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Thinking Critically about Energy: Advancing Energy Literacy

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Abstract

Society is continuously inundated with information about energy, from increasing demand driven by data centers to the urgent need for decarbonization. Navigating this complex landscape requires critical thinking to discern which facts are relevant, place them in context, and make informed decisions. This skill is especially important for younger generations, who will be challenged to balance sustainable growth with climate constraints.

This paper presents a classroom-based approach to teaching the complexity of the energy system through a structured decision-making exercise. Students engage in comparative assessments of deployable energy sources, evaluating trade-offs in cost, land use, carbon footprint, scalability and other factors. The exercise emphasizes the societal impacts of energy choices by analyzing five distinct regions, including island nations with limited natural resources, large industrial economies, developing countries, and regions with developed energy systems, each selected to illustrate different energy needs and cultural perspectives.

The method was implemented with students and educators in both the United States and Nigeria, engaging diverse audiences across different cultural and educational contexts. Participants worked in teams, discussed real-world scenarios, and reflected on how local values shape energy decisions. Feedback revealed a deeper appreciation of the complexity of energy systems and the importance of civic engagement. These findings highlight the value of integrating science, engineering and civics into energy education to prepare the next generation for the techno-societal challenges ahead.

Introduction

Society is increasingly saturated with information about energy, from rising demand driven by data centers to the urgent push for decarbonization. Navigating this complex landscape requires critical thinking to discern which facts are relevant, place them in context, and make informed decisions. These skills are especially important for younger generations, who will be challenged to meet the growing energy needs while balancing sustainable development and climate constraints.

Energy issues extend beyond technoeconomic considerations, they are deeply intertwined with societal views of risk, environmental stewardship and the economy. Therefore, educating young generations about the decision-making process in the realm of energy, including how to merge technical and societal aspects, is critical to meeting our collective energy needs over time in an optimal way.

The energy supply reference card [1,2,3] offers an unbiased comparison of current and emerging energy-generation technologies, evaluating tradeoffs in costs, land use, air emissions, performance metrics, and other factors. Building on this resource, a suite of education and training materials have been developed and delivered over the past decade to high and early college students [4]. In addition, science and civics teachers have received professional development using this curriculum. This paper summarizes these efforts, highlights lessons learned and discusses a potential path forward to expand energy education.

Objective of the curriculum on thinking critically about energy

Energy education is typically geared towards understanding the basic science of electricity generation and high-level introduction to the types of electricity generation technologies. This basic education, while an important pre-requisite, does not help students answer application-based questions like the ‘which one do we choose’, ‘how do we choose’, or ‘what are the implications of a given choice’. To fill that specific gap, the objective of this curriculum is for students to understand:

- relevant decision-making criteria guiding how energy decisions are made,
- to introduce students to the challenges of current energy generation technologies and to the importance of a mixed portfolio of generating technologies; and
- to make students see the challenges they will face, and innovation opportunities available, with designing the energy system of tomorrow.

The curriculum is divided into four main components: 1) Review of energy generation technologies; 2) Decision-making criteria; 3) Decision-making class project; and 4) Review of real-world case studies.

The scope of this effort is to provide an introductory-level education on decision-making building off of energy curriculum that is typically technology-focused. Because of the complexity and depth of the topic, energy decision-making is often only taught in advanced college courses. By providing an introduction that is accessible to younger students, this exercise can be easily integrated as a natural extension of existing energy curriculum and provide a basic understanding of the bigger picture.

Energy Generating Technologies

Students must first understand the range of available generation technologies to meaningfully participate in this exercise. Some may already have this knowledge from previous coursework, however, if a refresher is needed, a lesson plan with slides covering current and emerging technologies is available in [4].

The content of this section should be tailored to the audience and instructional goals. For example, when delivering this material to an audience in Nigeria to design the energy system for 2050, emphasis was placed on emerging technologies. In contrast, when discussing near term energy needs, current technologies are more relevant.

Instructors can further customize the technology set using the online reference tool available at https://es-refcard.epri.com/.

