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Characteristics and Discourses about Energy Transition: Insights from Crossdisciplinary Student Talk

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Abstract

Discourses of energy and energy transition have become increasingly prevalent in informal and formal learning spaces. Energy transitions differ across regions, contexts, and technologies. The contextual nature of energy is an opportunity for a sociotechnical approach to its study. Energy transition is not one big change effort but instead is made up of countless decision points negotiated by and through geography, technology, culture, and people. In this study, we examine the different discourses that engineering and liberal arts students engage in as they think about questions in energy transitions. This crossdisciplinary sample of students offers insight into the plurality through which people from different disciplines and backgrounds characterize issues of sustainable energy transition. Through this research, we examined how students think through and characterize issues of energy transition. We situated this study in a cross-disciplinary undergraduate course on sustainable energies, co-taught by two faculty members, one in political science and one in mechanical engineering. The study consists of semi-structured student interviews following the course's completion. We interviewed ten students across majors and backgrounds on topics of energy transition and their impressions of local and global engagements in the space of sustainable energy.

Through latent coding, we discerned four overarching themes. The first theme consists of students grappling with or recognizing contradictory systems. The second theme, while similar to the first, focuses more explicitly on economics, as students describe the complex entanglements of energy, technology, and free market capitalist paradigms. The third comprises social/technical dualisms in which students discussed energy concepts and contexts through a lens of disciplinary duality in knowledge formations and in reference to their disciplinary identities. Lastly, students' discourses included paradigms around techno-solutionism, where they reference or complicate the need for more innovation and technology for successful energy transitions. Within these themes, there are nuances in the different logics that underlie student thinking. In this paper, we surface students' different ideological frames in a sustainable energy course with a predominantly homogenous sample of students. Through this study, we attend to the situated lived and learned experiences of students, which reveal insights into the ways people come to access different positions of learning, questioning, and decision-making in relation to their considerations about the many possibilities that constitute energy transitions. These insights are critical to attend to as the students recognize and hold competing insights around sustainable energy transition much like discourses in real-world energy transitions (Sovacool & Dworkin, 2016).

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Introduction

An energy transition is not inevitable. What is even more tentative is an energy transition that is just. Traditionally, energy education in engineering programs is spread across different facets of the curriculum, which makes it difficult for students to contextualize energy-related course content (Hoople, Chen, Lord et al., 2020). Concepts and applications of energy make up our day-to-day experiences which present a direct application for students in their learning about topics of energy transition. Discourses of energy and energy transition have become increasingly prevalent in informal and formal learning spaces but are contextually dependent. What an energy transition entails is different across regions, contexts, and technologies, which presents an opportunity and critical need for more sociotechnical and interdisciplinary approaches to its framing and study. Many projects working to implement an energy transition are politically and economically incentivized to implement a just transition—in which new projects are to attend to environmental harms and historical inequities by providing environmental benefits and opportunities to workers who historically have been excluded from the energy sector. A just energy transition is not only a push to design and implement new technology and infrastructure but also an educational opportunity to imagine and equitably enact energy transitions that are contextually rooted and inclusive of different worldviews (Sovacool, 2019). Energy transition is not one big change effort but a process that is made up of countless decision points negotiated by and through geography, technology, culture, and people.

In this study, we examine the different discourses that engineering and liberal arts students engage in as they make sense of energy transitions. This crossdisciplinary sample of students offers insight into the plurality through which people from different disciplines and backgrounds characterize issues of sustainable energy transition. Through this research, we ask two questions:

(1) When students talk about (local/global) energy systems, what do they concern themselves with?

(2) What are students' overarching narratives found orienting them to energy transitions?

We situated this study in a crossdisciplinary undergraduate course on sustainable energies, co-taught by two faculty members, one in political science and one in mechanical engineering.

Background

Energy Education and Energy Literacy

Energy is a key element of any engineering curriculum as well as a key element of society. Yet many students learn about the science of energy in largely technical, fragmented, and decontextualized ways through courses like introductory physics, thermodynamics, circuits, heat transfer, and so forth (Hoople et al., 2020). Students' ability to successfully navigate these courses plays a significant role in their engineering identity formation (Hoople et al., 2020). However, their conceptual knowledge of energy, as well as how this knowledge intersects with their lived experiences, can be limited (Ramachandran, Ellis, & Gladwin 2024). Expanding students' energy literacy is not a matter of learning solely as a cognitive end, but as a way of expanding the way students make sense of energy in the world to apply this knowledge to different educational contexts and social processes (Kellberg et al., 2023).

Importantly, the construct of energy literacy has a history of being linked to geopolitical energy tensions and national agendas for energy conservation. The public emphasis on cultivating energy literacy has consistently paralleled energy vulnerabilities derived from geopolitical and eco-environmental motivations rather than at level of households which is where much of the energy literacy scholarship is situated (Adams, Kenner, Leone et al., 2022; Day & Walker, 2013). These public energy governance initiatives can be traced to the 1973 Organization of Petroleum Exporting Countries (OPEC) oil embargo that caused the energy crisis of the 1970s, which is when energy conservation became a national priority in the US and was implemented in K-12 schools through public policy.

Many of the nationally organized energy conservation initiatives were based on the premise that when people have higher levels of energy literacy, they will reduce their energy consumption which cuts their costs and benefits the environment (Dwyer, 2011; Hirst, 1976; Wert & Worthington, 1978). These initiatives and studies carry these geopolitical economic contexts, which inform a more normative and deficit-based scope of energy literacy.

Media campaigns pushed the national agenda of energy conservation during this time. One 1973 media campaign by the American Ad Council was called “Don’t be Fuelish.” In the ad, American Actor, James Garner laments the highway traffic beneath his view stating that all the cars below, stuck in traffic carried just one driver. Garner’s message was to share a car with friends and drive under the 55-mph mandated speed limit to reduce energy consumption. In closing, Garner’s message: “If we all help, we’ll really be helping ourselves, and if we don’t, there may not be enough gas for any of us.” (Ad Council PSA, 1973). Similar ads were run that featured children telling media watchers to think of their futures as in their energy consumption behaviors. These national priorities stemming from the geopolitical tensions that amounted to the oil embargo in the Middle East gave rise to a national energy media literacy agenda striving to reduce public energy consumption.

