accessible to non-experts.

Environmental systems are inherently complex, and it will take more than just knowing D and C to evaluate the full impacts of efforts to make changes in carbon emissions. A system life cycle analysis could be used to more comprehensively investigate options that aim to reduce CO2 emissions but could result in new indirect sources of CO2 emissions and lead to other unwanted adverse impacts on the environment. For example, lowering direct emissions by driving an electric vehicle would need to be balanced against the impacts of obtaining critical minerals, as their extraction, processing, and transport might also contribute to emissions and adversely influence local communities. More broadly, creation of new solar cells and extensive use of batteries require careful consideration of the material sourcing and recycling. Beyond systems thinking, we must also engage students in employing future thinking to understand how the decisions we make in our systems today either lead to or impede us from realizing the future to which we aspire.

The next steps for you? If you are an educator, think about how you can incorporate education on energy use and climate solutions into your curriculum. Environmental engineers can help provide methods for making calculations and thus climate solutions more accessible, but all educators need to think about how to best use this information within their own primary fields. Widespread education at universities will create a knowledgeable workforce capable of driving global laws and regulations that effectively reduce GHG emissions and ensure equitable and fair access to clean energy.

■ AUTHOR INFORMATION

Biography

Professor Bruce Logan is an Evan Pugh University Professor in the Department of Civil & Environmental Engineering, and Director of the Institute of Energy and the Environment (IEE) at Penn State. His research is focused on renewable energy production using bioelectrochemical systems for the development of an energy sustainable water infrastructure, desalination, green hydrogen and methane gas production, and education on energy and climate solutions. He is the author or co-author of several books and over 550 refereed publications (>120,000 citations, h-index=167; Google scholar). Dr. Logan is a member of the US National Academy of Engineering (NAE), an international member of the Chinese Academy of Engineering (CAE), and a fellow of AAAS, AEESP, and several other professional organizations.

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