Decision Making Criteria

Every generation technology has strengths and limitations, and its suitability depends on context. For example, wind and solar do not emit greenhouse gases, but they require significant land and cannot rapidly adjust output without available storage options. Natural gas plants, while emitting greenhouse gases, occupy less land and can ramp production up or down quickly.

The energy supply reference card [1] shown in Figure 1 presents these tradeoffs in a user-friendly format comparing advantages (green circles) and challenges (yellow circles) for each technology relative to others.

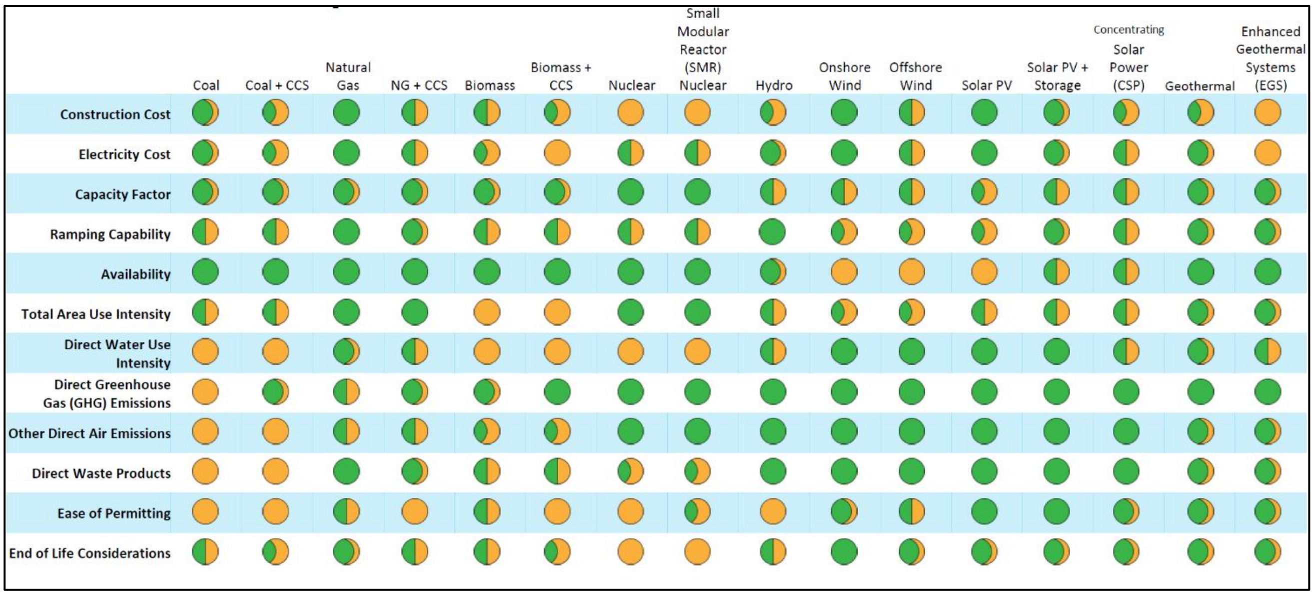

Figure 1 – Energy Supply reference card [1]

Some of these concepts, such as capacity factor and ramping capability, may be unfamiliar to some students. Therefore, teaching materials consisting of slides with instructor notes explaining each attribute have been designed to support understanding. Students learn, for example, that capacity factor reflects how much a plant actually operates during a year, regardless of its nominal capacity. Comparisons with capacity factors of transportation vehicles help reinforce the concept. Capacity factor, ramping capability and availability all come into play in understanding how well a given technology can be relied upon to provide electricity at the time it is needed, which is a critical factor in ensuring that the selected generation technologies can meet the actual need of the population.