The energy literacy scholarship that is rooted in this energy crisis era national initiative and people’s behavior around energy conservation takes on an important challenge of understanding and shifting the way people think and act (Adams et al., 2022). However, these behaviorist modes of learning are limited in their ability to engage in people’s complex understandings of energy systems, politics, technological development, and change. There is a need to expand the notion of energy literacy beyond economic and environmental frames that ostensibly predict and aim to shift people’s behaviors.

Energy literacy in educational research has developed into a more complex construct—bringing knowledge and attitudes into studies of behavior (DeWaters & Powers, 2011; DeWaters, Qaqish, Graham, & Powers, 2013; DeWaters & Powers, 2013). DeWaters and Powers scale of energy-literacy is one of the more prominent instruments in the space and focuses on three categories—energy knowledge, energy attitudes, and energy behavior. Questions pertaining to energy knowledge focus on students’ understanding of scientific concepts, rules and theories, energy transfer, and the role that energy plays in open and closed systems. Energy attitude questions focus on students’ attention to energy supply and shutdown and the consequent environmental impacts, the impact on human life, and the convictions and ideologies of people based on energy knowledge. Lastly, energy behavior questions emphasize how energy is used in everyday life—including how it could be used differently. Behavior questions look at students’ awareness of day-to-day actions, the responsibility of different actors, and the commitment to different actions that save energy (DeWaters & Powers, 2011). These studies of energy literacy are largely quantitative, scoping their inquiry to validated surveys across different contexts. While these offer important and broad views surrounding the shifts in energy literacy among different groups of students and from interventions, we are interested in a deeper understanding of how these views develop and are influenced through the students’ own sensemaking. In this study, we take the development of energy literacy to mean that it “generates a change of viewpoint, activity, or practice.” (Gladwin & Ellis, 2023, p. 1524).

Sociotechnical Energy Systems

Energy systems are an important way to engage students in sociotechnical systems that bring ways of knowing in engineering, social sciences, and the humanities together. Historically, Thomas Hughes conducted a deep examination of energy systems to arrive at the analytical frame of a sociotechnical system, which is predominant in the field of Science, Technology, and Society (Hughes, 1985). Through Hughes, we can take energy systems not solely as technological packages but as sociotechnical systems (Hughes, 1985). A techno-centric view of an energy system could be a pipeline, a way to simply and efficiently move oil or gas across land. But as a sociotechnical system, a pipeline includes the land, operators, knowledge, financing institutions, investors, energy traders, and consumers, among countless other facets of the system depending on scale and scope (Sovacool, Brown, & Valentine, 2016). In the context of a just energy transition (Biden Administration, 2020), the techno-centric view of electricity generation and transmission is being further interrogated because of the social, political, and economic tensions that have been left out of the system but are key factors as to why the transition is difficult (Geels, Sovacool, Schwanen et al., 2017; Hansen, Wilson, Fitts et al., 2024; Sovacool et al., 2016). Through the analytic of sociotechnical systems, energy systems are better understood because they engage the different actors who have vested interested—financial and emotional—that produce and perpetuate the energy system.

An energy transition is not necessarily a matter of improving technologies, but of taking up the array of cultural, political, social, and economic forces that technologies are constructed in and construct. Importantly, the rise in renewable energy technologies cannot necessarily be characterized as energy transitions but "energy additions" as Richard York and Shannon E. Bell have argued in historical studies of energy 'transition' (2019). York and Bell show that over the past two hundred years, energy transitions from one energy source to another have always resulted in an overall increase in the amount of energy consumed across all sources, even though the older energy source declined (2019). In this study, students engage in the sociotechnical complexity of energy systems and in building more sustainable forms of energy into the system—sometimes emphasizing specific cases of local energy transition and other times discussing the energy supply issues at a global scale.

This study is underpinned by an emphasis on different knowledge formations of students. In the domain of energy, conflicts do not arise simply because one side lacks the scientific facts or objective truths of the issue, yet much of the renewable energy and energy transition efforts lay in battling misinformation or educating the public (Oreskes & Conway, 2011; Sovacool et al., 2016). These solutions frame the problem as a lack of factual information by an unknown mass of people. Instead of these deficit-based perspectives, community engagement scholars are advocating for more asset-based ways of examining the publics views—emphasizing the heterogeneity of the public and their diverse interests, conceptualizations, and grievances (Bidwell, 2016; Smythe, Korein, Swett et al., 2025). These different contextual truths are important to recognize in communities near sites of sustainable energy projects as well as in educational contexts which consist of students from different disciplines, backgrounds, and lived experiences (González, Moll, & Amanti, 2005; Rios-Aguilar et al., 2011; Valencia, 2010).

Educational projects are an important site to learn from and attend to competing truths as they can offer a site that is rooted in people's sensemaking rather than following deficit-based, didactic campaigns. By attending to ideological differences, we can help students bring a layered awareness to the frames surrounding different ways of knowing. These ideological frames underpin the different conceptions of reality, and "how knowledge is shaped, conditioned, and digested." (Sovacool et al., 2016, p. 4). In this study, we examine undergraduate students' ideological frames around energy systems and the energy transition to engage with the complexity of their developing ideas following their completion of a co-taught, interdisciplinary upper-class course on sustainable energies.

Methods

To build on previous studies of energy literacy and sociotechnical thinking, the goal of this study is to characterize the qualitatively different ways that students concern themselves with energy systems and energy transitions. We use a reflexive thematic analysis (RTA) to gain more in-depth insight into the

phenomenon of the construction and communication of energy systems and energy transitions by undergraduate students majoring in engineering and the social sciences (Braun & Clarke, 2021).
We conducted 10 semi-structured interviews with students enrolled in a co-taught, interdisciplinary course on sustainable energy at a public university in the Northeast U.S. The interviews took place the summer following the completion of the course. The interviews were conducted by the first author who was not an instructor of the course but was present in most of the course lectures as an observer.