The discussion on decision-making criteria is the central component of this curriculum. The discussion challenges students to apply critical thinking skills by expanding beyond the more concrete, technical items in the reference card to include broader considerations such as political and cultural sensitivities surrounding particular energy sources, goals of energy independence, transmission distance constraints, economic restraints, and the value of diversifying the energy portfolio to reduce risk. These discussions can be very enriching and are especially productive in a civics-focused learning environment, moving beyond ‘what can these technologies do and how do they work’ to ‘what are the goals, needs and values of our society and what energy mix best helps advance these’. For this reason, when preparing high-school educators in Nigeria to deliver the curriculum, training was provided to both civics and science teachers to ensure a well-integrated approach.

Decision-Making Class Project

The most effective way for students to learn how to think critically about energy is through a group project that allows them to apply the concepts learned. In this activity, students are assigned one of six fictitious countries, each defined by unique constraints and resources. For example, one country is a large arid region with a densely populated, innovation-driven city, minimal coal or natural-gas resources, and a projected additional demand of 2,000 megawatts. Students act as engineers tasked with designing an energy system capable of meeting this demand (Figure 2). Supporting materials, including country descriptions, student handouts, typical energy outputs, and instructor notes, are provided in [4].

Each group is asked to present a brief overview of their assigned country, the energy portfolio selected, the expected electricity cost (low, medium or high), and one key takeaway from the exercise. The fictitious countries incorporate realistic challenges, such as limited water for cooling, high seismic activity, or restricted access to capital, to encourage students to think critically about context-specific energy planning. Instructors are given a list of questions to help guide students in the design process.

This project is designed to reinforce systems thinking and evidence-based reasoning, competencies that are central to energy literacy. Students must extract system requirements, evaluate trade-offs, justify design choices, and negotiate competing priorities, key elements of real-world energy planning.

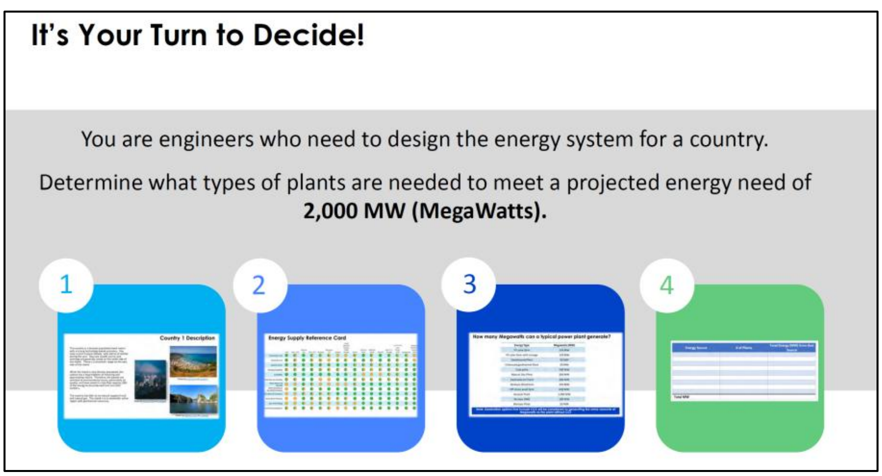

Figure 2 – Decision making in-class project

Real-World Case Studies

After students complete their design presentations, real-world case studies are examined as a group. Instructors introduce case studies from Japan, Germany, Brazil, Iceland, Hawaii and Arizona, each chosen to parallel one of the fictitious countries. These examples highlight how different regions adopt energy strategies based on geography, resources, policy, and societal values. This comparison generates discussions on how these choices affect sustainability and electricity costs.

The class concludes with two detailed case studies drawn from Japan and Arizona. The Japanese example highlights the interdependence between a nation's energy mix and the cost of electricity. Prior to 2011, Japan relied on a combination of fossil plants, nuclear, and limited hydropower. Following the large tsunami, all nuclear plants (more than 50 facilities) were taken offline for an extended period of time and the lost generation was replaced with imported natural gas, resulting in roughly 30% increase in electricity prices.

The Arizona case study underscores the importance of engineering ingenuity in resource-constrained environments. Although students often assume that coal and nuclear plants are unsuitable for arid regions due to cooling water constraints, Arizona is home to the second largest nuclear plant in the United States. This example prompts a discussion on cooling water strategies, as the plant sources treated sewage water from a city located 60 km away via a dedicated pipeline system. It also operates a water reclamation facility that treats the incoming wastewater before it is used for cooling.