The two research questions guiding this study are:
1. When students talk about energy transition, what do they concern themselves with?
2. What are students' overarching narratives that orient them to energy transitions?

Institutional and Course Context
We situated this study in an upper level crossdisciplinary undergraduate course on sustainable energies, co-taught by two faculty members, one in political science and one in mechanical engineering. The course has been taught at a State University in the Northeast region of the United States for thirteen years—shifting the curriculum as issues of energy transition have changed. The course has been co-taught by a political science faculty and an engineering professor in each of these iterations. We note that the faculty members are not the authors of this study but are involved in the overarching research project.

The course objectives range from students being able to understand and explain the main sources of energy that the U.S. uses in relation to global supplies to engaging with intersections of energy, social justice, human rights, environment, and public health issues. Students are given opportunities to learn about the science and engineering mechanisms in different energy conversion technologies as well as understand the challenges and benefits of each of the different technologies. Through the course, students are exposed to different energy policies that have incentivized and challenges different energy technologies and are provide opportunities to trace the different ways policy and technological development have interacted. In Table 1, we list a sample of the readings from different sections of the course designed by the course instructors. For the full syllabus, please reach out to the authors.

	Sample of Readings from Syllabus
Part 1: Energy Basics and Context	Sovacool, Benjamin. 2016. "The history and politics of energy transitions: comparing contested views and finding common ground." *WIDER Working Paper* 2016/81
	Smil, Vaclav, "Examining energy transitions: A dozen insights based on performance," *Energy Research and Social Science* 22 (2016): 194-197
	EIA (Energy Information Administration: Use of energy; Refining crude oil; Electricity explained; US energy facts explained
	"It's not just Willow: Oil and gas projects are back in a big way," *The New York Times* (Apr 6, 2023),
	The hidden costs of fossil fuels," *Union of Concerned Scientists* (30 Aug 2016)
	"The localized health impacts of fossil fuels," *Climate Nexus* (27 September 2017)
	LCOE vs LACE: "EIA uses two simplified metrics to show future power plants' relative economics" *EIA Today in Energy* (March 29, 2018)
	Cheatham, Amelia and Diana Roy, "Venezuela: The rise and fall of a petrostate," *Council on Foreign Relations* (Dec 22, 2023),
Part 2: Alternative Energy Sources and Technologies and their Impacts	Sustainable Energy without the Hot Air, David MacKay, 2009. Available at http://withouthotair.com Hydroelectricity Chapter 8 (pg. 55-56)
	GeoVision: Harnessing the Heat Beneath Our Feet (2019), US DoE
	"Germany built LNG terminals in months. Wind turbines still take years," *The Washington Post* (Jan 7, 2023),
	Freeman, Michael, "Offshore wind can lower energy prices and beat out oil and gas" *Center for American Progress* (Sept 23, 2022)

	Bayulgen, Oksan et al. "Tilting at windmills? Electoral repercussions of wind turbine projects in Minnesota," *Energy Policy* 159 (2022)
	"Clean energy technologies threaten to overwhelm the grid: Here is how it can adapt," [Vox]() (Nov 11, 2019)
	"A copper mine would advance green energy but scar sacred land," *The New York Times* (Jan 27, 2023),
Part 3: Tools and Challenges of Clean Energy Transition	"What is the Green New Deal? A Climate Proposal, Explained," *The New York Times* (Feb 21, 2019)
	* "A Conservative Climate Solution" *The New York Times* (Feb 7, 2017)
	*Hammond, D.R and Thomas Brady, "Critical minerals for green energy transition: A United States perspective" *International Journal of Mining Reclamation and Environment* (2022)
	Ip, Greg, "Why no one wants to pay for the green transition," *The Wall Street Journal* (Nov 30, 2023)
	"What Americans think about an energy transition from fossil fuels to renewables," [Pew Research Center]() (June 28, 2023)

In 2024, the course enrolled 36 students, split between students majoring in engineering and the social sciences. In the class, students participate in a group research project on a real-world energy issue. The groups are set by the instructors factoring in student interest, to include students from different majors. In addition to the group projects, students complete a weekly analysis that includes open-ended questions discussing different policies across regional contexts and ill-structured problems that require calculating real-world scenarios for different energy technologies.

Study Participants

Participants were compensated $40 for their participation in the full study. Historically, the demographics of students enrolled in the course have mirrored State University's undergraduate population. The student populations comprise significant income and racial gaps, in which 49% of students are racial and ethnic minorities and 36% of students are first-generation, meaning they are the first in their families to attend college (State University, 2023). A third of students interviewed were first generation college students, but due to anonymity concerns we offer this as a general distinction rather than identifying particular students in the Table 2. Institutional Review Board approval was obtained for this study (University IRB Protocol H23-0706).

Table 2. Demographics of interviewed participants

Label	**Major(s)**	**Year**	**Gender, Race & Ethnicity**
Eng_11	Chemical Engineer	Fourth year	White woman
Eng_17	Chemical Engineer	Fourth year	Latine woman
FinancePoliSci_03	Finance, Political Science	Third year	White man
EnvStudJournalism_04	Environmental Studies, Journalism	Third year	White woman
PoliSci.EnvSt_21	Political Science, Environmental Studies	Third year	White man
EnvSci.PoliSci_06	Environmental Science, Political Science	Fourth year	White woman
MolBioCommunitySt_02	Molecular Biology, Community Health	Fourth year	White woman
PoliSciPhiloso_13	Political Science, Philosophy	Third year	White woman
PoliSciEnv_10	Political Science, Environmental Science	Third year	White man
PoliSci.Insurance_18	Political Science, Insurance	Third year	East Asian man

Data Sources and Analysis

The study comprised semi-structured student interviews in the summer following the spring course's completion. We interviewed ten students across majors and backgrounds on topics of energy transition and their impressions of local and global engagements in the space of sustainable energy. The semi-structured interview protocol included questions listed in Table 3.