Decision Making Semester Project

In the last decade (2012-2022), the curriculum has been used in the US, with the instruction, group exercise, presentation and debrief done in one or two class periods. This approach was taken because the instructors were volunteer technical experts (engineers) from the energy industry coming to the classroom to implement the curriculum.

This approach was expanded during 2022 and 2023 into a semester-long student competition launched in Nigeria to encourage students to think critically about energy. Nigeria was selected because of its rapid growing youth population, with a projected 58% increase by 2050, and with a current energy system already struggling to meet demand. To support this expansion, the curriculum was formalized and expanded with clear instructor notes. Fifty-eight (58) civics and science teachers from eighteen (18) schools across two states of Kaduna and Abuja in Nigeria were trained on the material for their onward provision of a similar training to the students in their home Senior Secondary Schools through enhancement club activities.

Teachers were supported by industry experts throughout the semester term-long club activities. Thereafter, a competition was organized for the students of the 18 participating schools to design an energy mix for a particular Nigerian city for the year 2050. More than 200 students from the 18 schools participated in the competition. The curriculum, including class exercises, was taught by their local civics/science teacher pairs, where possible. The material was slightly modified as

Nigeria lacks resources for some of these generating technologies. Case studies and countries used in the training exercise were slightly modified as analyzing Iceland's geothermal based system would not be of much use to Nigerian students.

The students' competition task was to design Nigeria's 2050 energy system for two distinct regions. Region 1 comprised the area around the city of Kano that in year 2050 will have a projected population of 9,300,000 people. Students were asked to plan for an expected increase in energy need of 5000 MW. Region 2 comprised the corridor around the cities of Ibadan, Oyo and Abeokuta that in year 2050 will have a combined population of about 10,200,000 people. Students were asked to design an energy system that can meet an expected increase in energy demand of 5600 MW. Students were expected to consider existing generation options, advanced generation options and the potential impacts of innovation. Figure 3 showcases the students' award presentation ceremonies.

Throughout the term, both civics and science teachers received ongoing support to ensure the curriculum was delivered effectively.

Figure 3 – Award ceremonies for the winers of the competition to design the 2050 energy system in Nigeria. The Therbow School, Zaria Kaduna (1st position); Federal Government Girls College Bwari, Abuja (2nd position); Government Secondary School, Lugbe Abuja (3rd position); and Nigerian Defense Academy Staff Secondary School, Kaduna (4th position)

Class Experience

This curriculum has been delivered to high school students, early college students, and educators, each requiring a different instructional approach.

High school students: Over the past decade, the material has been taught in several high school classrooms. It is most effective when Lesson 1 on generating technologies is spread across several class periods. This pacing helps students build a solid understanding of each technology without becoming overwhelmed. After that, the energy supply reference card and the class project are used to introduce the critical thinking portion, wrapping up the unit of energy and consolidating the concepts covered.

Early college students: For early college students, the material can be used as an introduction to the complexity of energy generation. College-level students typically require deeper technical content than what is provided in this module, so the curriculum works best as a foundation that will be expanded in later courses where each technology is examined in detail.

Educators: This material has been delivered to 58 science and civics teachers from 18 high schools in Nigeria through a 3-day professional development workshop focused on reinforcing teacher knowledge on energy topics (Figure 4). A key insight from this experience was the importance of involving civics teachers, as energy is as much a societal challenge as it is a technical one.

Figure 4 – Educators during workshop sessions designed to train them on this material

A key learning from implementing this curriculum is the importance of taking advantage of "teachable moments" central to critical thinking. In particular, there were many moments around understanding and communicating underlying assumptions. The developers observed that both teachers and students would make implicit assumptions in interpretation of their region's needs that drove decision-making. A key skill for the instructor is to ask probing questions so those assumptions can be made explicit and analyzed. For example, a large debate occurred between two groups of students that were analyzing the same region – both were adamant that their technology choice was optimal based on the constraints – additional probing revealed that one group had ruled out a technology choice because it was *perceived* to be unsafe, while the other group *perceived* the technology to be safe. That prompted a discussion on perceptions of safety, societal risk thresholds, and how it was important to identify safety as a system requirement (instead of a hidden assumption) so research could be done to shift from *perception* to knowledge rooted in facts and the reduction of uncertainty through data gathering.