Table 3. Semi-structured Interview Protocol

	Interview Questions
Part 1 – Introductory questions	▪ How did you come to enroll in the sustainable energy course? ▪ Can you tell me about a time that you felt challenged by topics in the class? ▪ Can you tell me about a time that you felt confident by topics in this class?
Part 2 – Connecting course topics to student's field of study	▪ What aspects of the course connected most with your field of study? ▪ What are some elements that stick out to you regarding values, norms, and practices in your field of study based on topics in this class? ▪ What would you say your field of study values in trying to address sustainability or energy problems? Would this differ from what you would value?
Part 3 – Shifting impressions of different disciplines	▪ Do you think your impressions of engineering have changed from engaging in this class? In what ways? ▪ Do you think your impressions of political science have changed from engaging in this class? In what ways?
Part 4 –Student final group projects	▪ What was the topic of your final project? ▪ What types of roles did you take up in your project groups? Did your roles change over the semester? In what ways? ▪ If you had more time and resources to work on your final project, or if you were hired to continue the work of your final project—what sorts of things would you consider in continuing the work? Is there anything from the project work or the course content that may have brought about a shift in your thinking?
Part 5 – Questions on affect, motivation, hope	▪ How would you say your thinking on energy systems and energy transitions has changed (or not) over the past few years? ▪ How are you feeling about an energy transition? (affect). Do you see yourself pursuing this type of work in the future? What is motivating you?

In the sample, two of the interviewed students were chemical engineering majors and fourth year students about to graduate. Eight of the students were majoring in a variety of social and natural science disciplines including political science, environmental science, journalism, environmental studies, philosophy, finance, economics, community health, and molecular biology. Many of these students had co-majors. Of the ten students, seven identified as women, and three identified as men. All the students were third and fourth years. The lead author conducted each of the interviews, the lead author and third author transcribed the interviews, and the three authors worked together on the analysis.

The reflexive thematic analysis (RTA) followed an iterative and comparative process conducted by the three authors, "where themes are developed across cases from codes, following the coding of the entire data set." (Braun & Clarke, 2021). We began by reading and re-reading the interview transcripts as a process of data familiarization (Braun & Clarke, 2021). Next, we conducted three cycles of semantic and latent coding. We conducted an initial cycle of semantic coding to capture the explicit meanings expressed by students in their interviews (Braun & Clarke, 2006). In the next two cycles of coding, we constructed latent codes which focus on "deeper, more implicit or conceptual levels of meaning" (Braun

& Clarke, 2021, p. 102). In latent coding, we drew on Braun & Clarke as well as Berg's (2009) perspective of latent codes as interpretive codes that attend to the meanings encoded within or manifest through text or talk. In each cycle of coding, the three authors reflected on each assigned code individually and together to reach theoretical consensus. We used the latent codes to examine different onto-epistemologies or the deeply entangled ways of being and knowing that are imbued with axiological perspectives that students exhibited in their discourses. With complex sociotechnical systems such as changing energy systems, there are entanglements of onto-epistemologies across discourse. To contend with this plurality, we adopt this RTA method of inquiry that broadens our analysis to embrace different and competing ways of thinking.

In generating themes, we focused on drawing together conceptual patterns across the codes to discern when codes had shared meanings and what Braun, Clarke, and Rance call a distinct central organizing concept (2014). These central organizing concepts are what scholars have discussed elsewhere as ideological frames, which tell us about students' characterization of energy systems and transitions but also something broader about their way of seeing the world and potential tensions and shifts within those ideologies (Cech, 2013; Slaton, 2015; Sovacool et al., 2016). Based on the latent coding, we generated four central organizing concepts that are presented in Table 3 as themes with theme summaries.

Limitations

There are two main limitations to this study. The first limitation of this study is that the students' reflections and experiences are dynamic and evolving phenomena. While this study can offer a window into these students' characterizations of energy systems and transitions from their learning and lived experiences, these constructs are snapshots of their perspectives and self-described experiences. The other main limitation is that the students self-selected to participate in the study, which can constrict whose experiences and perspectives were elevated through this scope of inquiry. While some students noted the difficulties and challenges with the curricular engagements, most had positive experiences. The study would have been strengthened with insights from a broader range of students.

Findings

Table 4. Overview of four latent themes, summaries, and student excerpts.

Latent Theme	***Theme Summary***	***Representative Student Excerpt***
Complex & contradictory systems	Students sharing insights, questions, reflections on contradictions or competing elements of systems pertaining to sustainability, politics, and energy.	Like, why do people feel so like, why do people disbelieve in climate change? And then also, like, why do people feel so strongly about like, not wanting to deal with renewable energy sources and this kind of thing? And that really motivated me to study that kind of thing when I came here. So and I think partly Yeah, cause I like grew up around that stuff. I don't know, that was just always so baffling to me how you can be like, a dairy farmer and like, rely on the environment for your livelihood, and then also be like, inherently opposed to like, measures that are supposed to help the environment? [PoliSci.EnvSt_21]
Energy, Technology, and Free Market Capitalist Paradigms	Students grappling with or recognizing contradictory systems with specific focus on their sensemaking as it pertains to describing the complex entanglements of energy, technology, and free market capitalist paradigms.	"like, yeah, we have ambitious . . . renewable goals and . . . emission reduction goals. But at least what I kind of found was that a big problem with it is that we have a deregulated electricity market . . . it's like sort of starting to work now, in the sense that people are like, being able to, like, pay less money for it. But one thing that I found that was really alarming and super weird was that . . . 2021 was the first year that [Northeast State] ratepayers ended up actually saving money in the deregulated market." [PoliSci.EnvSt_21].