Feedback from Educators

A survey was conducted with the educators participating in the professional development workshop in Nigeria in 2023. The goal of the survey was to assess whether the training and materials provided were sufficient for educators to teach this material. Participants were asked to provide an overall assessment of the quality of the workshop. Results indicate an overwhelming positive reception of the workshop and this material, as shown in Figure 5.

Two key indicators of the effectiveness of the workshop are teachers' readiness to teach the material and the assessment of the completeness of the instruction package. The readiness of the educators to teach the material was very positive, with approximately 92% feeling ready to teach the material as shown in Figure 6. A similar response was obtained when asking if the material provided was sufficient to support teaching.

Finally, participants were asked to assess the most valuable aspects of the curriculum. The in-class decision-making project was considered as providing the most value, followed by the teaching of critical thinking skills related to energy, as shown in Figure 7. Open-ended responses to this question highlighted: high value on hands-on project work, strong appreciation for components related to critical thinking skills, need for more time and deeper discussions, and the benefits of including audiovisual material to complement the curriculum.

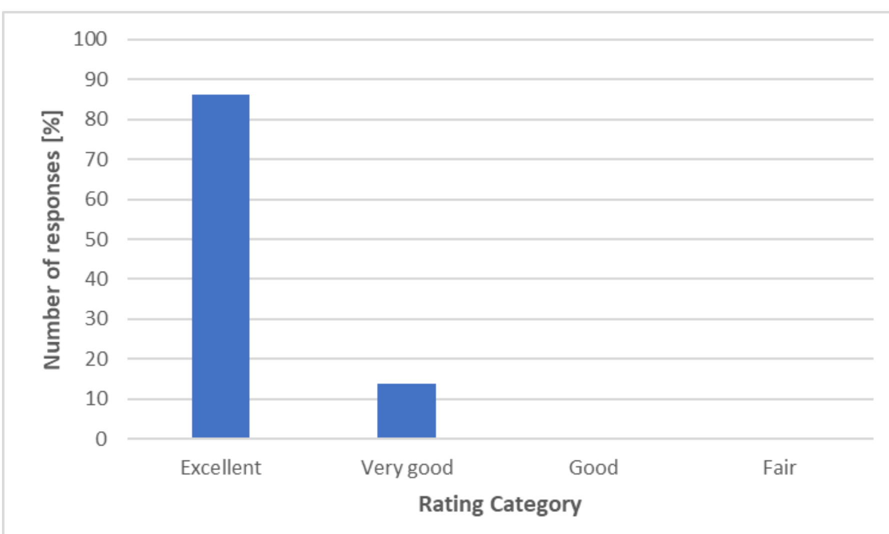

Figure 5 - Distribution of participants' overall evaluation rating of the workshop

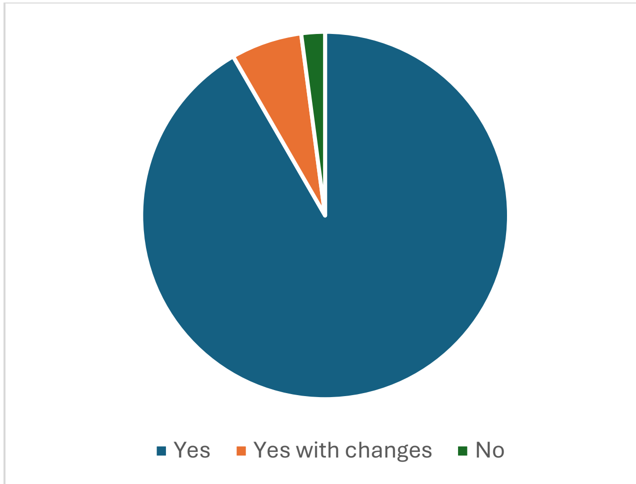

Figure 6 – Participants' readiness to teach this material after the workshop.

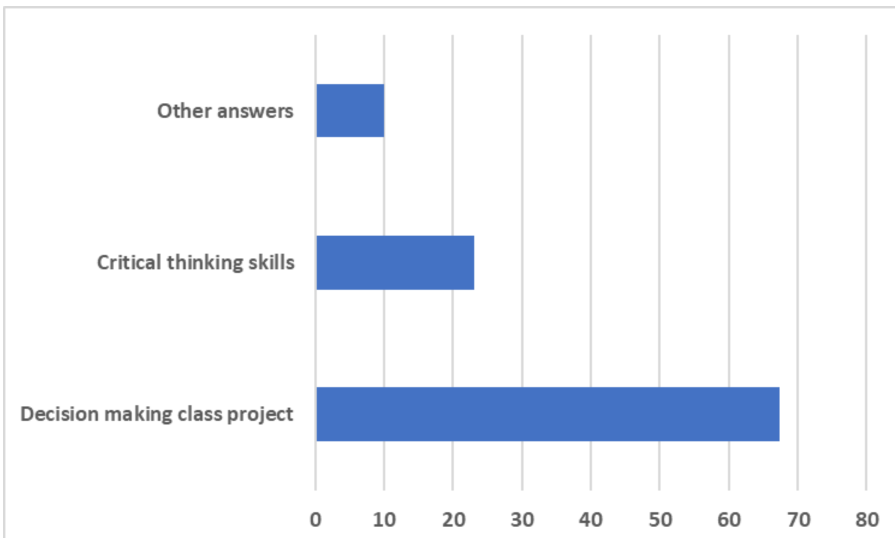

Figure 7 - Feedback on the most valuable aspect of the curriculum

Lessons learned

As this curriculum has been implemented across different settings, we have continually refined the content based on teacher and student feedback. The main lessons learned include:

- Integration – This curriculum is most effective when embedded in an existing class, with content delivered over multiple class periods to improve comprehension.
- Adaptability - This content is adaptable to high school and early college students. However, in one case, it is better as a wrap-up of the discussion on energy technologies, and in the other as an introduction to the discussion of the energy landscape.
- Content customization - The content needs to be adapted according to the audience. This may include reducing the number of technologies covered, or reducing the number of countries used in the class exercise.

- Civics concepts – Because energy decisions are both technical and societal, involving civics instructors in this curriculum has been essential to delivering a well-rounded learning experience.
- Ongoing educator support - Focused workshops with educators are highly effective, but educators benefit from continued guidance as they implement the material. The success of the term-long student competition demonstrated the value of this sustained support.
- Strong engagement – Feedback received from students and teachers consistently highlights that this is a relevant and needed subject.
- Value of the project exercise – Teachers highlighted the decision-making project as the most impactful component for delivering this content.

These insights hint to the importance of expanding this work with broader teacher training, scalable implementation models and continued emphasis on critical thinking skills.

Path Forward

Since its inception, the primary goal of this effort has been to equip educators to teach energy concepts effectively. The approach is being refined for reaching teachers and standardizing the curriculum for broader use.

To date, the material has been implemented through school clubs, regular classroom instruction, and student competitions. Additional avenues are being explored to integrate this curriculum more fully into mainstream energy education.

Although the program has seen strong success in Nigeria and in North Carolina, its long-term impacts depend on building the capacity to sustain and expand this work. A key next step is to partner with other organizations engaged in energy education, aligning content around a unified framework such as the energy supply reference card.

Moving forward, this effort will focus on developing a broader network of trained educators, strengthening institutional partnerships, and expanding the curriculum's critical-thinking components.

As this work scales, it will be important to anticipate logistical and resource constraints—including the need for sustained funding, reliable educator training infrastructure, and mechanisms for delivering materials to schools with varying levels of capacity

References

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