Social/technical dualism	Students discussed energy concepts and contexts through a lens of disciplinary duality in knowledge formations i.e. articulating a separation between engineering/science and politics/policies.	The [project] prompt was kind of broken up into three different questions. And it was like what are the technical reasons for why electricity prices are so high. And then the other two were more policy-related questions. Oh, the second one was like, how is it affecting homes and businesses in [Northeast State]. I think. So, when we got in our group, they were like, oh, we're both political science or human rights majors. And I think, oh, I'm chemical engineering major. And so that made the question easier to divide just in terms of what we know. So I took the, 'why are electricity prices so high' like what technical reasons are there that electricity costs that much? So the divide of the research was pretty easy for our group. [Eng_11]
Solutions, Techno-solutionism	Students reference or complicate the need for more innovation and technology for successful energy transitions.	You know, these batteries for their future hybrid and electric vehicles which go into like the transportation space of clean energy and kind of electrification of our world, which I think is really awesome. I'm feeling really excited. But I do feel really hopeful about people doing research and people going into technological spaces and kind of trying to." [Eng_17]

1. Students grappling with complex and contradictory systems

This latent coding theme, recognizing contradictory systems, focused on students sensemaking as it pertains to describing the complex entanglements of energy systems, political systems, and technological systems. Students shared reflections and questions on different contradictory or competing elements of these systems. In their interviews, each of the students shared how their thinking on subjects of energy systems and sustainability has become more complex and varied.

An engineering student reflected on how her opinions shifted based on her exposure to different perspectives. She reflected that even as a fourth-year engineering student, she had not been exposed to different views on which she could form an opinion until this elective course on sustainable energy.

> It was really interesting for me to see like conservative people. And so like, that's just something that I was like pretty surprised to see. And I was like, Oh. you know. So, I think that it shifted my social views a little bit in the sense like everything isn't always black and white and I really really appreciate that, because sometimes, as an engineer, you're just not exposed to it unless you have to take the course. So, taking the course in this way, I think, allows you to form your own opinions, which I think is really important. And a lot of times I feel like you're not allowed to in universities. But I really do appreciate. I think this course really like encourages you to do so. [Eng_17]

A different student shared that she held more conservative views in the past and through university has become "much more left leaning than [she] was in the past." [PoliSciPhiloso_13]. She shares that she "bec[a]me educated in college," pointing out that "who you're around influences your thinking." [PoliSciPhiloso_13]. She described how her understanding of electric cars developed over time, in which she cited costs, tax incentives, electricity prices in her thinking.

> You know, electric vehicles are a big discussion for folks. And it's changing. And we've seen a lot of changes in the prices of, you know, Teslas and whatnot. […] We've seen a lot of changes in prices in that respect. I was always used to be like, Oh, electric vehicles, they are so expensive, and why can't I just get, you know, my $10,000 gas guzzler that I have, you know, so but I've definitely become more open, especially, you know, in terms of the past six months, and just learning more about like learning the science behind it, and learning, like, the facts. And then just seeing that really opened my eyes to, you know, what's available as far as tax rebates go in all of

that, I've just definitely become more open to the whole discussion. And I've really changed my mind on a lot of things, which I think is a good thing. [PoliSciPhiloso_13].

This student and a different student studying finance described how they have become more open to electric cars but are still concerned with the high vehicle costs and high electricity costs as barriers to adoption and access. Through her research project, the student studying political science and philosophy raised important points about the recent high electricity prices in [Northeast State] as important to consider.

> Okay, so you get the tax incentive. [But] it's still an expensive car. And then if you're living in [Northeast State], you're still paying hundreds of dollars every month for electricity. It's like, well, then I don't, you know, I think, I still think it's still beneficial because of the human health point. But, it's just, it's still a discussion. I mean it's hard to be for and against 100% when there's so many different things to consider. [PoliSciPhiloso_13]

A student studying community studies and molecular biology and from a very different background shared her concerns with the Electric Vehicle (EV) system on a global scale.

> We're creating 5,000 more consequences that we have to deal with, especially with like the crisis in Congo and Sudan, which is powered by lithium batteries, which is being used by cars. And like when you have projections of like Tesla, and like SpaceX going up to space with these batteries. Yes, we want EV like, because yes, CO_2 is decreased. But 10 million people are dying in Congo because of this, and we're losing natural resources. So it's like, how can we talk about this, but not the other one. [MolBioCommunitySt_02].

Through these insights, students are recognizing the complexity of decisions in energy transition and how they impact people and groups differently across regions.

While the students discussed the increasing awareness of the complexity of energy systems, they also discussed their own role in these systems. Some posted questions of the usefulness of this understanding, while others shared an interest in research and learning. A student studying political and environmental science shared reflections on how learning during her time in university and the complexity of energy and environmental systems has shifted her focus to be more grounded in solutions, even if they are not as she says, “the full solution.” [EnvPoliSci_06]. She shares how one might shift the way they approach issues of climate change.

> I think, learning about energy systems, and just learning about kind of our, just like societal structures in general […] both clarifies kind of like what we're addressing, but it also makes it very clear how complex things are. So I think like, especially my time at [State University] has illuminated a lot of things that need to be addressed, but also has complicated them in the sense that like, it's the reality like, I don't think I, like obviously, if you're thinking about when you're first introduced to the idea of climate change, or just environmental problems in general, it's very easy to take a naive approach and be like, "Well, why don't we just fix it? Why doesn't someone just change it?" [EnvPoliSci_06].

She continues on to explain why and how this thinking is insufficient in matters of energy transition.

> I think my time at [University C] has made it very clear that it isn't just like a switch, it's like all of these pieces that need to come together and then it needs to be both community informed. And there needs to be integration of equity. And it's not just someone coming in and changing things. It's like, it's a systematic and just, there's like so many different elements that need to be addressed in order to solve things. And I think energy is the perfect example of that with like, energy transitions, especially, it's not someone just switching over to solar and wind, like, an overnight, we're all fixed and everything's great. It's, it's a slow transition. And there's lots of different social, technological, and just environmental aspects to it. So yeah, I guess that there, there's been a lot of things that I've learned at [University C]. And there's also a lot of things that I don't think I have the answers to yet, and will take a long time to come to those like solution-sides of things, when I'm looking like towards my future, and like, definitely, like, I know, for a fact that whatever I end up doing career-wise, like I want it to be grounded in addressing

> environmental problems and kind of like being a part of the solution, I guess, even if it's not the full solution. [EnvPoliSci_06].

2. Energy, Technology, and Free Market Capitalist Paradigms

This latent theme, as detailed earlier, was in some ways similar to our latent code focused on grappling with or recognizing contradictory systems, however it focused more specifically on students sensemaking as it pertains to describing the complex entanglements of energy, technology, and free market capitalist paradigms. This was perhaps best exemplified when a student noted, "flaws I consistently found were like, the economic side of it, or like the finance side of it" and asked. "Like, who who's gonna pay for it? who's gonna pay for it?". [FinancePoliSci_03]. This concern for the "economic side" of energy broadly or electricity more specifically, also emerged as a focus of students' capstone projects for the course, as one student detailed her group's project, "Mine was about why electricity prices are so high in [Northeast State]. I think it's like, what can we do about it? And what are other states doing to lower their electricity prices, like through policy." As students thought about the embeddedness of energy in capitalistic systems in which people might be strained by costs of energy access they considered things like the deregulated energy market. Specifically, one student shared,

> like, yeah, we have ambitious . . . renewable goals and . . . emission reduction goals. But at least what I kind of found was that a big problem with it is that we have a deregulated electricity market . . . it's like sort of starting to work now, in the sense that people are like, being able to, like, pay less money for it. But one thing that I found that was really alarming and super weird was that . . . 2021 was the first year that [Northeast State] ratepayers ended up actually saving money in the deregulated market. [PoliSci.EnvSt_21].

This same student went on to note how for 20 years, "we were actually paying more money because of that" and worried about how, "you kind of get into the whole thing of like, okay, if you're not regulating your generators at all, then where's the incentive to provide electricity in a greener way". [PoliSci.EnvSt_21]. Beyond these considerations about the role of capitalists systems as they relate to energy and energy transitions, when considering sustainability, the ways in which the unstoppable economic force of supply and demand were accepted as inevitable were found as one student thought about how, "You know, those big companies like Coca Cola, and like Exxon Mobil, things like that, they wouldn't be in power, if we didn't also have that demand for their products and things like that." [EnvStudJournalism_04]. This same student critiqued the capitalist system where actors like ExxonMobil have worked hard to shift the focus from corporate accountability to individuals noting, "getting your carbon footprint . . . that's good to know how much you're contributing to the degradation of the environment. But also, it's not fair to take all that blame on yourself . . . there's so many different people and companies and, you know, different things that are at part in this." [EnvStudJournalism_04].

3. Social/Technical Dualisms and Integrations

In contrast with the latent code recognizing contradictory systems broadly or thinking through capitalistic entanglements, students exhibited notions of social/technical dualisms in their discourses. We define social/technical dualisms by drawing from Faulkner (2000) and Cech (2013), who detailed this ideological frame as the artificial separation between technical (often elements that are more repeatably quantifiable, reducible, and measurable) and the social dimensions of a system. In separating the social from the technical, there is often a difference in value, where, in engineering, the technical dimensions are valued over the social dimensions (Faulkner, 2000; Cech, 2013; Leydens & Lucena, 2017). In this section, we detail how students exhibited social/technical dualisms in their energy transition discourses. An articulation of this dualism and power difference is exemplified by a student majoring in political science and philosophy. In her interview, she states:

> I think the biggest thing I got out of that section of the course was how engineering can be, can be used to answer all of the questions that we're talking about from a practical standpoint. So really, policy can't be created without some scientific base. Or any good policy can't be created without

> some type of valid scientific research attached to it. So that's where I was, kind of, seeing the overlap. [PoliSciPhiloso_13]

This student emphasizes the duality of engineering and policy by discussing how they are complementary but have a temporal boundary between them. First, engineering/science, then policy. Notably, she uses engineering and science interchangeably throughout her interview, further supporting evidence that many students struggle with an idea of what engineering is. She describes this dualistic thinking through the example of nuclear energy.

> You know, okay, talking about nuclear. Like, we were saying, what is the science behind nuclear? Is it safe? And what is the risk associated with it? That's all science. That's all engineering, right there. Because you have to understand how it works in order to make a policy that's effective for it. [PoliSciPhiloso_13]

While her emphasis on how technology works is an important aspect of designing appropriate policies, she articulates the sequential and seemingly separate nature of understanding the science and engineering to then design the relevant policy.

A different political science student shared her appreciation in "learning about processes that happen for energy to be generated." She shared that this learning "gave [her] a lot of respect for the people that created the processes, like the engineers." [PoliSciEnv_10]. She went on to share how this knowledge might influence her energy transition views:

> Knowing more about how the [energy generation] processes actually happen makes it more realistic for me to support energy transition. I didn't really know what I was talking about when it came to nuclear power. And I know people put solar panels on their roofs of their houses and that makes energy. But I didn't know exactly how all of that stuff worked. So when it comes to like, combining the engineering aspects with the policy, it makes me feel, I guess, more hopeful that if someone was able to discover these processes already, we have so much to work with, and so much to evolve with our technology to make the world a more cleaner and sustainable place. [PoliSciEnv_10].

However, she was quick to cite her limited future use of the equations and the advanced level of engineering as reasons for her disinterest in the topics. [PoliSciEnv_10].

> But then when it came to the equations, frankly, I didn't really care about the equations, because I knew I personally would never be using them. Except for in the homework. And there, most of the time, I got the questions, right. But that's like after a lot of work. And I also, like, kept reminding myself that this is a junior level class, this is junior level engineering. I don't know what I'm doing. I've never taken an engineering course before. So getting thrown into such a high level of engineering was like, made me panic a little bit. [PoliSciEnv_10]

This student had difficulties with the equation-focused problem-solving due to unfamiliarity, but did share that this 'immersion' was helpful for her to gain an understanding of engineering processes.

> But it was also really good for me to like, immerse myself in a different, not a different major, but like a different field of environmental issues. And like I said before, it was just good to know more about the engineering stuff that happens behind the scenes, because again, like, I don't just want to be clueless about what's actually happening in these processes that we're talking about. [PoliSciEnv_10].

The framing this student uses to describe the engineering is consistently separate from her interests and general learning about energy and environment. She articulates a separation in the role of people, citing her respect for the engineers who 'discovered' energy generation processes. We also see her bound the engineering processes (or engineering stuff) as happening 'behind the scenes' from the spaces she inhabits and perhaps hopes to inhabit.

These students discussed their appreciation for engineering knowledge while positioning themselves on the outside of this discipline and not necessarily questioning how engineering decisions or insights are made. A different student shared his surprise in learning more about engineering processes. He noted his change in thinking from the course. “The engineering was a little less hard and fast than I thought it was gonna be.” [PoliSciEnv_21]. He went on to share:

> I always kind of thought about it as like, engineers have answers, right? But then a lot of [the course] was kind of like, it could be this, it could be that, you know, I'm not really sure. Like, the hydrogen fuel unit was really interesting, because it was kind of like, yeah, there are a lot of different kinds of hard hydrogen, like, we're not really sure, a lot of people have different opinions about this. And so that was kind of neat to like, learn that it was a little more interpretive than I guess, I thought. [PoliSciEnv_21].

This student shared his shift in thinking from engineering as a field with answers to include different opinions based on different people. Through this experience, he states that his “thinking has just become a lot more nuanced”, and that energy transition requires different people from different fields to work together in multidisciplinary ways.

> Like, I just understand that [the energy transition] is a more complicated issue than, like, ‘we need to put a lot of solar panels on our houses.’ […] There are a lot of really intense, like, geopolitical dynamics, but also like, economic dynamics. And you have to think about, like the feasibility of technology and the all the scientific stuff. And it's just so ridiculously complicated that I, like, I've realized, as I've learned more and more about it, but especially with this class, that it's about so many different people from so many different fields working together. Like no one, nobody's going to be able to figure it out by themselves, right, you need like, it really has to be a multidisciplinary kind of thing. [PoliSciEnv_21].

4. Solutions and Technological Advancement

The fourth latent theme that surfaced from the student discourses was their discussions of solutions and technological advancement to solve transition issues of energy systems. Through this latent theme, we gained insight into the way students perceive technology and innovation in the context of energy systems and energy transition.

For one student majoring in finance and policy, he was comforted by the prospect of “revolutionary technologies that are coming in.” While he holds that “maybe we don’t have the answer yet, [he] is confident that in the coming years, [revolutionary technologies] are part of the solution.” [FinancePoliSci_03]. Without much specificity, this student offers a more techno-deterministic perspective that highlights the inevitability of technological advancement and that their suitability for the unnamed problem is inherent. Interestingly, the same student discusses the limited adoption of energy technologies in their own family.

> “To be completely upfront, my family's like Republican and pretty strongly on that. And so when it comes to like, clean energy, like wind energy, solar energy, there's, like a reluctance to adopt that, let's say. Like, my dad has, like a massive diesel truck, like, that's the type of the background that we're talking.” [FinancePoliSci_03].

The student goes on to reflect their insights into different energy technologies from the course acknowledging that his background has influenced his learning process.

> “I remembered a lot of the flaws of like, […], like, there's some pros to [renewables]. But I honestly could not name you that many of them. Like, looking back on it, I remember that like hydro[power] had like devastating impacts in the ecosystems and like, NIMBYism of like, not in my backyard for ‘X,Y, & Z’ reasons. And the electric vehicles is not that feasible because it's too heavy for some trucks. And so things like that, I would say I picked up on and I remember it. And I think it's strictly because of sort of some sort of cognitive bias there. Of not that I have anything against electric vehicles, and I would say I lean Republican myself. But just looking back on it, I definitely remember the negatives of it. Definitely, in terms of my background, and then in terms of cognitive bias.” [FinancePoliSci_03].

The student brings some specificity into his discussion of renewable energy technologies, noting that the negative impact of these technologies is what he has remembered due to his family’s politics and background. However, in the previous excerpt, he stated his confidence that revolutionary technologies would be a part of the solution. Through his discourse, there is seemingly a discrepancy between what is considered a 'revolutionary technology' and existing technologies. Additionally, his discourse brings up questions of technological impact with respect to the harms of existing and proposed solutions.

An engineering student also emphasized improvements to technology in her discussion of energy transition. She frames the need for more incremental technological advancement, stating issues of waste in her energy transition discourse:

> "I think that improving what we already have is very essential to our, like, clean energy transition. Because if we were to just discard everything like, 'okay, we're not doing natural gas anymore,' and just threw away a whole rig... I feel like that's a crazy waste and completely counter, like counterproductive. 'You're like, oh, we're gonna shut down an oil plant,' like that's pretty wasteful. And I think that we've already seen that with like at least coal plants around the United States like, they're very harmful. No one uses that space. It's pretty much abandoned, and it's pretty disgusting in general."
> […]
> So I'm thinking, like, how do we improve the spaces like the things that we've already created? Because at the end of the day. The engineers that came before us had really very amazing ideas that got us to where we are right now, and there's no reason, even though it's really polluting completely acknowledging that. How do we improve that? I think that that's a completely valid approach to our clean energy transition. […] It's counterproductive to just throw away whole structures and completely abandon projects when there's, I think, a way to optimize them, improve them, and really fund our money into that, instead of just keep producing over consumption." [Eng_17].

In this students' discussion of a clean energy transition, her focus on improving existing technologies and honoring past engineers' ideas reveals her frame of the problem: as creating obsolescence by changing technologies beyond incremental ways. Importantly, her emphasis on past engineers' 'amazing ideas' spotlights this student's lack of some of the economic and geopolitical dimensions in her insight around the clean energy transition. Instead, she frames the clean energy transition largely as a technological problem that requires incrementally enhancing technological solutions.

Discussion

Through this paper, we examined how students think through and characterize issues of energy transition. The study revealed four categories of ideological frames that students hold in their energy transition discourse. The multiplicity of knowing is a critical feature of energy transition work because energy systems, themselves, are places in which people *shape* and are *shaped by* these worlds in terms of their different identities and relationships. Through an examination of students' ideological frames, we can glimpse into their different conceptions of reality, and "how knowledge is shaped, conditioned, and digested." (Sovacool et al., 2016, p. 4). While this is not a comprehensive study of students' ideological frames around energy discourse, this study put forth four ideological frames that students exhibited in their characterization of energy transitions. We discuss these frames through two main takeaways of this study.

The first main takeaway of this work is that students are not naïve to the complexity of energy transitions. In their characterizations, students recognized the contradictory and competing element of different systems—often citing how their former understandings of energy systems were more idealistic or 'black and white' [e.g. Eng_17]. Students wrestled with the complexity of real-world tradeoffs between different scales of need. One of the students brought in elements of justice and equity, relating these tradeoffs to historical harms and inequities between the global north and global south. For many, economics were a significant feature of the students' recognitions of competing and complex systems, where they grappled with the contradictions between environmental needs and economic motivations and paradigms.

For many of the students, their recognition in the complexity and contradictory nature of energy transition is a new development based on their experience in the course. Importantly, we see that the themes in students' discourses of energy transition can be connected to concepts of sociotechnical systems. Sociotechnical systems are an analytical concept developed since the 1980s by STS scholars to bring complex heterogeneous frames to technological systems, which are made up of people, artifacts, norms, laws, resources, and cultural characterizations (Hess & Sovacool, 2020). As students wrestle with contradictory visions of renewable energy implementation around competing environmental, economic, and societal values, some venture away from techno-deterministic frames that locate new technology as the driver of societal change. Instead, students are wading into spaces of technological momentum—reckoning with the sheer scale of energy and economic systems but holding space for societal shaping of these systems (Hughes, 1969, 1994). Through these latent themes, students see technology and economics as a force in shaping energy transitions, but they do not see it as the sole driving force.

As students wrestled with facets of sociotechnical energy systems, their impressions of energy transition were also discernable. Through the course lectures, issues of transition were discussed through the frame of tradeoffs, explicitly bringing in contextual dynamics regarding energy technologies and policies. Students' engagement with tradeoffs consisted of their bringing in class discussions, their own lived experiences, and even worldviews. Previous scholarship on energy transitions have discussed the paradox that what have historically been deemed energy transitions are instead energy *additions* (Bell, Daggett, & Labuski, 2020; York & Bell, 2019). Richard York frames this as a "displacement paradox" in which current market logics favor growth and addition rather than conservation or environmental protection (2012). For many of the students citing cost and economic barriers in their discussions of renewable energy technology, there is a limit on their engagement with the market logics that favor growth and hide historic subsidies that have engendered particular growth trajectories (e.g. Postwar era funding that catalyzed the petroleum and petrochemical industry (Shah, 2004)). While students did not specify energy transition in many of their insights, the themes constructed from their interviews indicate a variety of the ideologies inherent in energy transition politics and logics.

While students do recognize that the work of renewable energy transition is complex and difficult to navigate, our second main takeaway is that students do exhibit dualistic thinking around social and technical elements of energy systems. These social/technical dualisms are apparent in how students frame technology and solutions in their energy transition discourses. Students also bring in their disciplinary identity, often citing their major as reason for deeply engaging or stating their struggle in different topic areas. This dualism was likely reinforced by the course structure, in which the mechanical engineering professor's lecture days and political science professors were split. There was cross-professor interaction in the lectures, however it was clear who was leading the lesson and who was in more of a learner role. Students seemed to take up this dualism in course structure even though they engaged in complex, interrelated ways when discussing energy transition through specific places and renewable energies.

The separation between technical knowledge and social knowledge is what Cech and others before her have referred to as a technical/social dualism (2013; Faulkner, 2000). This ideological pillar of the engineering curriculum is important because of the power relations involved in the perceived dualism—that is, the valuing of technical knowledge over social knowledge. For engineering students, the technical/social dualism is often implicitly reinforced through separating the components into different courses (Leydens & Lucena, 2017). Some social science students gained insight into the contextual nature of engineering decision-making, sharing that 'engineering was a little less hard and fast' of a subject [e.g. PoliSciEnv_21]. Other social science students emphasized the need for science and facts to precede and inform policy work—clearly distinguishing and stating the need for the science to inform policy. The engineering students were varied in their conceptualizations, one emphasized the need for incremental technological innovation and advancement and the other discussed complex discrepancies between physical infrastructures and political economic initiatives. Students came away with a variety of conceptualizations of problems in the space of local and global energy transitions.

Conclusion and Implications

Ultimately, this study offers insight into the ways students from different disciplines, backgrounds, and lived experiences start to make sense of complex sociotechnical energy systems such and facets of energy transitions. In this study, students exhibited four ideological frames in their discourses of local and global energy transitions. Students grappled with contradictory systems as they describe the complex entanglements of energy, technology, and free market capitalist paradigms. Students also exhibited social/technical dualisms in which they discussed energy concepts and contexts through a lens of disciplinary duality and hierarchy. Lastly, students' discourses included paradigms around techno-solutionism, where they reference or complicate the need for more innovation and technology for successful energy transitions. Through this study, we attended to the nuances across the different logics that underlie their thinking to broaden the way energy literacy is studied in education, particularly engineering education.

We conclude that energy literacy cannot be understood as a normative educational initiative in which students become better informed on the subject of energy. Instead, energy education is inherently complex and contextually relevant. We emphasize that the tensions and histories of energy are important for students to contend with so they can make sense of present-day actions and inactions in relation to their lived experiences *and* curricular insights.

Energy systems are an important site for engaging students in sociotechnical engineering and historically have been studied as sociotechnical systems in fields like Science, Technology, and Society (Hughes, 1985). Engaging students in sociotechnical energy systems can help to expand students' notions of what it means to be an engineer or what engineering is, because energy systems involve deep entanglements of social, technical, political, and economic considerations. Energy transitions are different across regions, contexts, and technologies, which presents an opportunity and need for more sociotechnical approaches to its study. In energy-focused work, there is a need for engineers and social scientists to bring an integrated sociotechnical lens to their work, which includes the definition of the problem to its solution (Downey, 2015). Without sociotechnical framings of energy education, students become limited in their understandings of the complexities and inequities that underpin local and global energy transitions.

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